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Micro-macro analysis of creep behavior in a multipass weld

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Introduction. Welded components in power plants and chemical plants often operate at temperatures which are high enough for creep deformation to occur. Under these conditions, the rate of accumulation of damage may be significantly higher in the weld region than elsewhere. The present work is devoted to the description of the creep and damage behavior of the welded constructions based on the micro-mechanical properties of the weld metal. Multi-pass weld microstructure that consists from columnar, coarse-grained, and fine-grained zones is considered.

Problem Definition and Objectives

A typical weld in a component consists of parent material, heat-affected zone and a weld metal. Moreover, in the case of multi-pass welds, the weld material is also inhomogeneous[1]. It consists of overlapping weld beads that will create specific heat affected zones within the weld metal as a result of cooling and heating from the next pass. Due to mismatch in creep deformation properties between different zones of the weld metal, non-favorable weld shapes, which result in stress concentrations developed within the weldment, and combined with the fact that creep produces damage in the form of voids and micro-cracks leads to material failure. Objectives of this project were following:

- describe the behavior of the multipass weld metal and define the properties of the equivalent homogeneous material,
- analyze the influence of the microstructure of the weld metal on the macroscopic behavior of the welded constructions

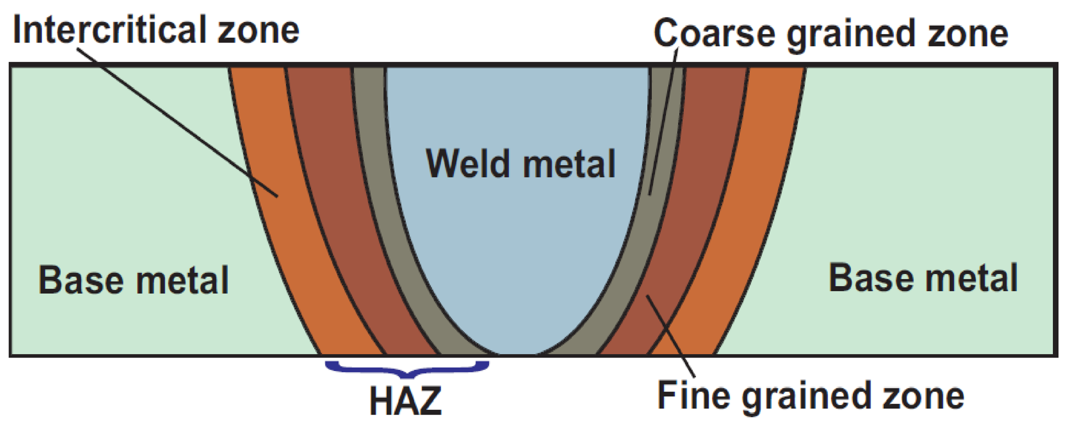

Figure 1. Typical microstructure of a weldment

Analytical Description

Material properties of weld metal grain size zones are assumed to be isotropic. To describe the creep damage behaviour of weld metal zones, the Kachanov-Rabotnov isotropic creep damage model is used:

$$\dot{\varepsilon}_{vM} = C\frac{\sigma_{vM}^n}{(1-\omega)^m},$$

$$\dot{\omega} = D\frac{\sigma_{eq}^k}{(1-\omega)^l},$$

where the equivalent stress:

