View Inside Material Systems with Tribological Contact Experiments

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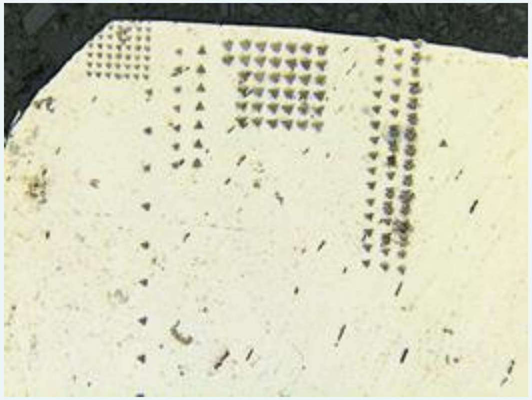
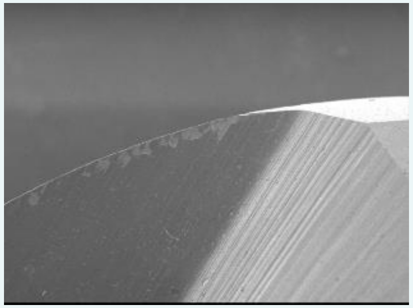
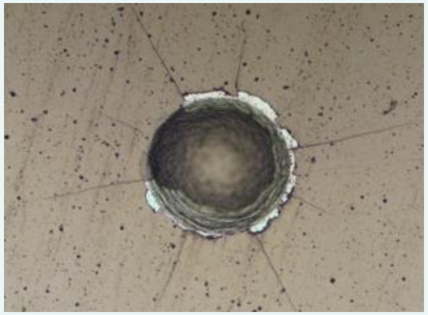
Outline

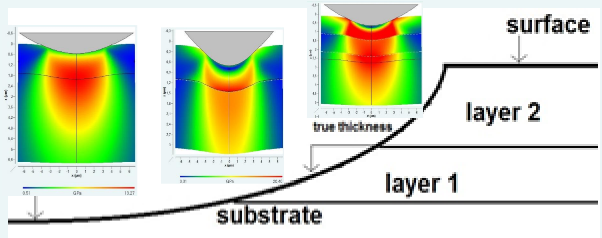
- Gather material parameters



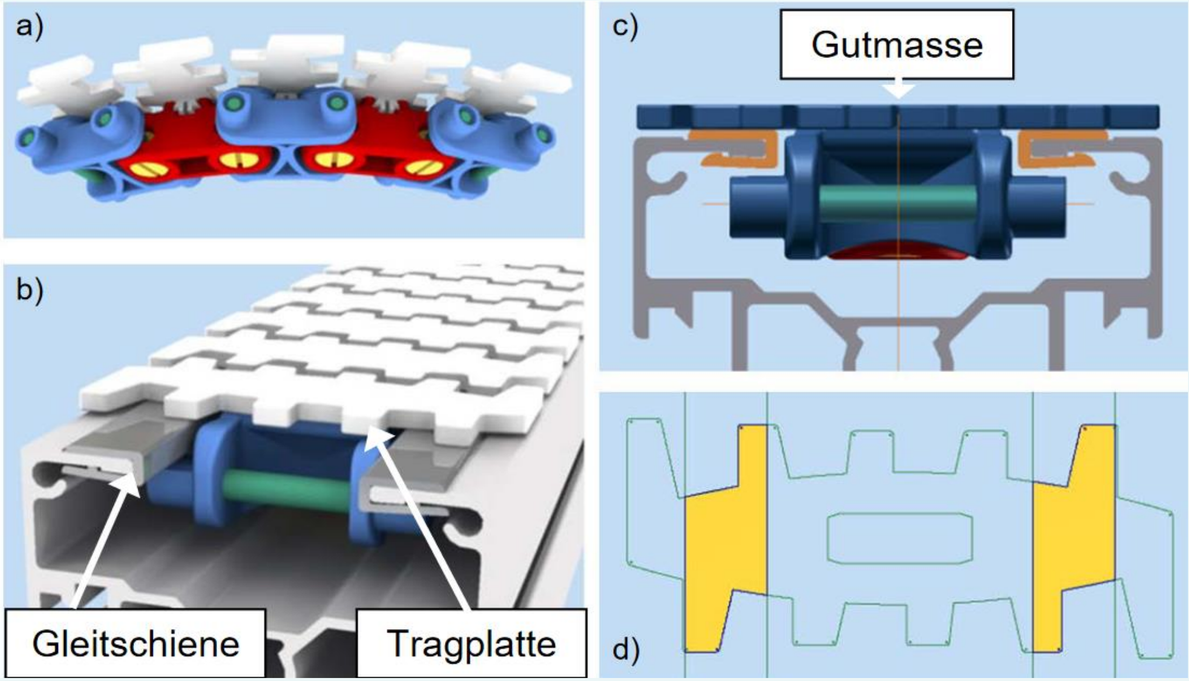
  - Base idea and theory
  - Existing software modules
  - New software module for created extension



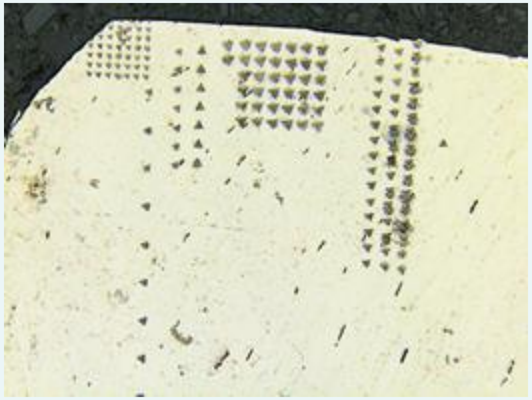




- Predict lifetime/performance
- Actual project OstriA with
  - TU Chemnitz
  - TU Darmstadt



Reference module



Developed for project with technical university of munich

SPP 2013

www.spp2013.tum.de

Indentation device from MicroMaterials

Theory

Extended Hertzian stress distribution

Effective indenter concept

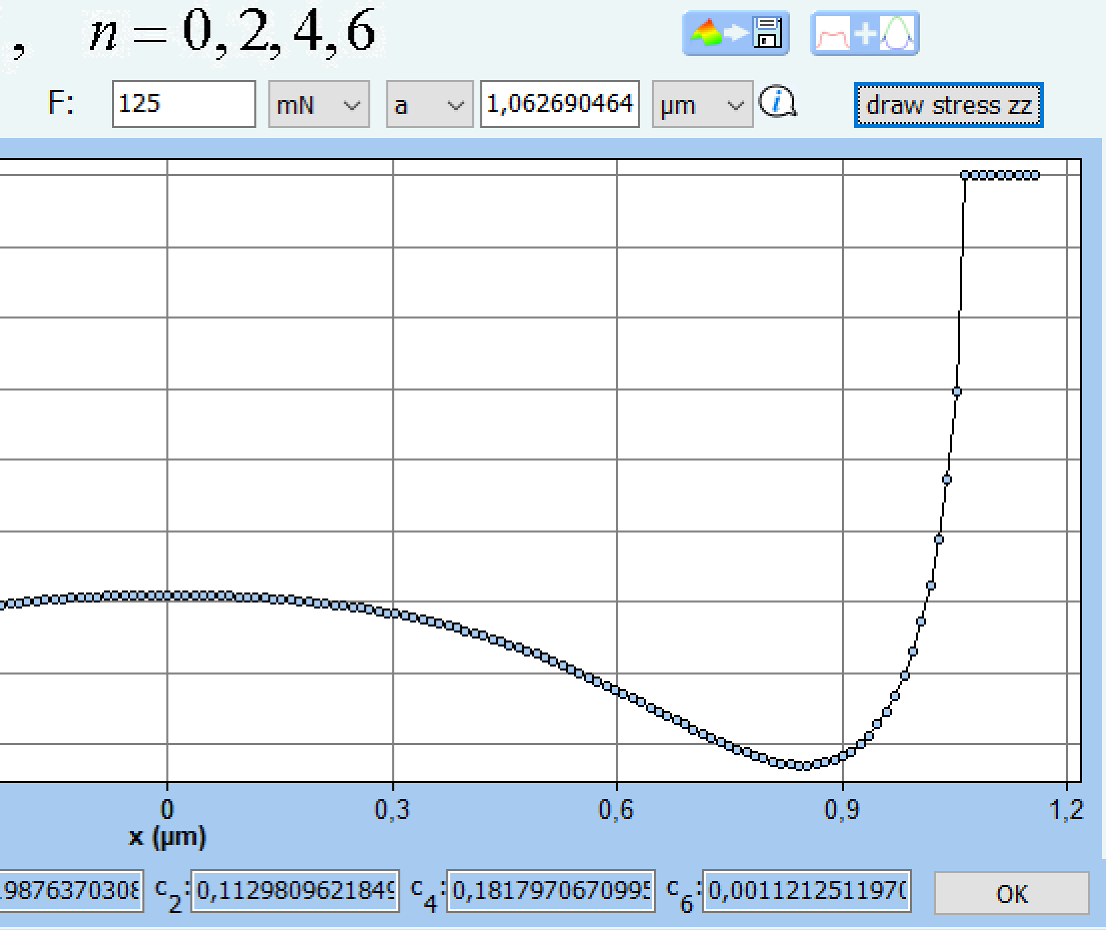
Exponentially shaped indenter

Analytical models for stress-strain-field calculations

Extended Hertzian stress distribution

normal surface stress:

$$\sigma_{zz0}(r) = norm * \sum_{n=0}^{N} c_n r^n \sqrt{a^2 - r^2}, \quad n = 0, 2, 4, 6$$



