Karlsruhe Institute of Technology

Institute for Applied Materials
Fusion Materials Laboratory

Characterisation of Poly- and Singlecrystalline Tungsten by Instrumented Indentation

B. Albinski[a], W. Yao[b], J.-H. You[b], H.-C. Schneider[a]

[a]*Karlsruhe Institute of Technology, Institute for Applied Materials, Karlsruhe, Germany*
[b]*Max-Planck-Institute for Plasma Physics, Materials Research Division, Garching, Germany*

What we are interested in – Motivation & Materials

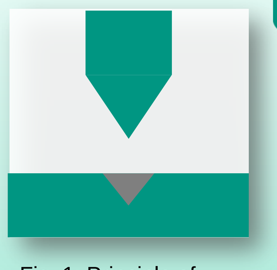

Fig. 1: Principle of instrumented indentation

- Instrumented indentation is a suitable technique for characterising small samples of materials being candidates for divertor and plasma facing materials in future Fusion applications; especially if no conventional specimen are available or applicable.
- Our investigation includes polycrystalline tungsten (PCW) as well as singlecrystalline tungsten (SCW) of three different crystal orientations (100, 110, 111). We used rod material as delivered, without any further heat treatment.

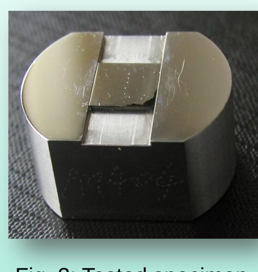

Fig. 2: Tested specimen, fixed on sample holder

From indentation to material characteristics – The method

- A multicyclic indentation process combined with an analysis by trained Neural Networks (NN) reveals the input parameters for a viscoplastic material model. Using them in a simulation of the tensile test allows getting stress-strain-curves of the investigated materials [1].

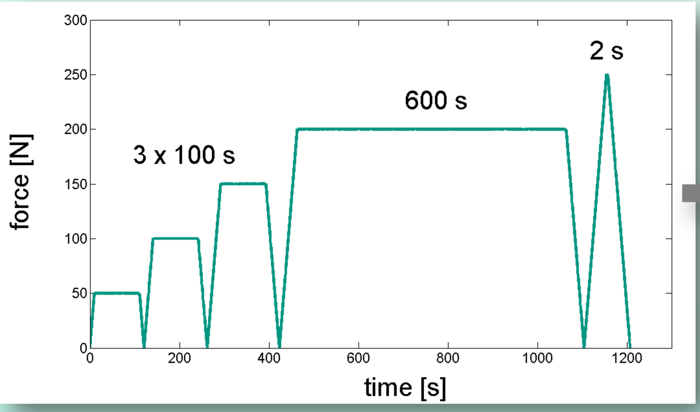

Fig. 3: Time vs. force-graph of indentation experiment on PCW

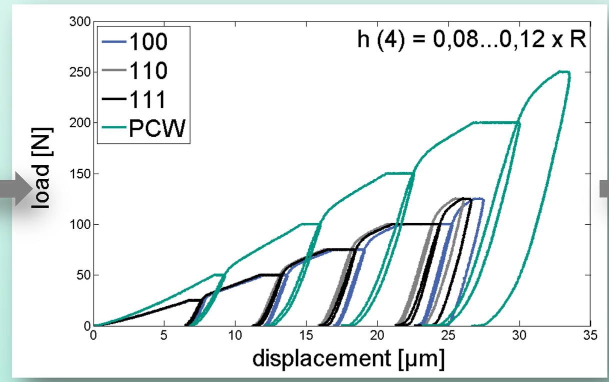

Fig. 4: Load-displacement curves from indentation experiments on PCW and SCW

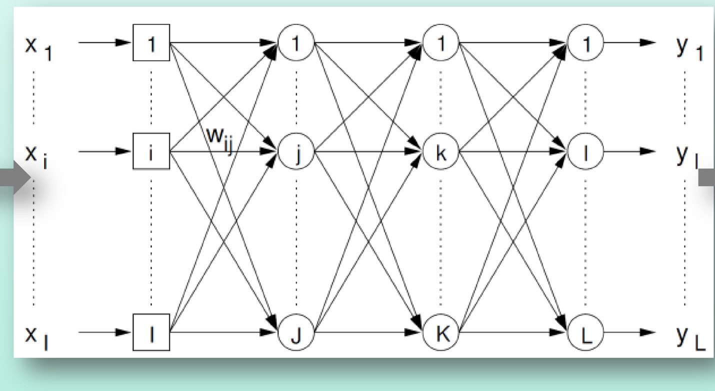

Fig. 5: Structure of the neural network analysis programme (Tyulyukovskiy, 2005)

