Inelastic Behavior of Advanced Steel at Elevated Temperature

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Introduction. The inelastic mechanical behavior of 9 -12 % Cr based advanced steel at elevated temperature (up to 650 ˚C) is of great interest. Due to its strict safety issue and reliable material assessment for use in power generation industry, specifically, creep behavior, It is more severe and increases with temperature. Moreover, from the point of microstructure, some parts of the grains deforms intensively during creep and produce cell or subgrain structures. Such structures are usually composed of inelastic soft subgrain interior regions with low dislocation density and inelastic hard subgrain boundary regions with high dislocation density. During creep deformation mobile dislocations move from the soft regions to hard subgrain boundaries and remain there, which in turn, contributes to the creep rate. creep can be treated as within the frame of crystal viscoplasticity. The method of representative volume element (RVE) to analyse the macroscopic material behavior is state of art in these days, therefore, we take advantage of this method to create idealized microstructure to simulate creep deformation of polycrystalline materials, from these, we could estimate overall macroscopic material behavior by homogenizing the RVE.

Problem Definition

Subgrain creep deformation behavior at high

temperature at cyclic loading conditions.

Objectives

To simulate the creep deformation behavior of polycrystalline materials at high temperature condition by employing polycrstal viscoplasticity model .

Cooperation

Mr. Prygorniev, Oleksandr

Numerical Experiment

To simulate creep deformation of polycrystalline materials, first step is to generate geometrical model which could represent microstructure of 9-12 % Cr based advanced steel during creep deformation, The Python scripts has been developed by Mr. Oleksandr Prygorniev (member of the GRK1554) by modifying Voro++ library to represent three-dimentional subgrain structure, with embedded inelastic soft and inelastic hard regions and it allows us to design of the unit cell structure in commercial software ABAQUS as it shown in the Fig.1. With Python code we could define number of subgrains, average subgrain size and subgrain boundary thickness. In that way, we could define mechanical properties for each region in the unit cell in ABAQUS from material properties definition.