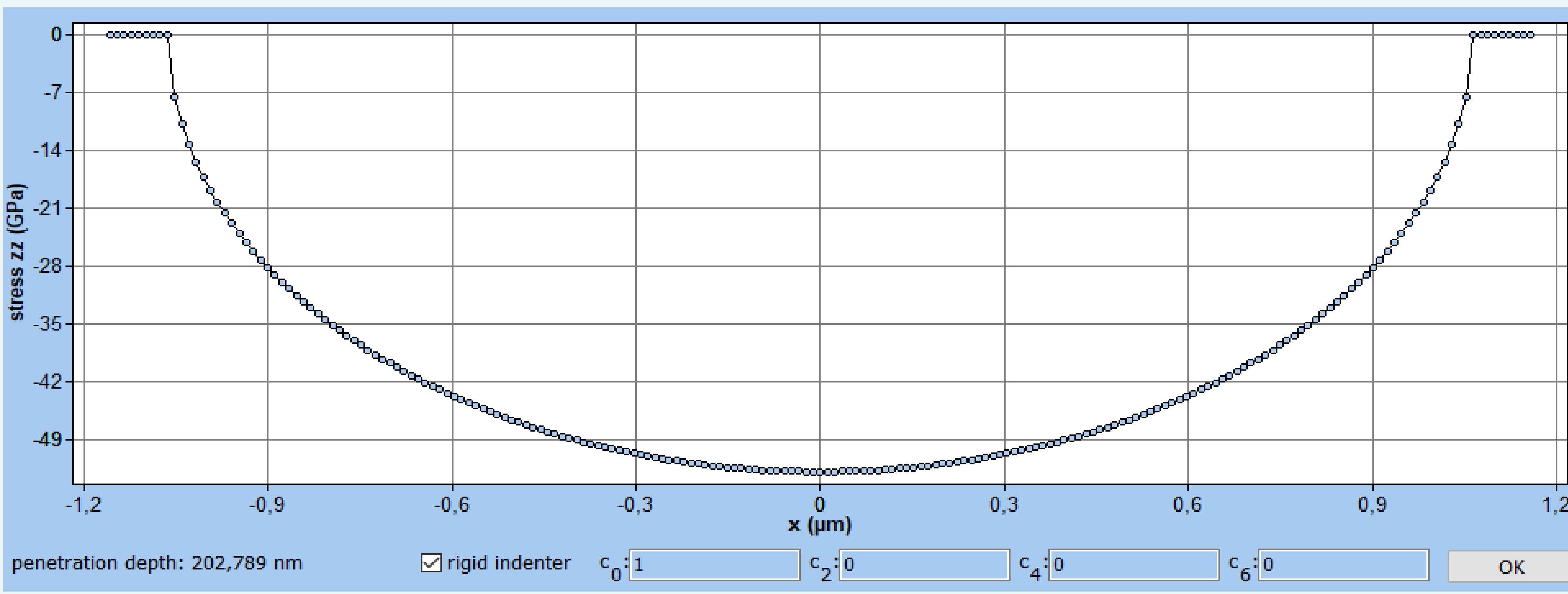
Extended Hertzian stress distribution

C0=1, C2=C4=C6=0 -> Hertzian stress distribution

normal surface stress:

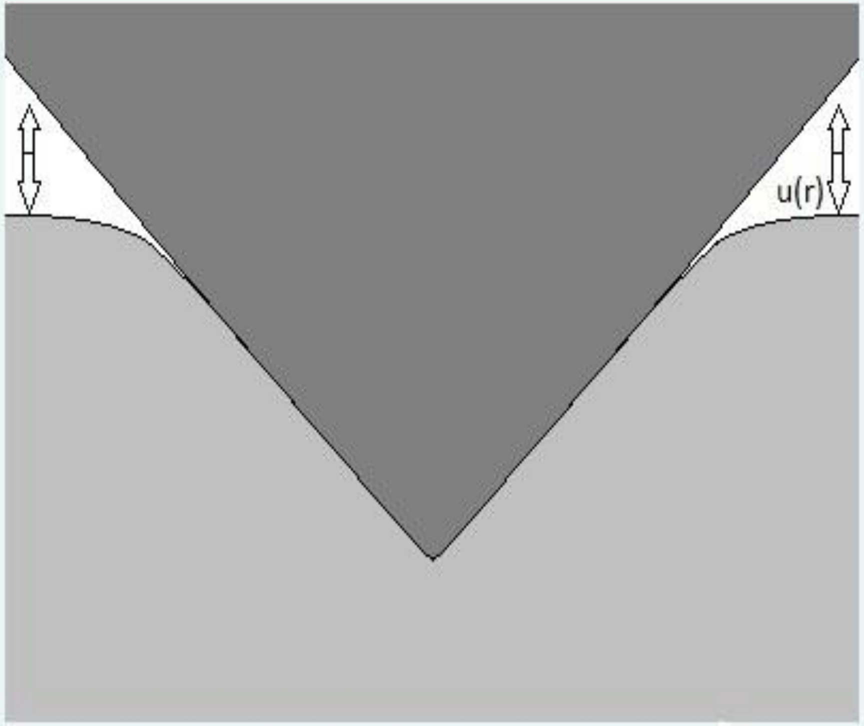
$$\sigma_{zz0}(r) = norm * \sum_{n=0}^{N} c_n r^n \sqrt{a^2 - r^2}, \quad n = 0, 2, 4, 6$$

