**An ABAQUS User Material (UMAT) Subroutine for the Simulation of Deformation Behavior of Metallic Glasses Using the Free-Volume Model**

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## METHODOLOGY

For the information of the Spaepen's free volume model and the finite element implementation, please refer to "*An implicit finite element method for simulating inhomogeneous deformation and shear bands of amorphous alloys based on the free-volume model*," by Y.F. Gao, Modelling Simul. Mater. Sci. Eng. 14, 1329-1345, 2006.

ABAQUS allows the addition of a variety of user subroutines. We define a user material subroutine by UMAT. Basically, this subroutine updates the stress tensor and specifies a material tangent, which will be used for the Newton-Raphson method to compute nodal displacements. The calculation of the material tangent requires the development of an integration scheme of the governing constitutive law. More coding details can be found in ABAQUS Theory Manual.

## FILES

- metallic_glass_umat.for — User Material subroutine (Fortran file)
- metallic_glass_umat_example_1.inp — a test example (Fig. 5 in the paper)
- metallic_glass_umat_example_2.inp — a test example (a metallic glass composite)
- metallic_glass_umat_help.pdf — this help file
- gao_msmse06.pdf — the reference paper

## USAGE

- You must have ABAQUS and Fortran complier installed on your computer.
- Type: abaqus job=metallic_glass_umat_example_1 user=metallic_glass_umat

## REMARK

*Example (1)*

This recovers Figure 5 in the reference paper. Shear bands are initiated from two elements, which have been perturbed to have higher initial free volume values. (Be sure to uncomment Lines 63-65 in the Fortran code.)

*Example (2)*

The example simulates the initiation and propagation of shear bands from a rigid inclusion. Only a quarter is modeled with symmetric boundary conditions at bottom and left lines. (Actually, once the shear bands are initiated, the symmetry cannot be maintained, since one shear band can dominate the response. It'll be interesting to simulate a full plane for comparison.)

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