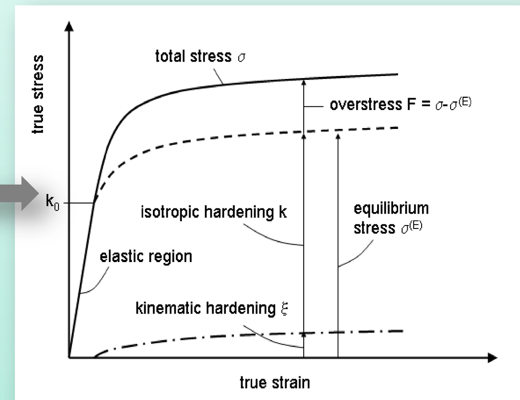

Fig. 6: Results from neural network analysis (Tyulyukovskiy, 2005)

- The samples (see fig. 2) were indented at room temperature using a spherical indenter (R = 250 µm).
- For the NN-analysis a Young‘s modulus of E ≈ 400 GPa was assumed for both PCW and SCW.

What we got – Results

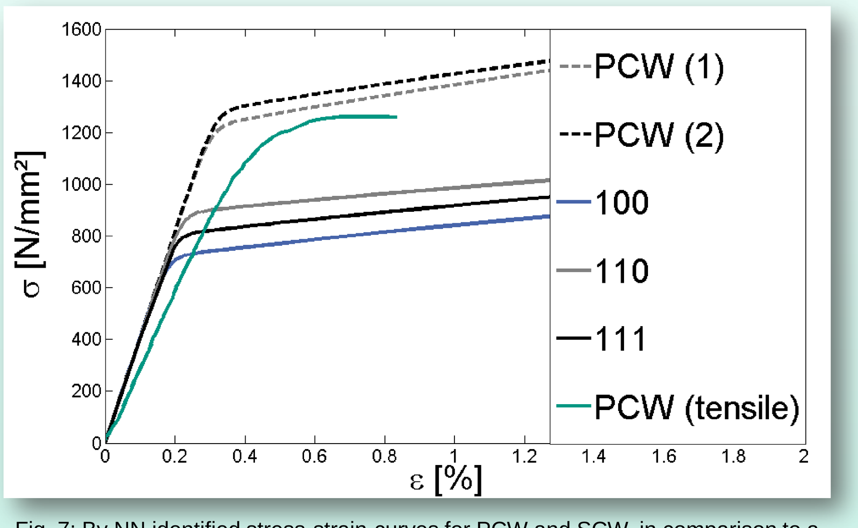

Fig. 7: By NN identified stress-strain-curves for PCW and SCW, in comparison to a PCW tensile test (by W. Basuki)

Material	Overall system compliance C_m [mm/N]	Young's Modulus E [Gpa]	Mater. param.: Yield stress k_0 [Mpa]	Calculated: Techn. elastic limit $R_{p0,2}$ [MPa]
100	3,2E-06	404,8	198,13	705,06
110	3,4E-06	401,6	344,43	788,92
111	3,2E-06	403,5	268,05	760,25
PCW (1)	2,5E-06	404,0	563,17	807,18
PCW (2)	1,8E-06	406,4	585,85	811,99

Tab. 1: By NN identified material parameters for PCW and SCW

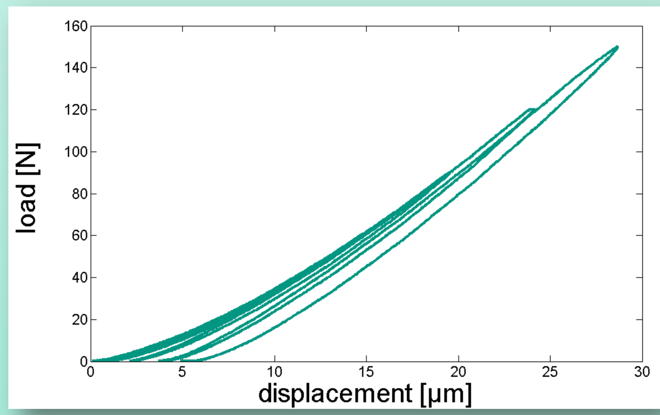

Fig. 8: Load-displacement-curve from indentation experiment on fused silica

- For PCW the σ-ε-curves show a good reproducibility as well as good comparability to a tensile test, up to σ_{max}.
- SCW shows lower strength.
- The crystal orientations of SCW have only slight influence on the σ-ε-curves.
- For evaluation of the yield stress the techn. parameter $R_{p0,2}$ is more suitable than the viscoplastic material param. k_0.
- The indentation creep at room temperature in tungsten (see fig. 4) does not appear in fused silica (fig. 8). This has to be explained by one of the known creep mechanisms [2].