F: 125 mN a 1,062690464 µm draw stress zz

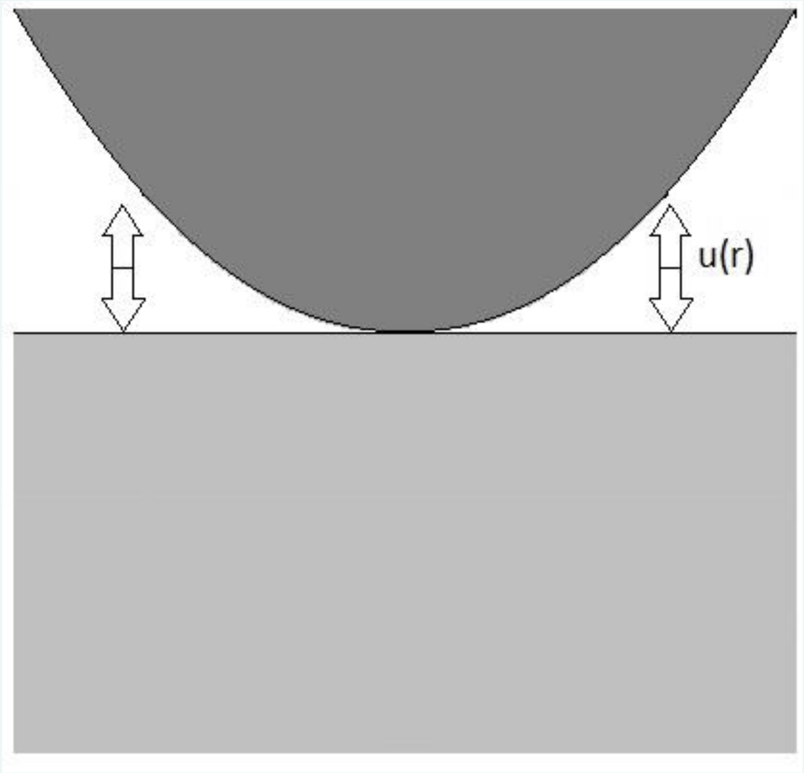


Theory

Effective indenter concept



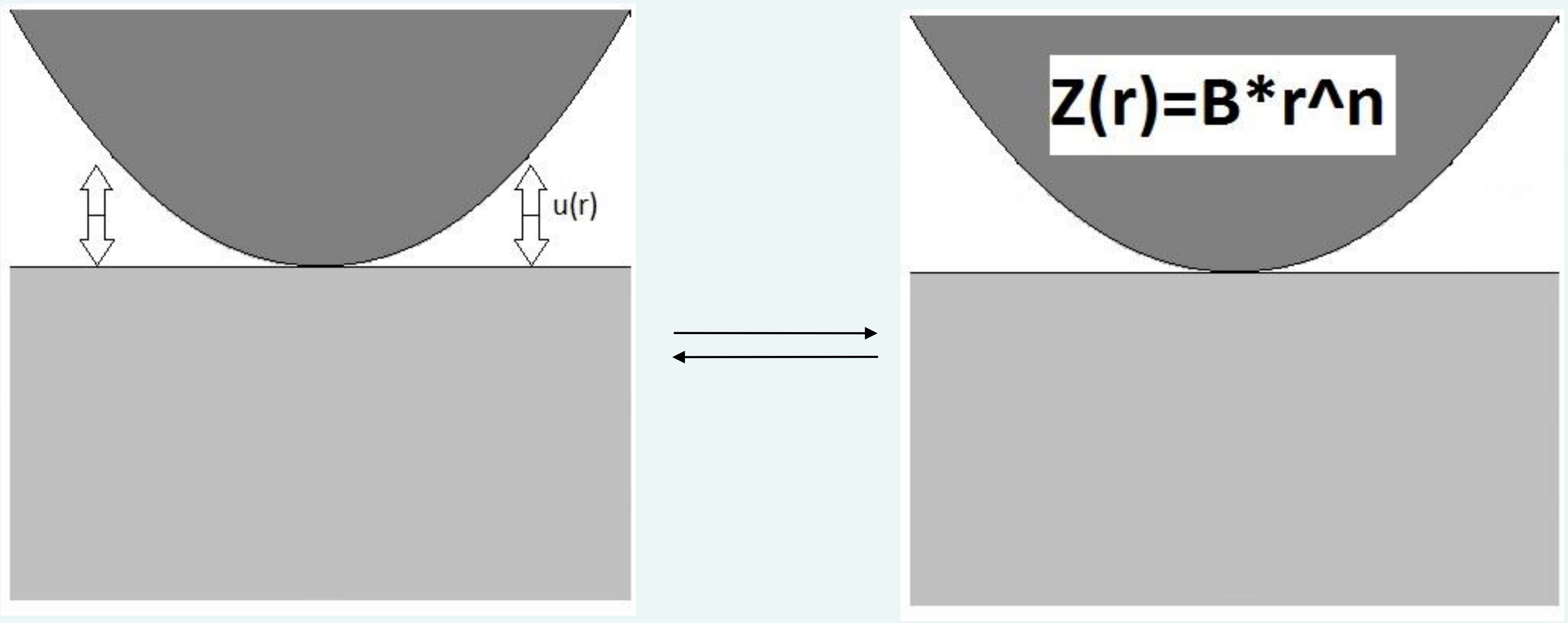
real surface



transformed surface

Theory

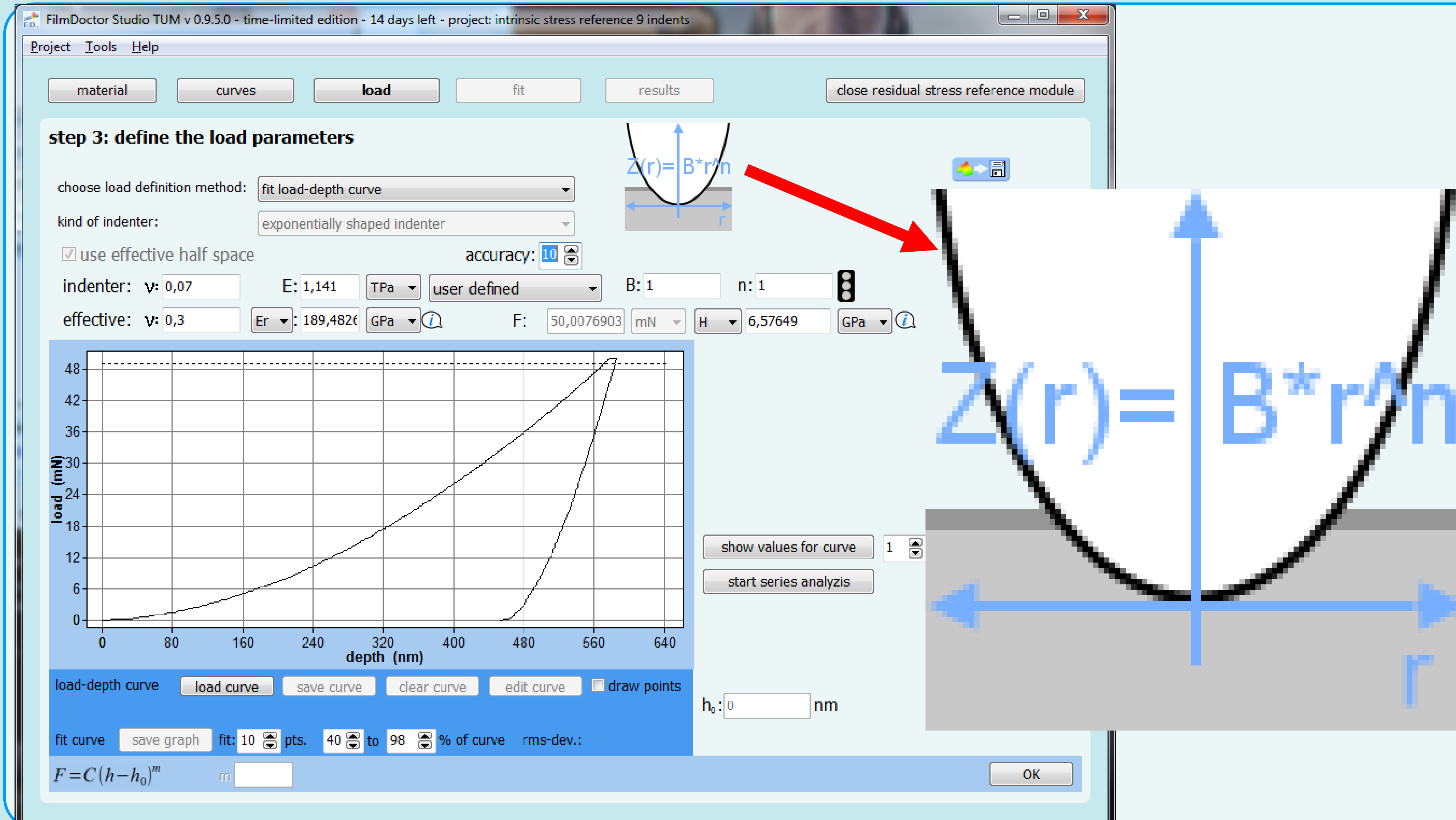
Exponentially shaped indenter



transformed surface

effective indenter

Theory


FilmDoctor Studio TUM v 0.9.5.0 - time-limited edition - 14 days left - project: intrinsic stress reference 9 indents
Project Tools Help
material
curves
load
fit
results
close residual stress reference module
step 3: define the load parameters
choose load definition method: fit load-depth curve
kind of indenter: exponentially shaped indenter
use effective half space
accuracy: 10
indenter: ν: 0,07 E: 1,141 TPa user defined
B: 1 n: 1
effective: ν: 0,3 Er: 189,4826 GPa
F: 50,0076903 mN H 6,57649 GPa
Z(r)=B*r^n
r
load (mN)
depth (nm)
show values for curve 1
start series analyzis
load-depth curve
load curve
save curve
clear curve
edit curve
draw points
h_0: 0 nm
fit curve
save graph
fit: 10 pts.
40 to 98 % of curve
rms-dev.:
$F=C(h-h_0)^m$
m
OK

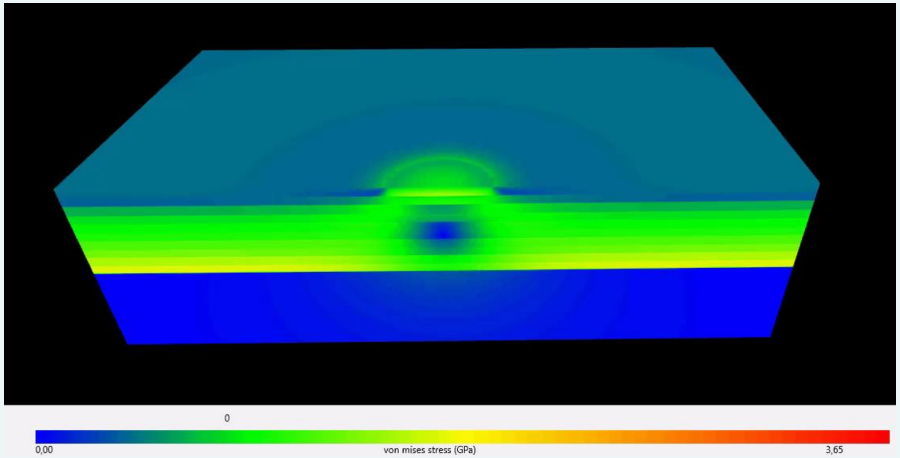
Analytical models

Optimize the materials and material combinations to increase application performance to reach certain goals (e.g. longer application life time of our composite structures)

No FEM system – closed formula calculations

but structures are more and more complex nowadays

need computers and models, personal experience and rules of thumb are no longer enough