$$\sigma_{eq} = \alpha\sigma_{max} + (1-\alpha)\sigma_{vM},$$

$$\sigma_{max} = \frac{|\sigma_I| + \sigma_I}{2}$$

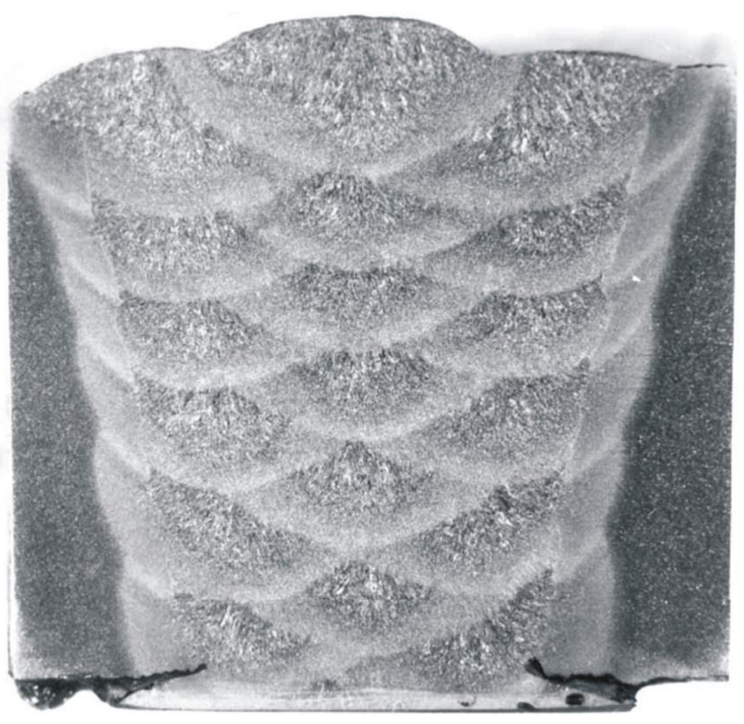

Figure 2. Micrograph of a multipass weld

To model the creep damage behaviour of the equivalent material for the weld metal the model of the anisotropic creep damage model taken form [2] was used. Tensor B is responsible for the anisotropy of creep properties, and tensor D reflects anisotropy in damage proneness of the material:

$$\dot{\boldsymbol{\varepsilon}} = \frac{\sigma_{eq}^{n-1}}{(1-\omega)^n}\mathbf{B}\boldsymbol{\sigma}, \qquad \dot{\omega} = d^*\frac{\sigma_{*eq}^{k-2}}{(1-\omega)^{k-1}}\mathbf{D}\boldsymbol{\sigma},$$

$$\dot{\omega} = d^*\frac{\sigma_{*eq}^{k-1}}{(1-\omega)^k}, \qquad \omega(0) = 0, \qquad \omega(t^*) = 1$$

and the equivalent stresses are assumed as follows:

$$\sigma_{eq}^2 = \boldsymbol{\sigma}\cdot\cdot\mathbf{B}\cdot\cdot\boldsymbol{\sigma}, \qquad \sigma_{*eq}^2 = \boldsymbol{\sigma}\cdot\cdot\mathbf{D}\cdot\cdot\boldsymbol{\sigma}$$

For identification of material constants , six independent numerical tests should be executed – tension tests in three principal directions, and three shear tests on three principal planes.

Numerical experiments

To model the creep damage behavior of the equivalent homogenous material for weld metal, representative volume element (RVE) was created to perform the numerical experiments on one-component loadings.

