Finite element crystal plasticity analysis and microindentation tests of single crystal tungsten

W. Yao[a,*], B. Albinski[b], H.-C. Schneider[b], J-H. You[a]
[a]Max-Planck-Institut für Plasmaphysik, EURATOM Association, D-85748 Garching, Germany
[b]Karlsruher Institut für Technologie, Institute for Applied Materials, D-76131 Karlsruhe, Germany

Motivation:

► Tungsten, as candidate materials for divertor of the ITER
► Localized behavior (eg.blistering) when subjected to high-flux deuterium-tritium plasma and high heat flux during operation
► Mechanical properties of tungsten in local scale
► Microindentation test to obtain local mechanical properties
► Identify the material parameters included in certain constitutive models (eg. crystal plasticity model in this work) based on experiments and extensive finite element analysis.

Experiment and simulation

► Indentation tests were conducted on the (100), (110), and (111) oriented single crystal tungsten samples (see Fig.1). A Zwick Z2.5 testing machine was used to obtain load-displacement curves (see Fig.3 and Fig.4.). After indentation tests, the indents were scanned by surface profilometer to acquire the imprint profiles (see Fig.5.).

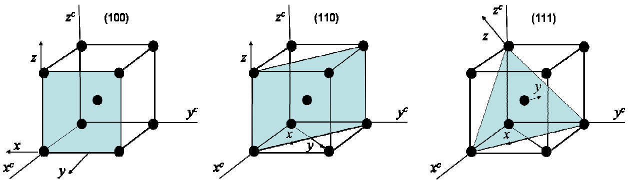


Fig.1. Crystallographic planes of tungsten and ABAQUS analysis coordinate systems

► The FEM simulations on single crystal tungsten were performed with the commercial finite element code ABAQUS. Details of the model are given as following:
Size of the ball indenter: diameter 0.5 mm
Size of the cylinder substrate: radius 1 mm; height 1 mm,
Direction of indentation: Y-axis,
Maximum indentation depth: ca.24 µm.

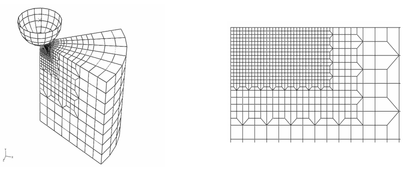


Fig. 2. FEM model: partial FEM domain (left) and details of the mesh at the region of contact (right).

Determination of model parameters

► The parameters of the crystal plasticity material model were identified by inverse fitting method. After extensive FEM calculations the numerical load-displacement curves and imprint profiles were fitted to the experimental data to obtain material parameters for the crystal plasticity model. See the figures below.

Indentation test

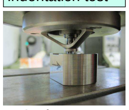


Fig.3. Indentation experiment on Zwick 2.5

Parameters identification of crystal plasticity material model

h_0 n q $\dot{a}$
τ_s τ_0 E...

Finite-Element-Calculation

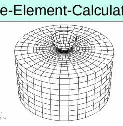


Fig.7. FEM simulation of indentation

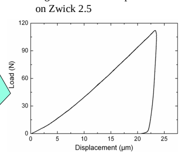


Fig.4. Experimental load-displacement curve

Inverse fitting

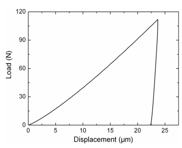


Fig.8. Numerical load-displacement curve

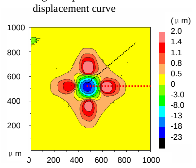


Fig.5. Experimental imprint profile

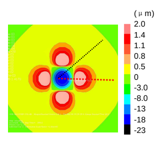
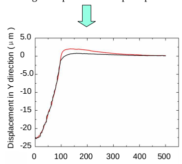


Fig.9. Numerical imprint profile



Inverse fitting

Fig.6. Experimental imprint profile (section)

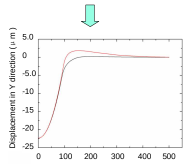


Fig.10. Numerical imprint profile (section)

Results and discussion

► The experimental and numerical load-displacement curves shown in Fig.11 indicate that the indentation forces are very close to each other at the same depth for indentation on all three orientations.