Analytical models

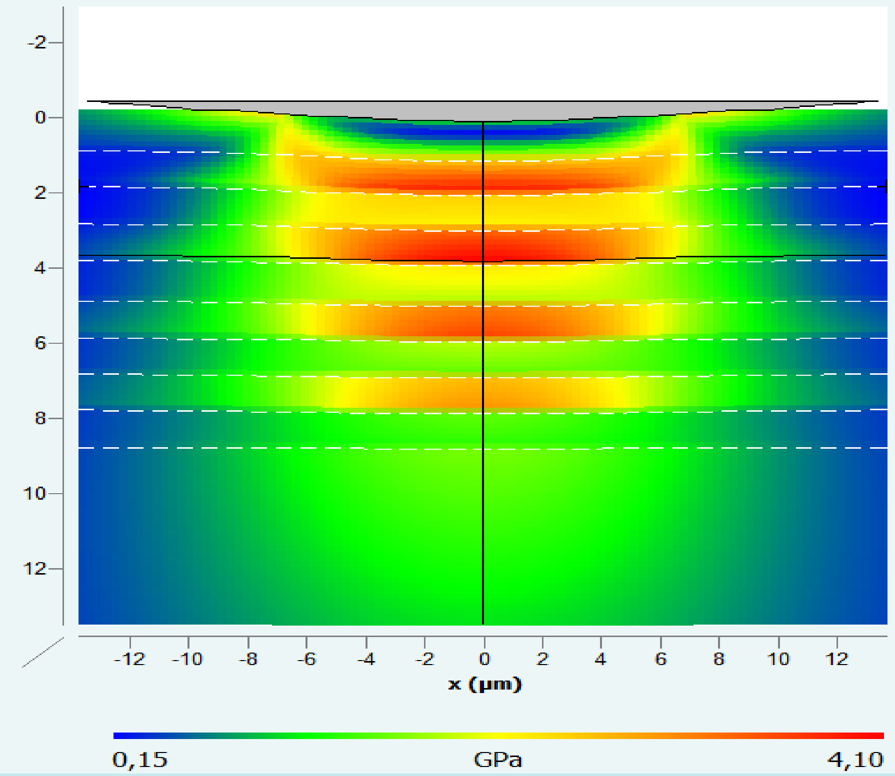
Much faster calculations possible

→ thus allows software for

experimental analyzis

simulation

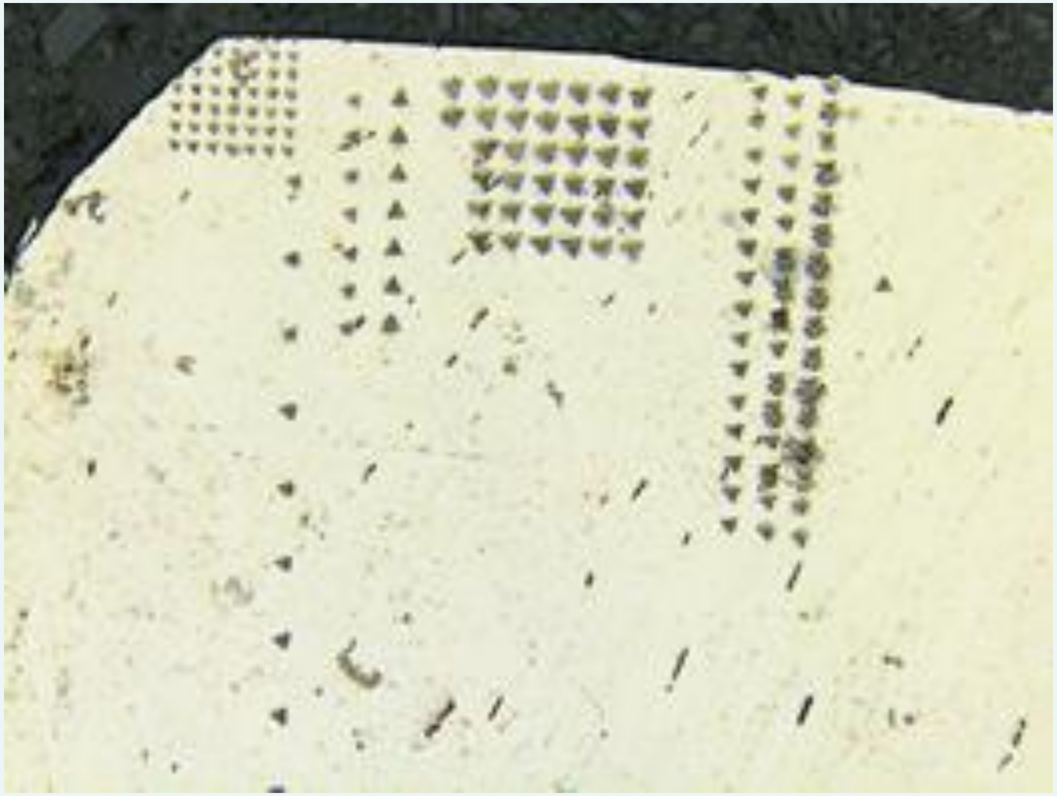
optimization



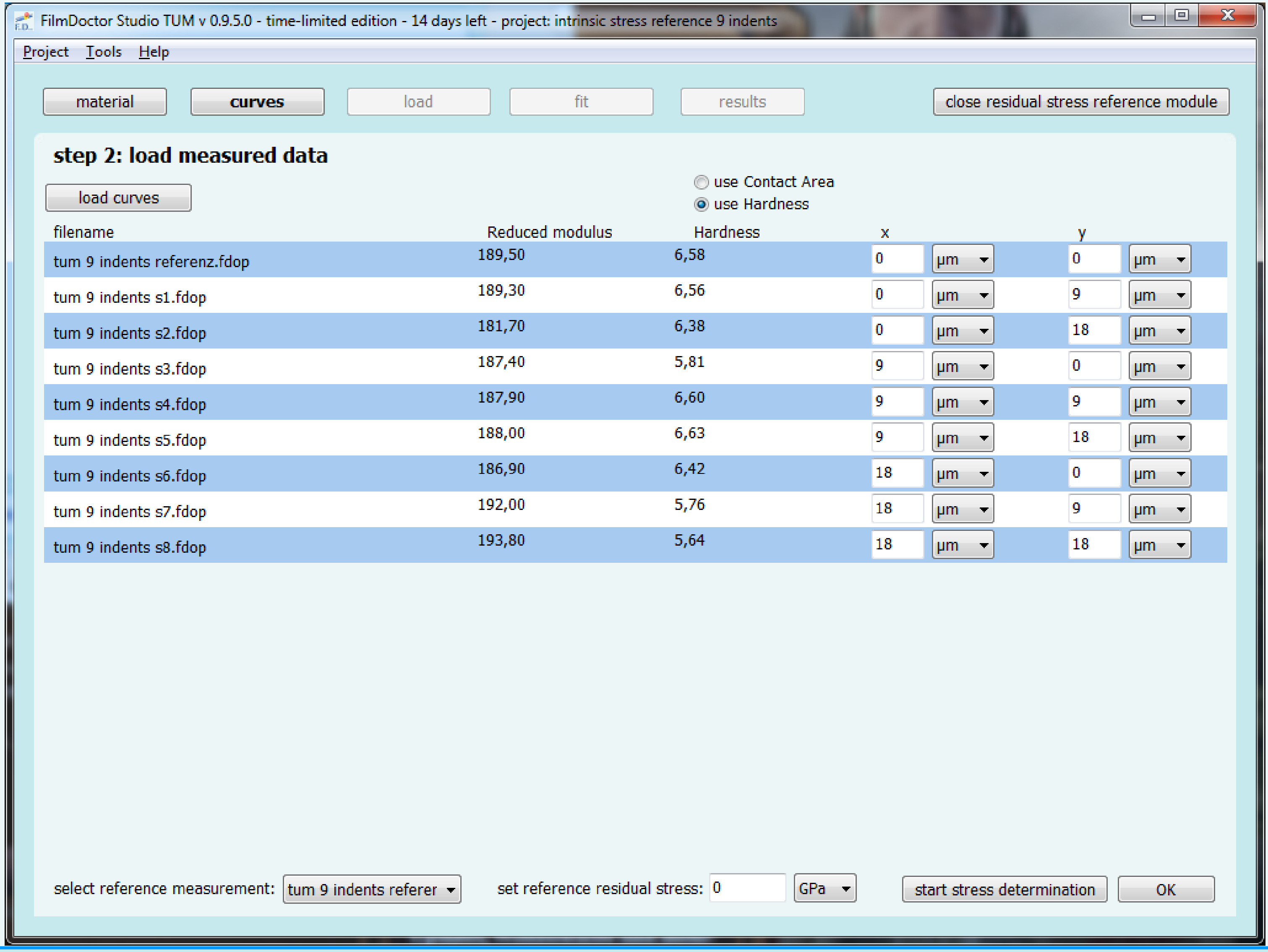
Reference module

Analyze a series of indentation measurements

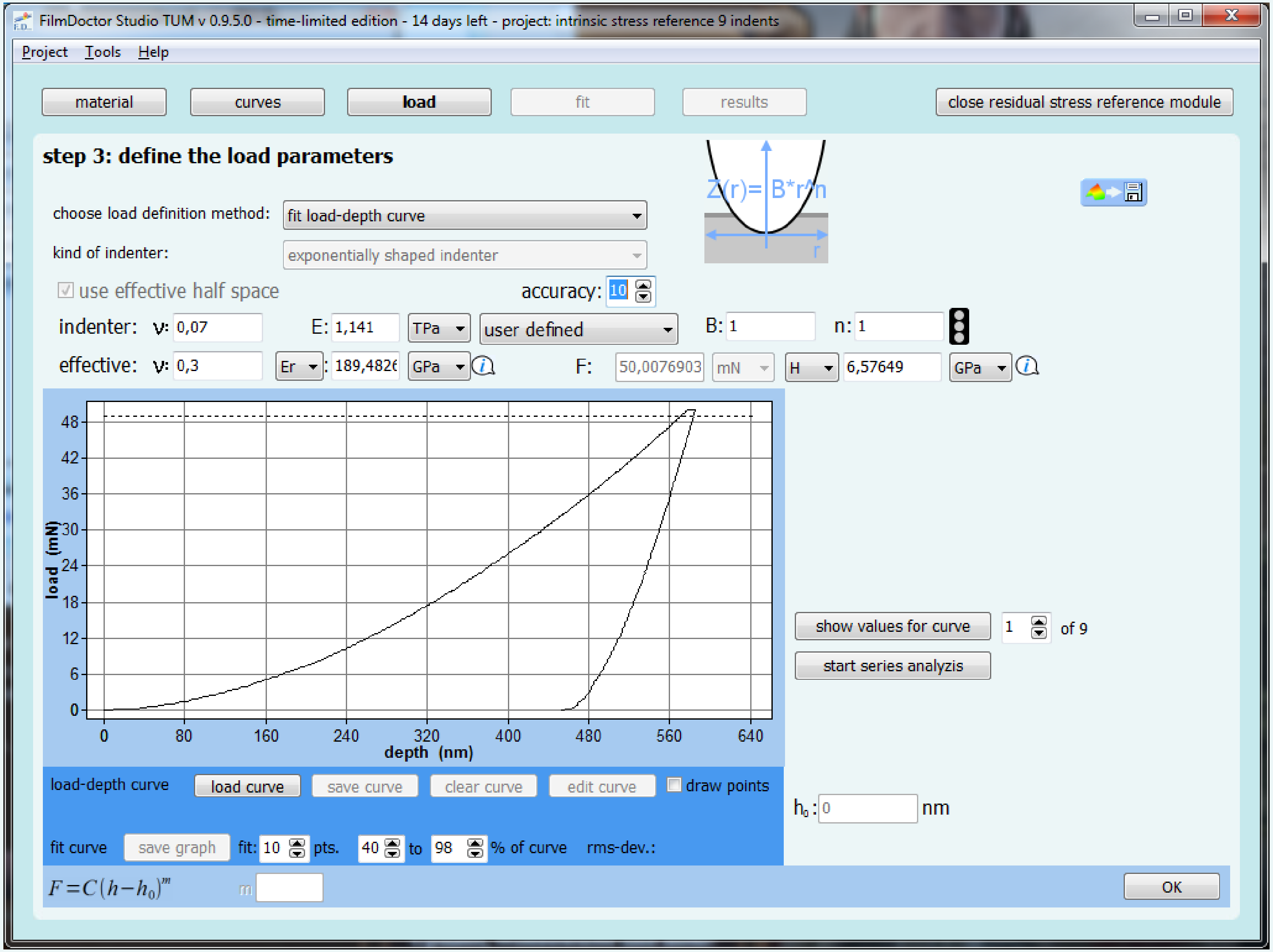
Calculate relative residual stress values for each indent