A lunar landscape? – The pile-up-effect

- A remarkable pile-up of the material around the indent (fig. 9, 10) impedes a correct determination of the real contact radius using the O&P-method [3].
- A new method for spherical indentation is to be evaluated.

$$\frac{h_p}{h_r + h_p} \overset{?}{\leftrightarrow} \frac{d_c}{d}$$

- An experimental approach shall link FE-studies with measured indentation profiles.

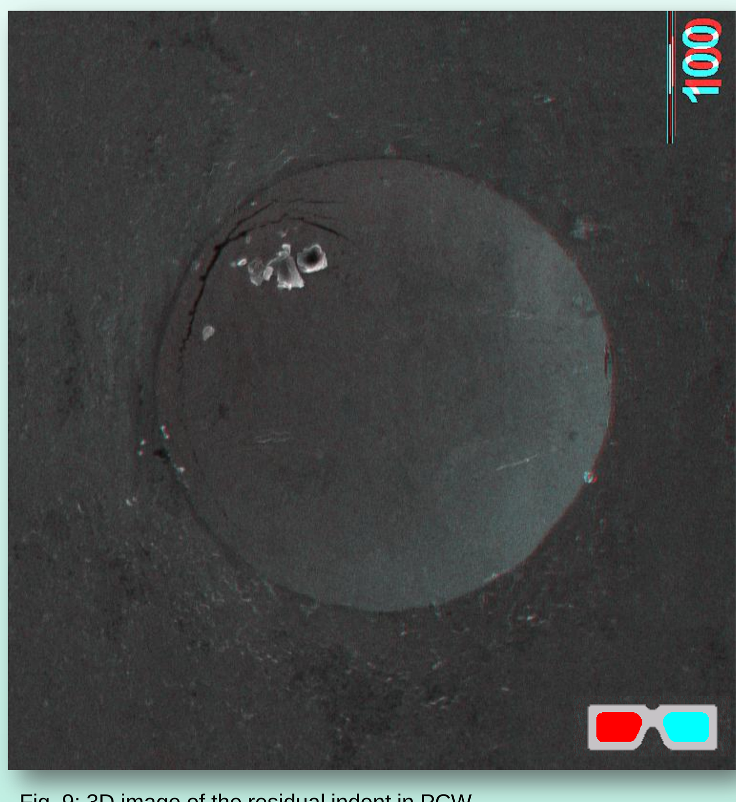

Fig. 9: 3D image of the residual indent in PCW

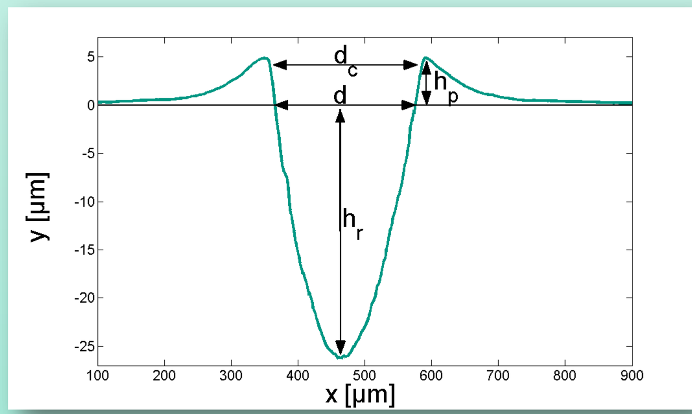

Fig. 10: Measured cross-section profile of indent in PCW

What we plan for the future – Outlook

- Relationship between residual plastic pile-up and real contact radius in loaded status for spherical indentation
- Determination method for machine stiffness for spherical indentation
- Indentation experiments at elevated temperatures
- Investigations on irradiated tungsten samples

These are the highlights – Summary

- The mechanical properties of tungsten can be evaluated by instrumented indentation combined with Neural Networks.
- During indentation at room temperature tungsten shows creeping due to very high pressures.
- The pile-up of tungsten changes the contact area of the indent resulting in the necessity of a new calculation method for it.

Further information – Literature

[1] E. Tyulyukovskiy et N. Huber, J. Mater. Res. 21, 664-676
[2] W.B. Li et al., Acta metall. mater. 39, 3099-3110
[3] W.C. Oliver et G.M. Pharr, J. Mater. Res. 7, 1564-1583

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