► The simulated load-displacement curves agree well with the experimental data in all three orientations. See Fig.12.

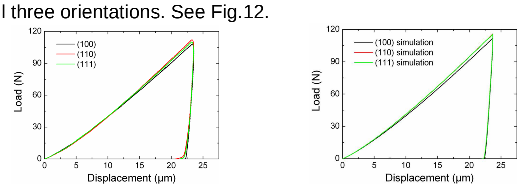


Fig.11. Experimental and numerical load-displacement curves on single crystal samples of different crystallographic orientations.

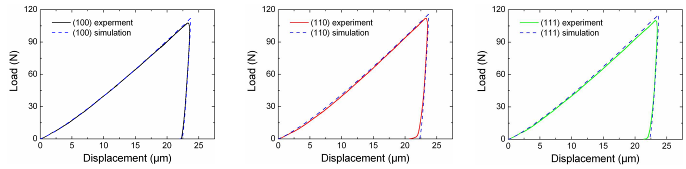


Fig.12. Comparisons between experimental and numerical load-displacement curves on single crystal samples of different crystallographic orientations.

► The experimental and numerical imprint profiles shown in Fig.13 and Fig.14 indicate that the differences are significant in both patterns and magnitude among all three orientations.

► The simulated imprint profiles show agreement with experimental data in both pile-up patterns and maximum pile-up.

► The comparisons of the section profiles shown in Fig.15

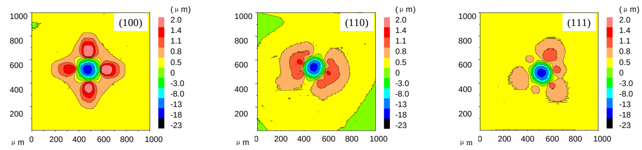


Fig.13. Experimental imprint profiles of single crystal samples of different crystallographic orientations.

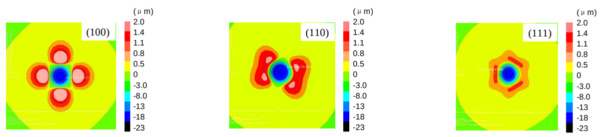


Fig.14. Numerical imprint profiles of single crystal samples of different crystallographic orientations.

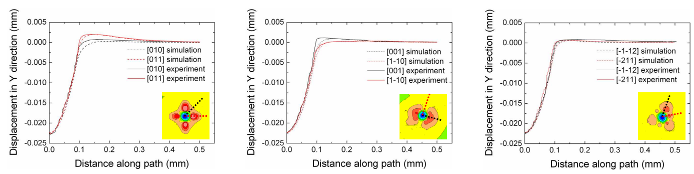


Fig.15. Comparisons of the section profiles of imprints on all three orientations

► The Mises stress distributions (Fig.16. simulations) of the indented planes show significant dependence on crystallographic planes.

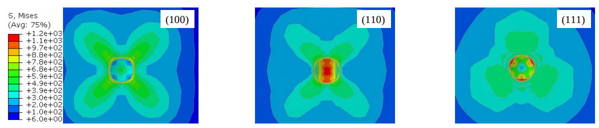


Fig.16. Mises stress distributions on the indented planes of different orientations.

Conclusions

► 3D crystal plasticity model simulation results consistent with both load-displacement curves and imprint profiles: validation of the current material model.

► Material behavior: the imprint characteristics, the magnitude of the pile-ups, Mises stress distributions, depends strongly on the crystal orientation while the load-displacement curves appear independent.

► Comparison between the experimental and numerical results indicates that the material model and parameters are reasonably appropriate in predicting the local mechanical properties of single crystal tungsten.

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weizhi.yao@ipp.mpg.de

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