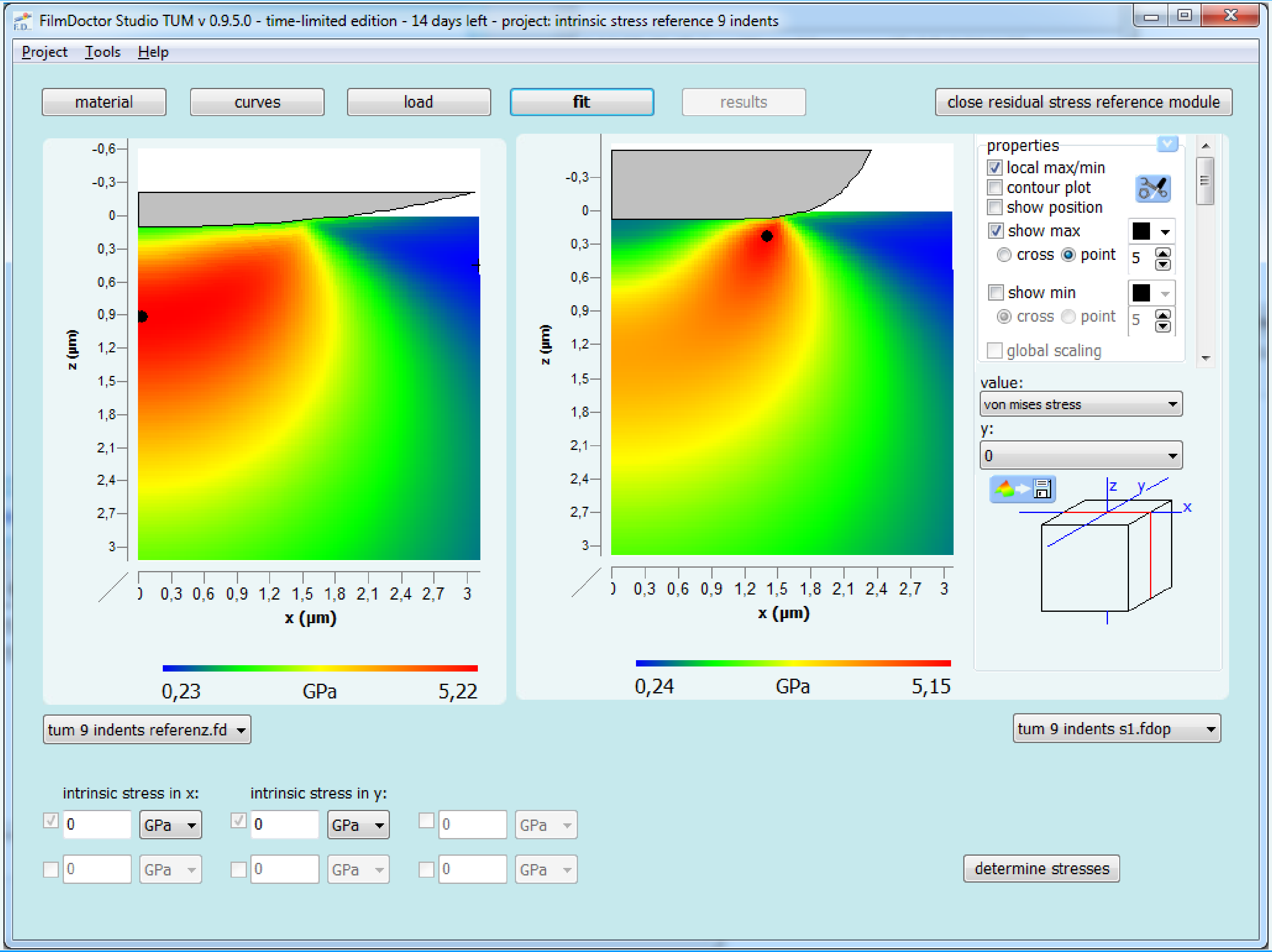
Reference module



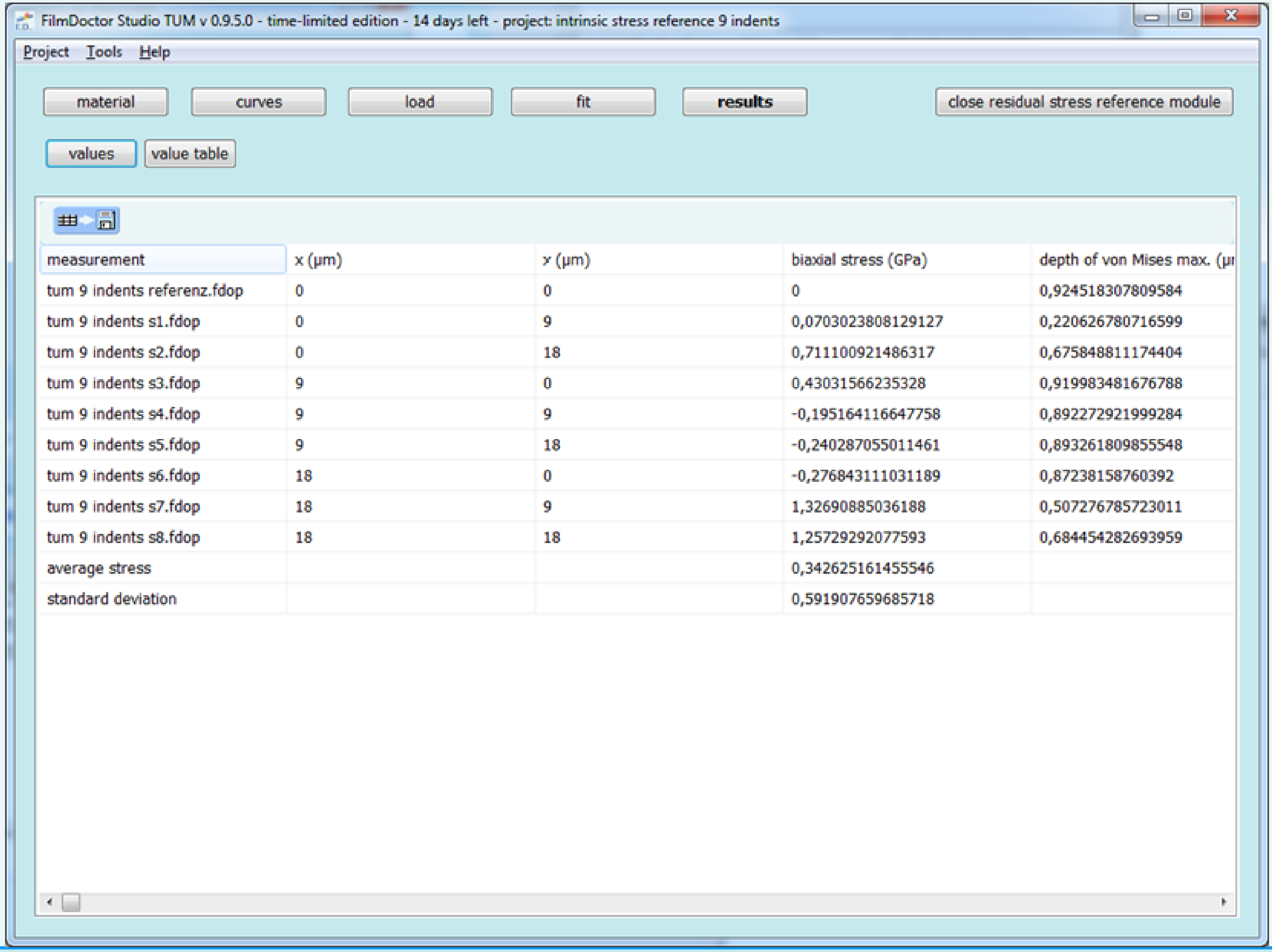
Reference module



Reference module

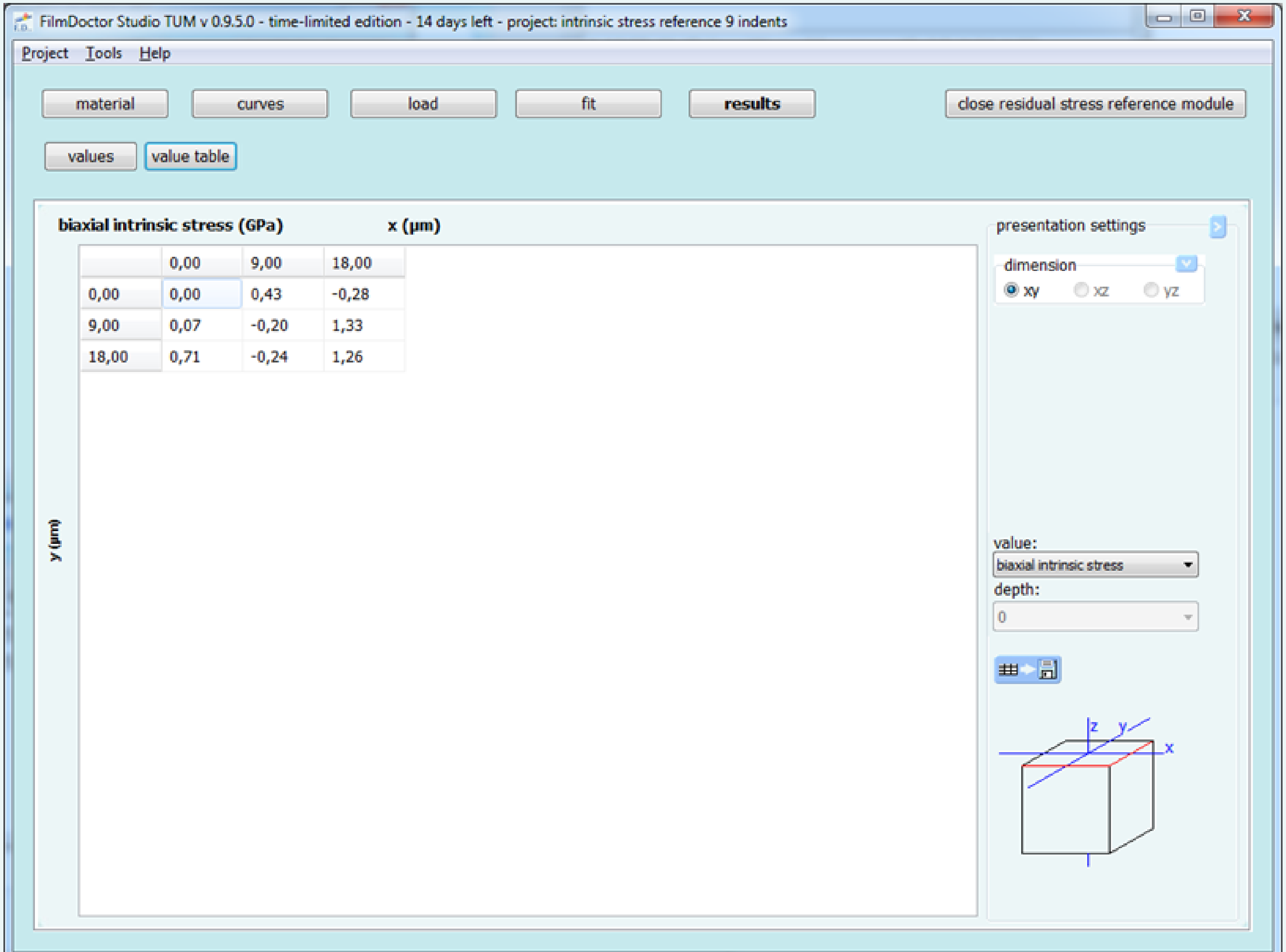


Reference module



measurement	x (µm)	y (µm)	biaxial stress (GPa)	depth of von Mises max. (µ
tum 9 indents referenz.fdop	0	0	0	0,924518307809584
tum 9 indents s1.fdop	0	9	0,0703023808129127	0,220626780716599
tum 9 indents s2.fdop	0	18	0,711100921486317	0,675848811174404
tum 9 indents s3.fdop	9	0	0,43031566235328	0,919983481676788
tum 9 indents s4.fdop	9	9	-0,195164116647758	0,892272921999284
tum 9 indents s5.fdop	9	18	-0,240287055011461	0,893261809855548
tum 9 indents s6.fdop	18	0	-0,276843111031189	0,87238158760392
tum 9 indents s7.fdop	18	9	1,32690885036188	0,507276785723011
tum 9 indents s8.fdop	18	18	1,25729292077593	0,684454282693959
average stress			0,342625161455546	
standard deviation			0,591907659685718	