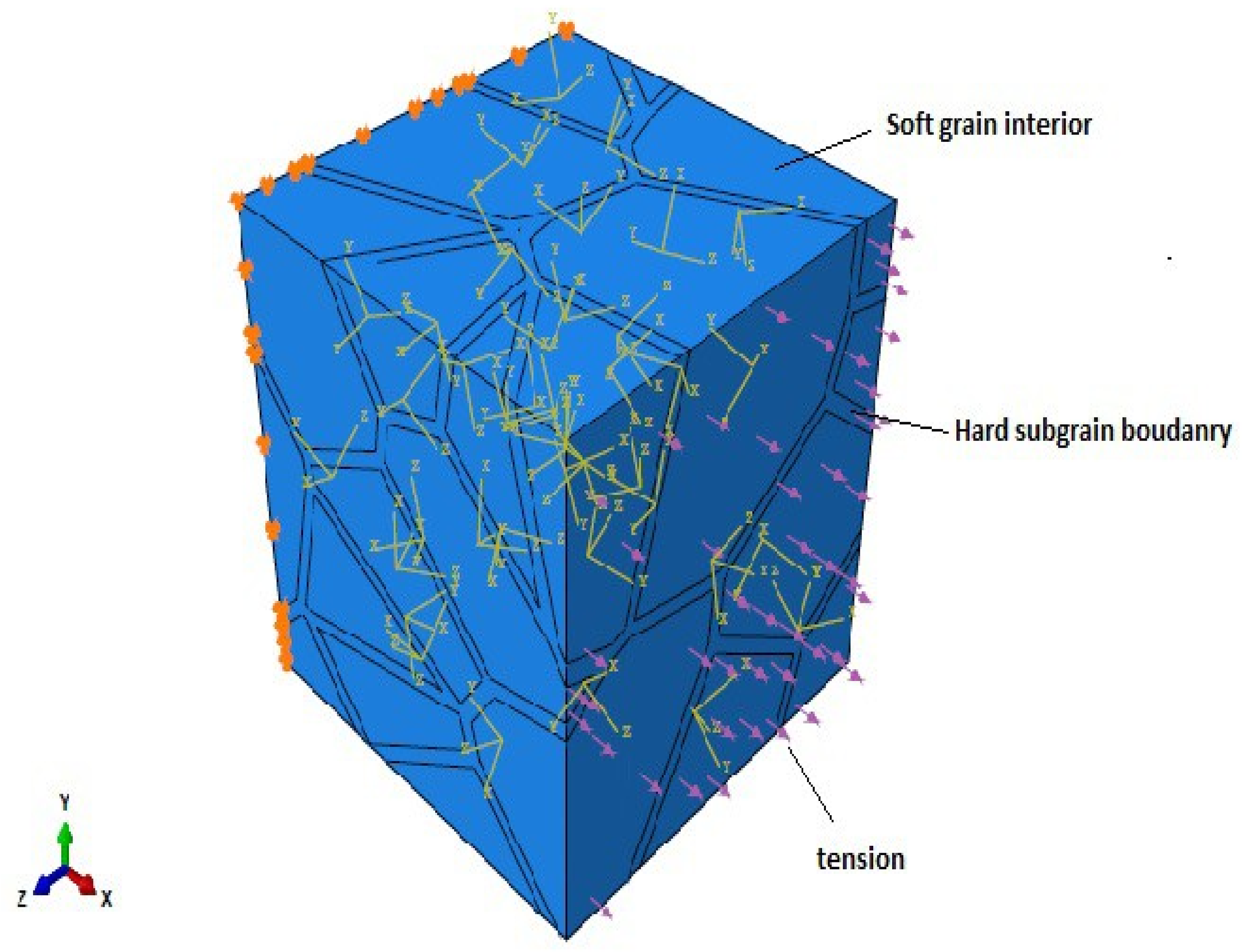

Figure 1. Subgrain geometrical model

Constitutive Model

1. Decomposition of stress gradient into elastic and plastic parts.

$$\mathbf{F^e} = \mathbf{F}\mathbf{F^{p-1}}, \quad \det\mathbf{F^p} > 0$$

2. Evolution of plastic deformation.

$$\mathbf{L^p} = \dot{\mathbf{F}}^{\boldsymbol{p}}\mathbf{F}^{\boldsymbol{p}-1} = \sum_{\alpha} \dot{\gamma}^a \mathbf{s}_0^a$$

3. Shear rate calculation.

$$\dot{\varepsilon^{cr}} = \dot{\gamma^a} = \dot{\gamma_0}\left|\frac{\boldsymbol{\tau^\alpha} - \boldsymbol{\chi^a}}{g^a}\right| \operatorname{sgn}(\boldsymbol{\tau^\alpha} - \boldsymbol{\chi^a})$$

4. Resolved shear stress calculation

$$\boldsymbol{\tau^\alpha} = \boldsymbol{T} \cdot (s^a \otimes m^a)$$

5. Slip resistance evolutions.

$$\dot{g^a} = \sum_{\beta=1}^{nslip} h^{\alpha\beta} \left|\dot{\gamma^\alpha}\right|$$

6. Back stress evolutions.

$$\dot{\chi^\alpha} = c\dot{\gamma^\alpha} - d\chi^\alpha|\dot{\gamma^\alpha}|$$

Results and Discussion

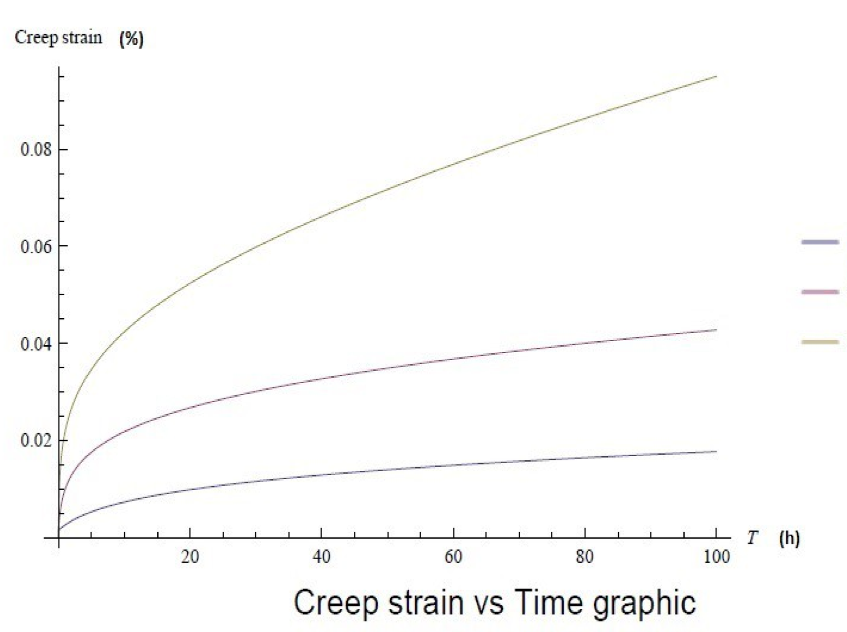

Figure 2. creep curve

Number of numerical tests have been performed in commercial software Package ABAQUS via UMAT. It can be clearly seen from the creep curve at different stress level that the higher the stress , the higher the creep deformation will be. Moreover, several numerical test has been performed in different loading direction to test material anisotropy, which has been observed in the experiment of polycrystalline material in tension and it is coincide with experimental results as well.

Conclusions

Subgrain polycrystalline microstructures are generated in ABAQUS with different crystallographic orientation and to account for low angle grains boundaries, The representative volume element as shown in Fig.1 is subjected to uni-axial tension to simulate creep deformation. Material parameters are taken from the literature. Several numerical tests has been performed to generate the creep for different stress levels.

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