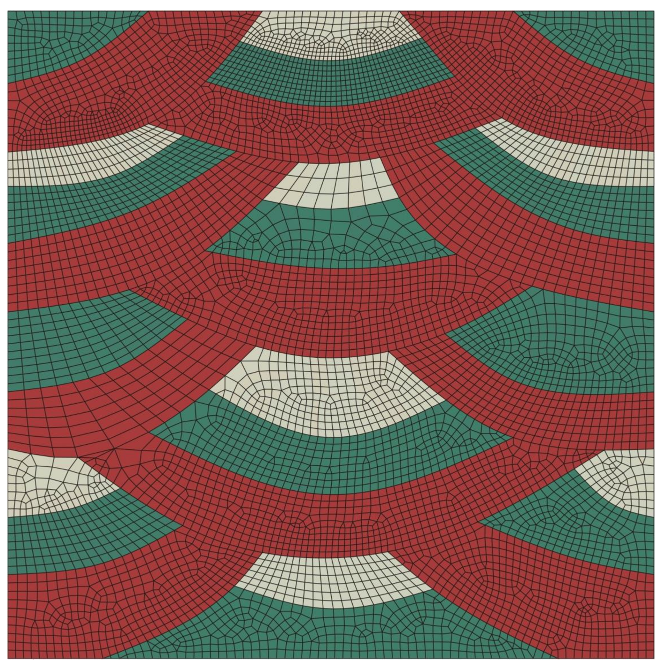

Figure 3. RVE of a multipass weld metal

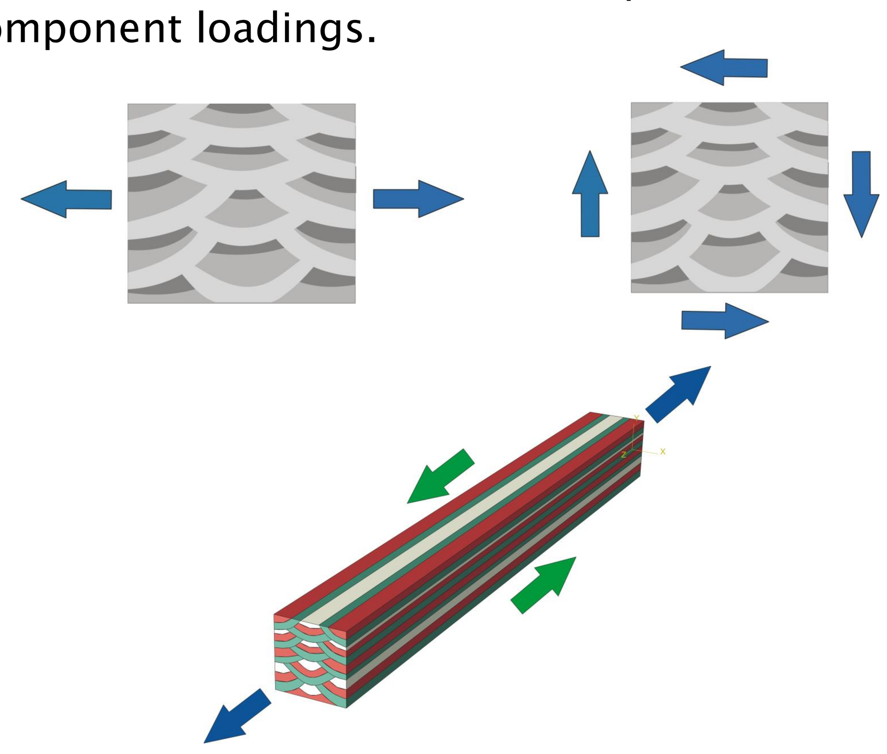

Figure 4. Numerical experiments

As results of this numerical experiments , averaged creep strains and damage parameter evolution during time was obtained.

Results and Discussion

Processing the results from numerical experiments, the parameters of tensor **B** were found for the considered material[3]. To describe the anisotropy in the damage properties of the equivalent material, parameters of tensor **D** were defined. Analyzing the results, one can make an conclusion that both the creep and damage properties show anisotropy of the equivalent material.

Simulation of the pressured vessel with the welding was performed to consider the influence of the weld metal properties on the macro-scopic behaviour of the welded construction. It was defined that damage primly concentrates on the HAZ of the weldment, while the stress accumulates in the weld metal, making both zones important in research of the lifetime of The welded components.

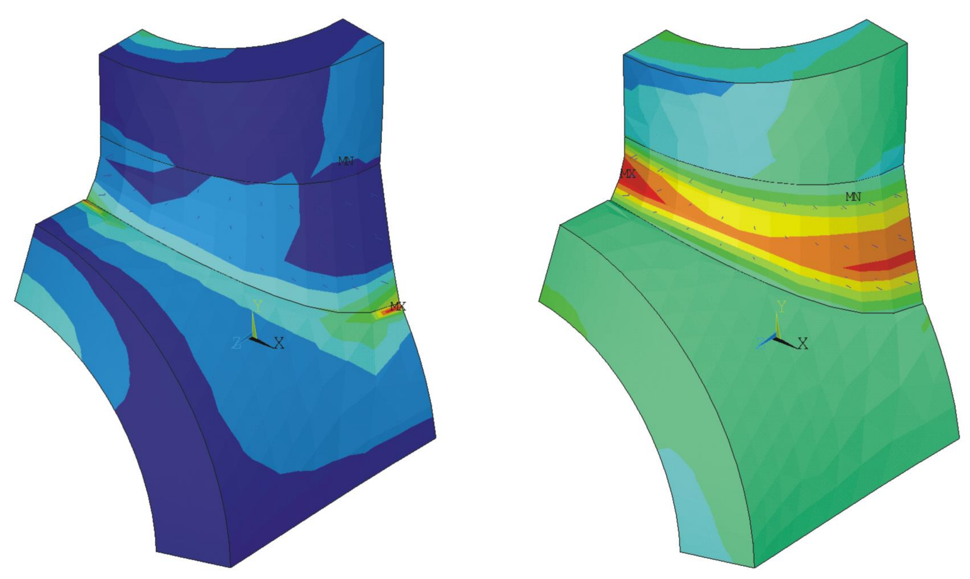

Figure 5. Damage parameter and equivalent stress redistribution after 10 years of creep (simulated)

Conclusions

Results of the work can be summarized to the following conclusions:

- The multi-pass weld as a complex heterogeneous object was considered.
- As a result of the finite element analysis on uni-axial loadings of a RVE the material parameters for creep damage constitutive equation of the equivalent material were found.
- The influence of damage processes on the life period of the welded elements was investigated.

Cooperation

As a part of a graduate school 1554, this project was made in a collaboration with a number of fellow researchers and help of external scientists:

- development of the RVE model was made with cooperation with A. Girchenko and O. Ozhoga-Maslovskaya;
- Multipass welding and micrograph production performed with Prof. Dmytryk (NTU KhPI, Ukriane)

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