Reference module



Reference module extension

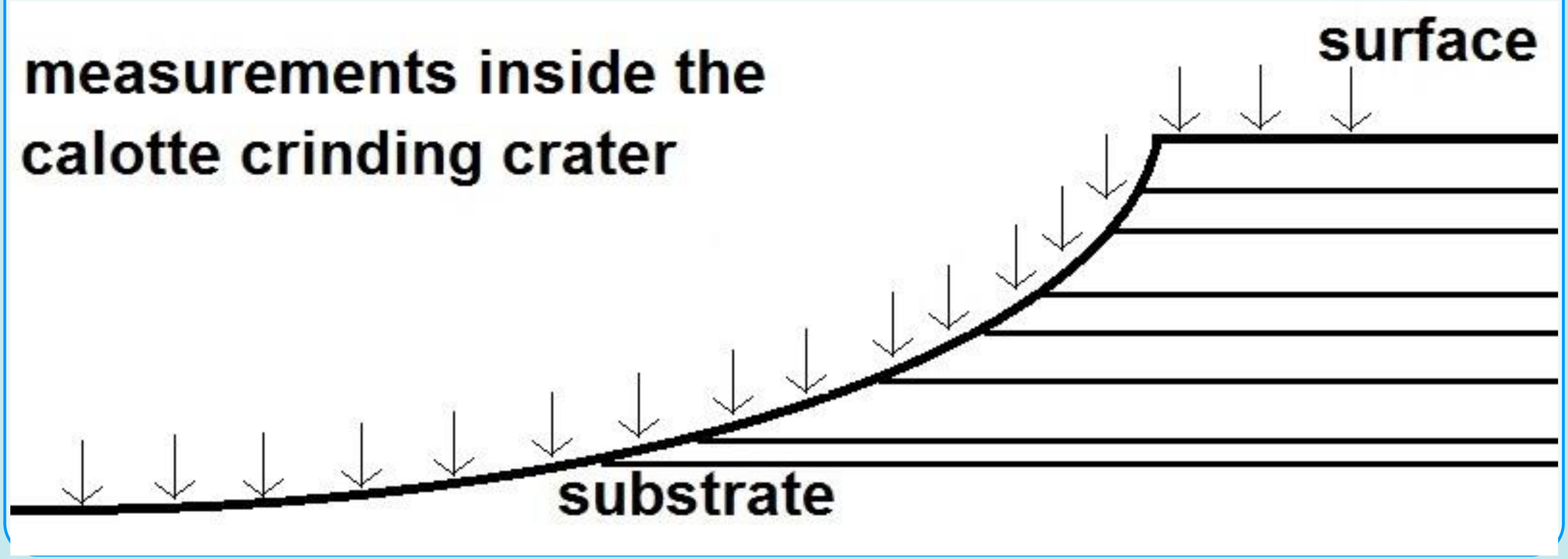
Extend the analyzis by using the third dimension

Get profile information along the z-axis (into the material)

How?

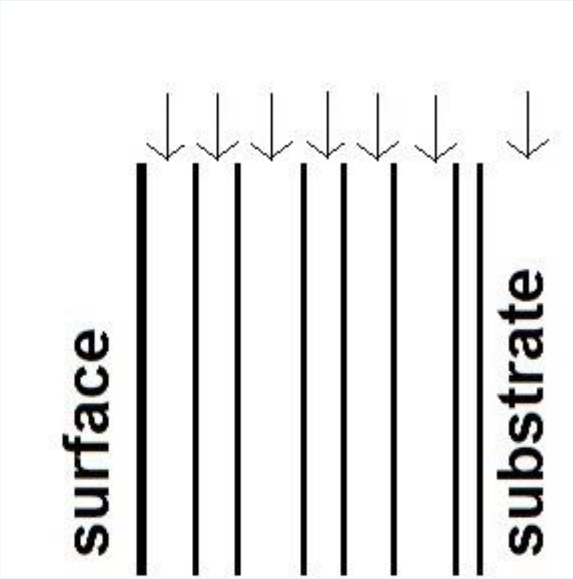
Combine with another existing method
-> calotte grinding

Now perform a series of indentation measurements inside and outside of the crater

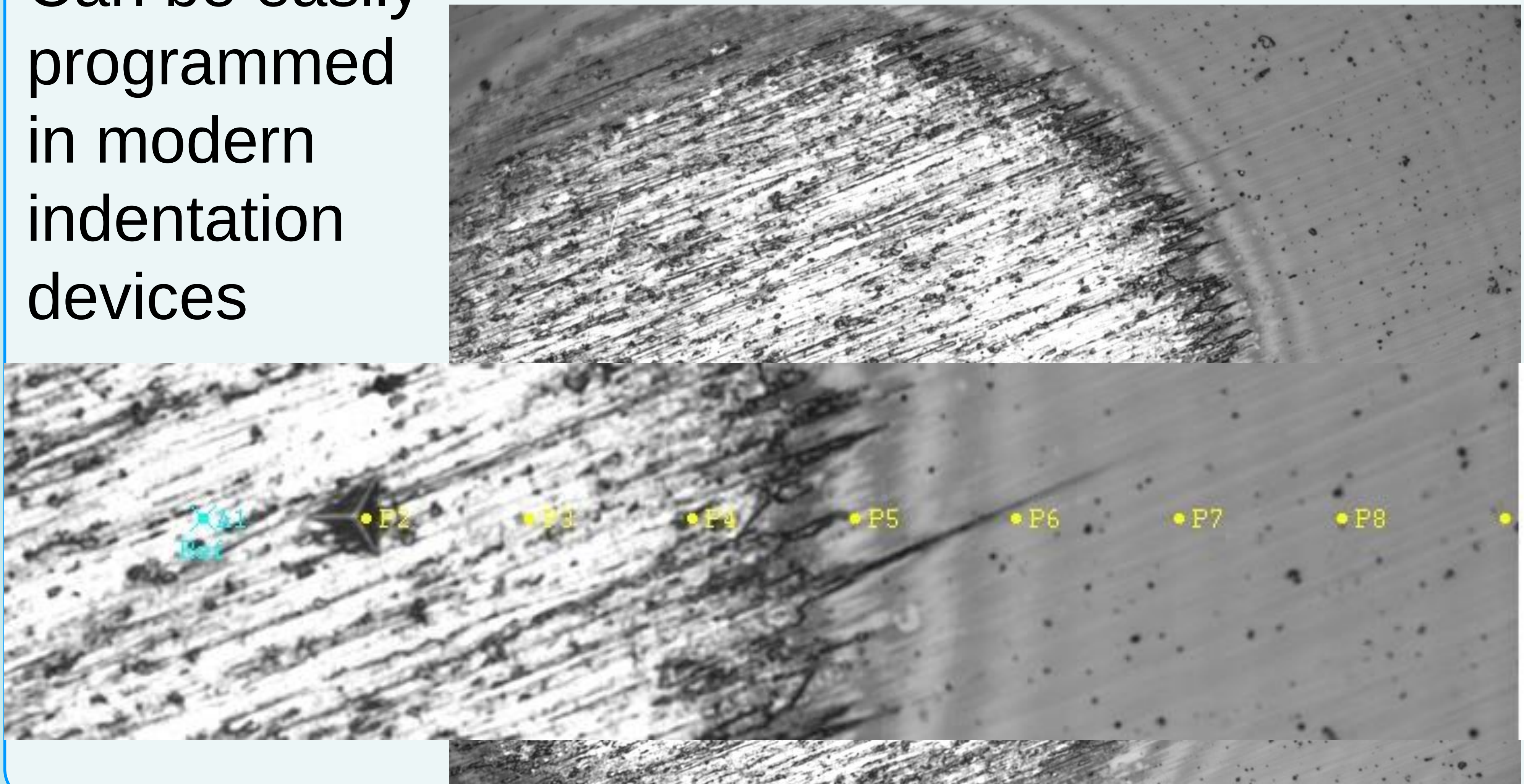


Why calotte grinding?

- easy and cheap, already available in most labs
- creates a huge area which could be used for indentation measurements compared to vertical cuts

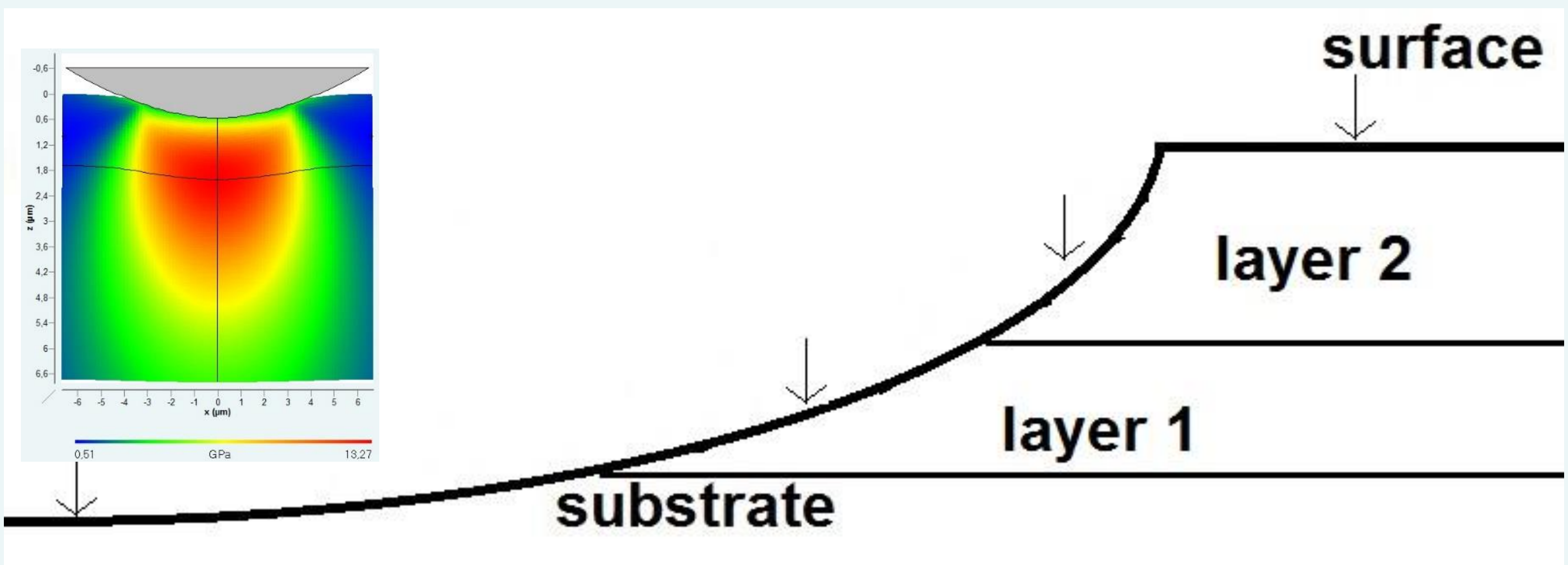


Can be easily programmed in modern indentation devices



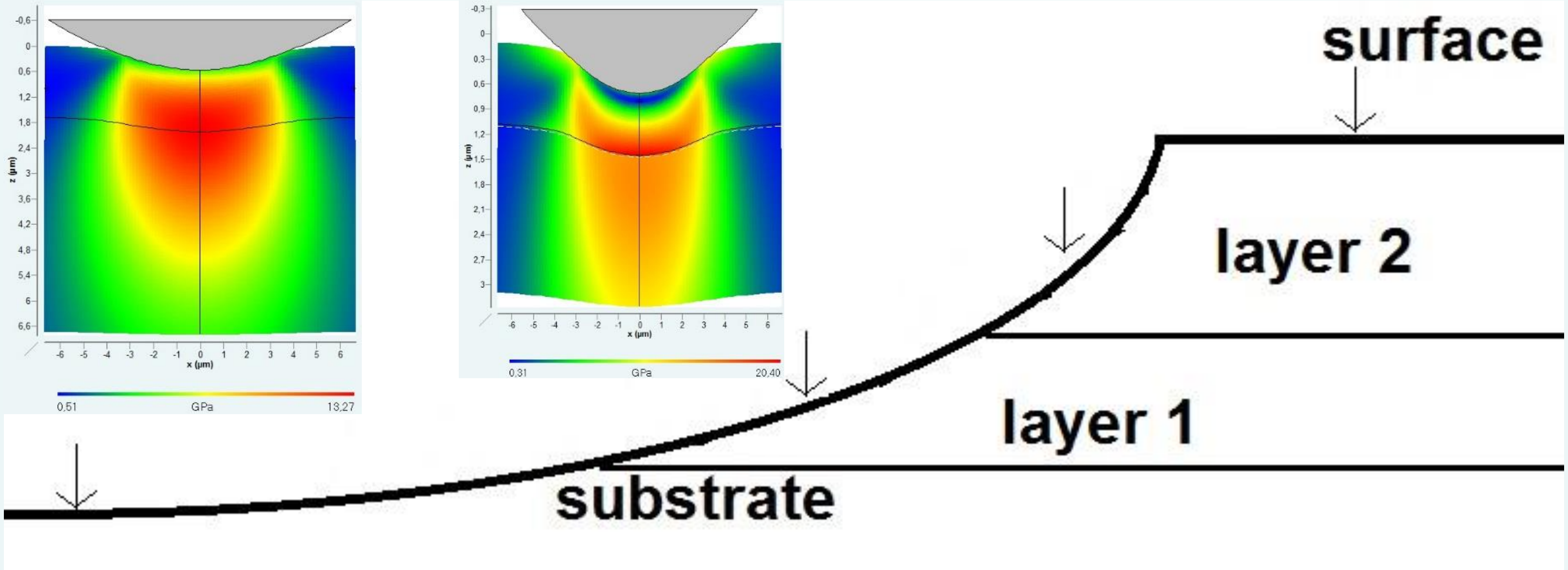
How it works in detail

- Analysis I: substrate measurement → E_s



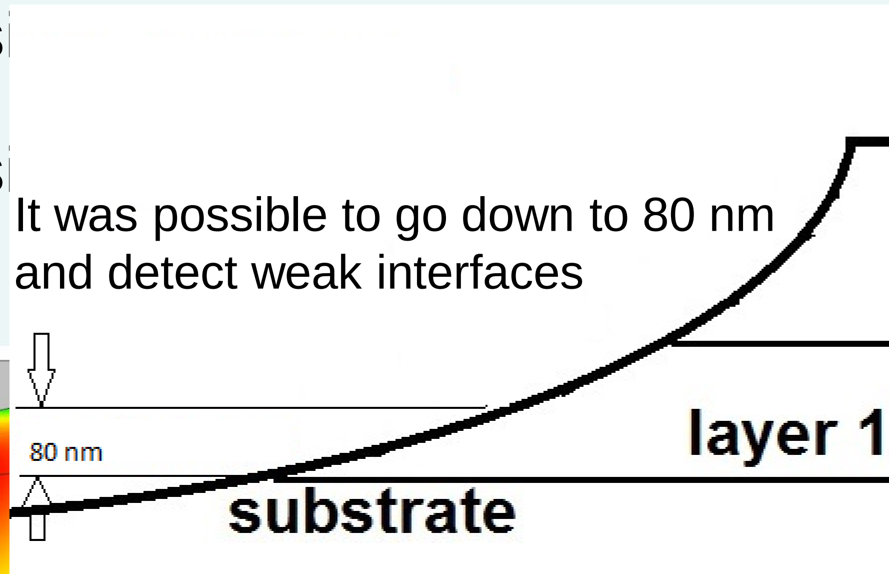
How it works in detail

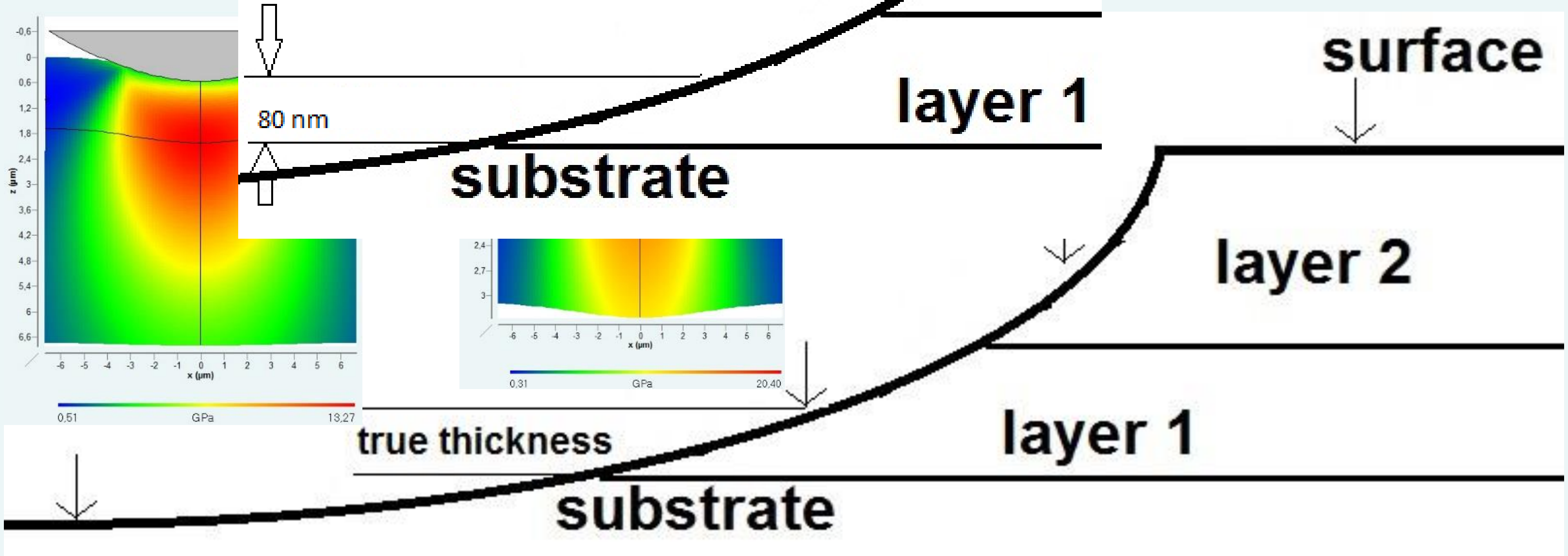
- Analysis I: substrate measurement → E_s
- Analysis II: 1 µm thick layer 1 → E_1



How it works in detail

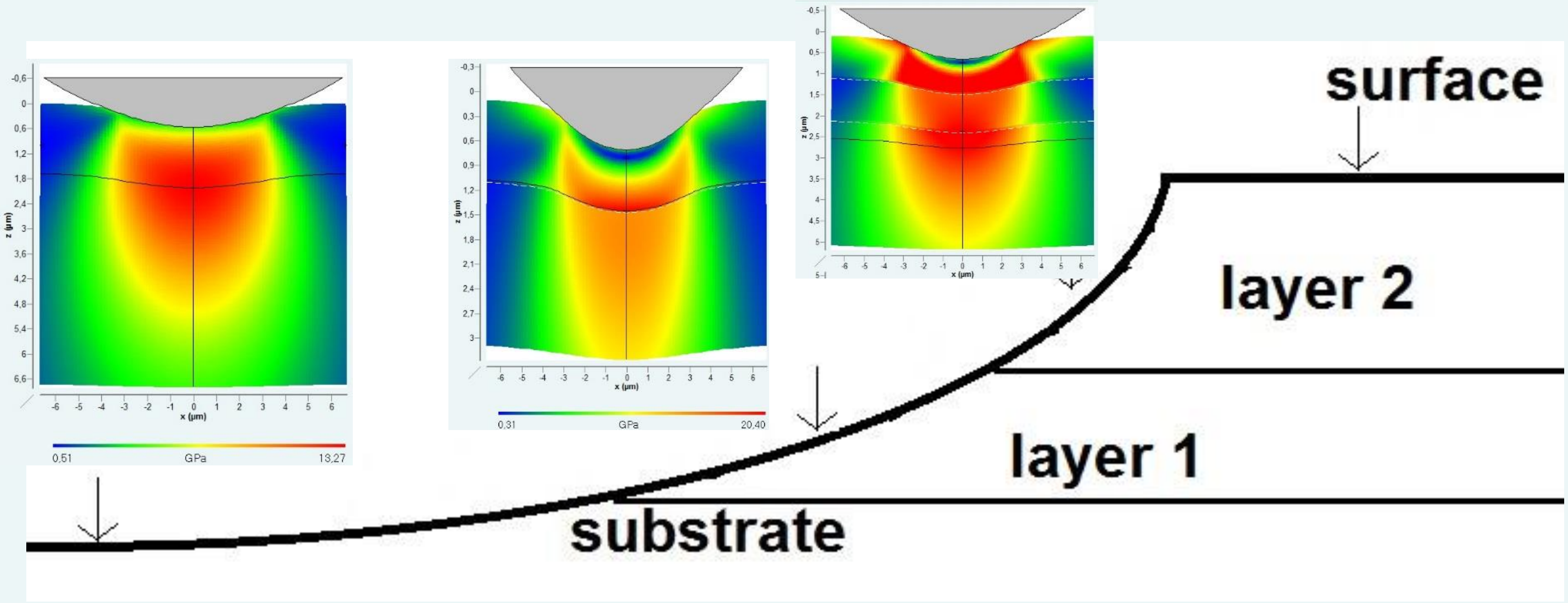
- Analysi … E_s
- Analysi





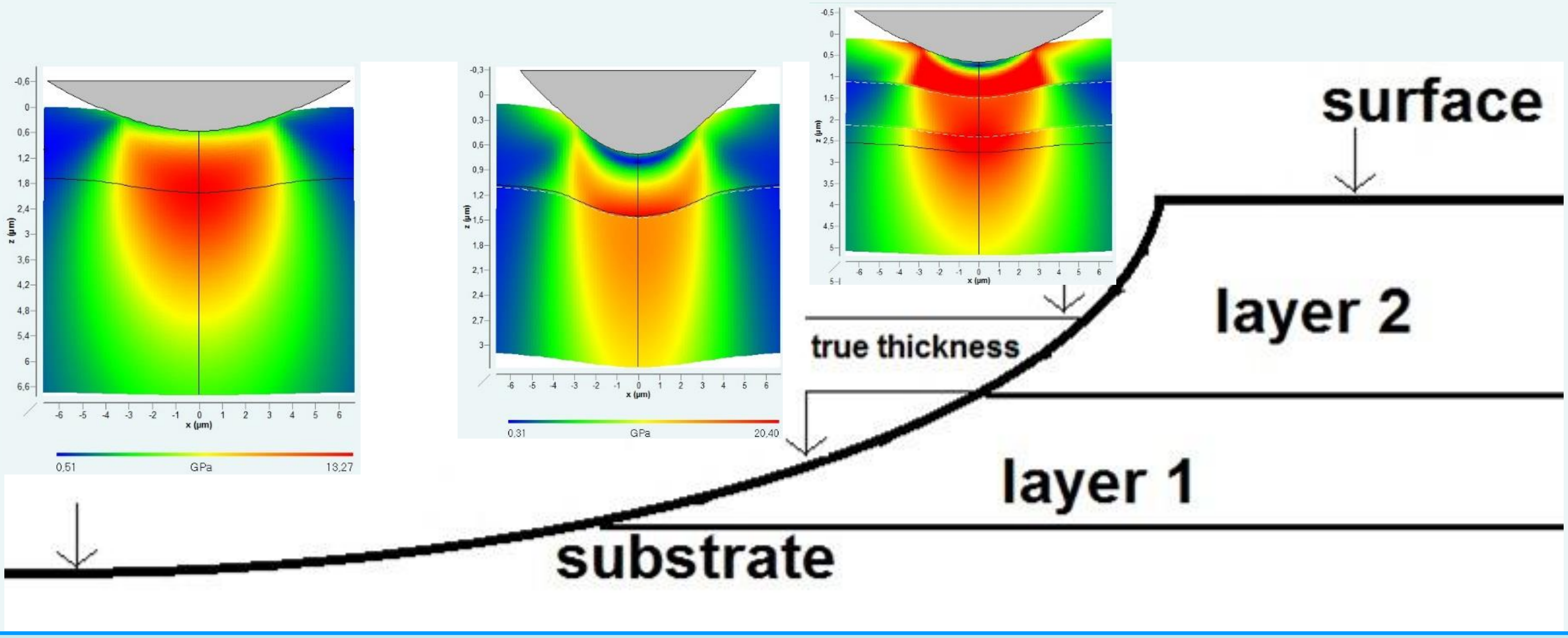
How it works in detail

- Analysis III: 1 µm thick layer 2 → E_{21}

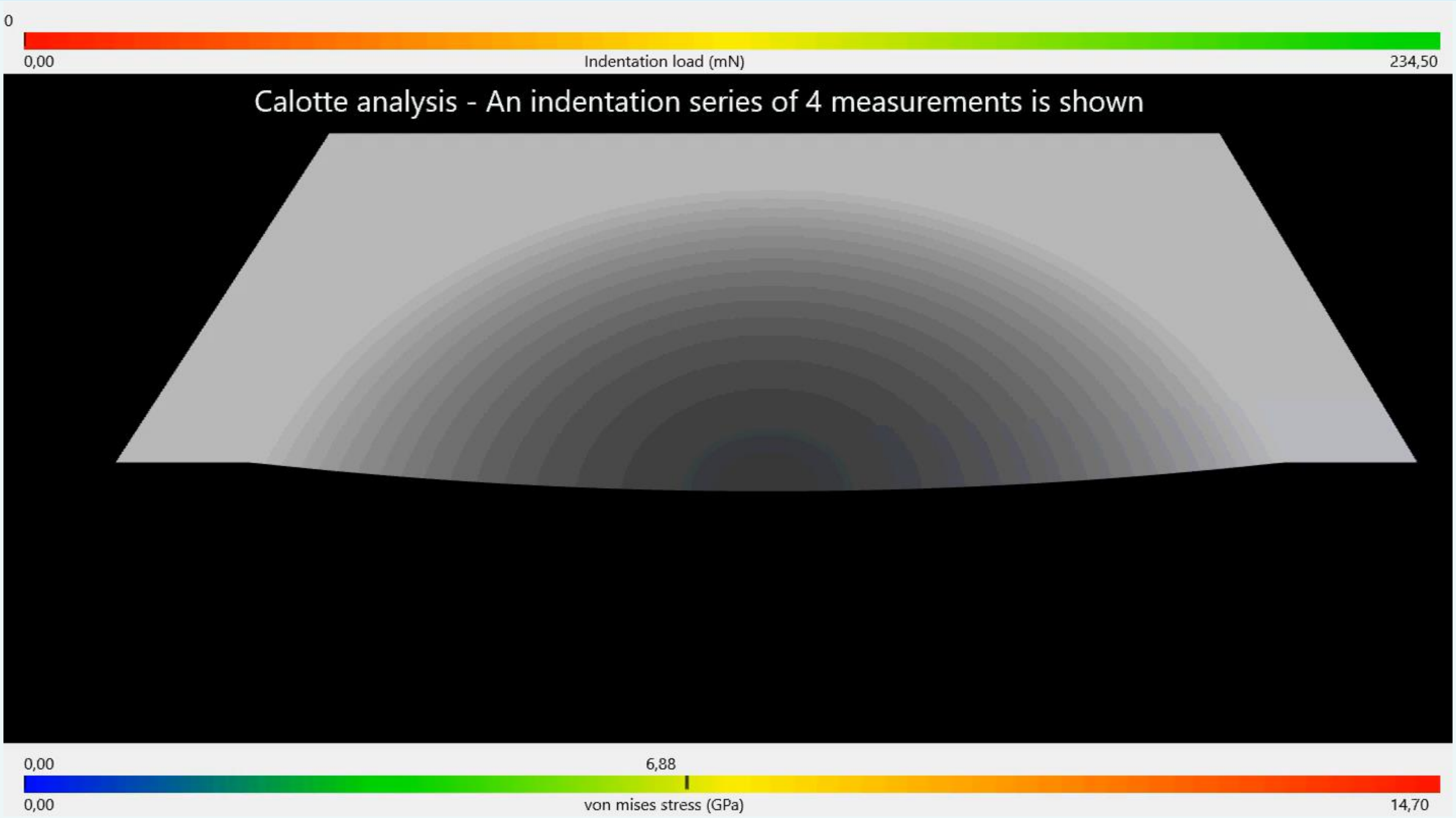


How it works in detail

- Analysis III: 1 µm thick layer 2 → E_{21}
- Analysis IV: 3 µm thick layer 2 → E_{22}
- If E_{21} and E_{22} differs significantly check homogeneity!



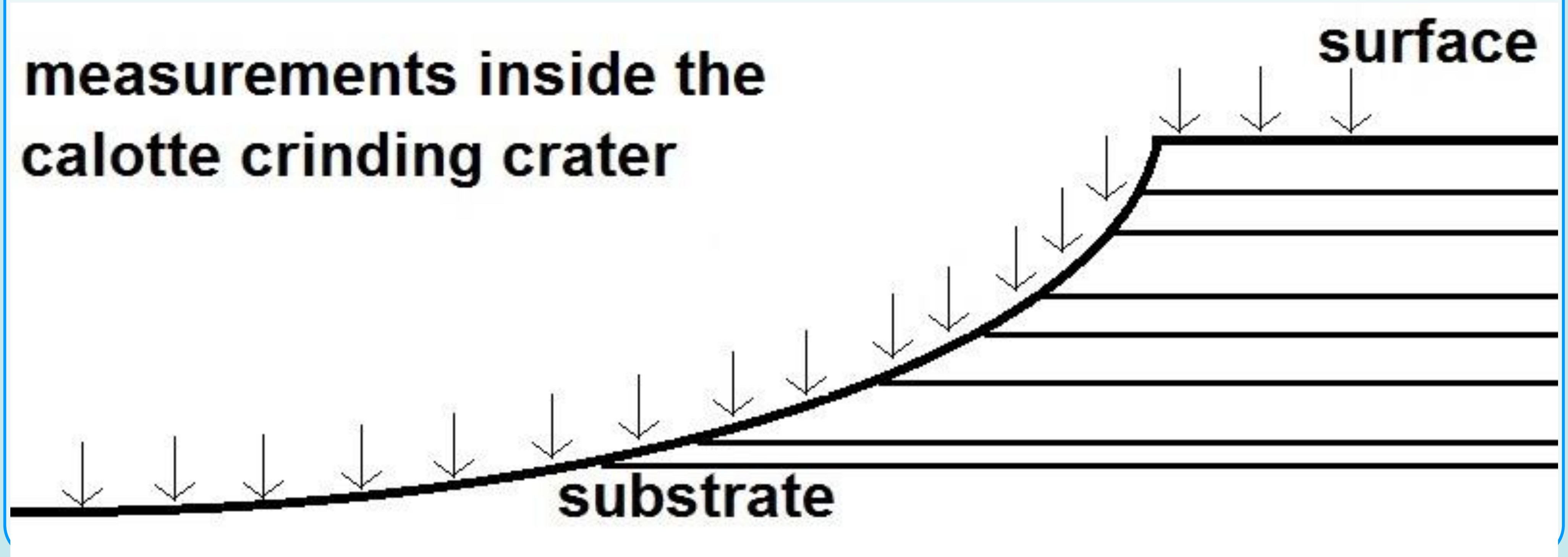
SIO Calotte Module



https://worldformulaapps.com/portfolio/calotte

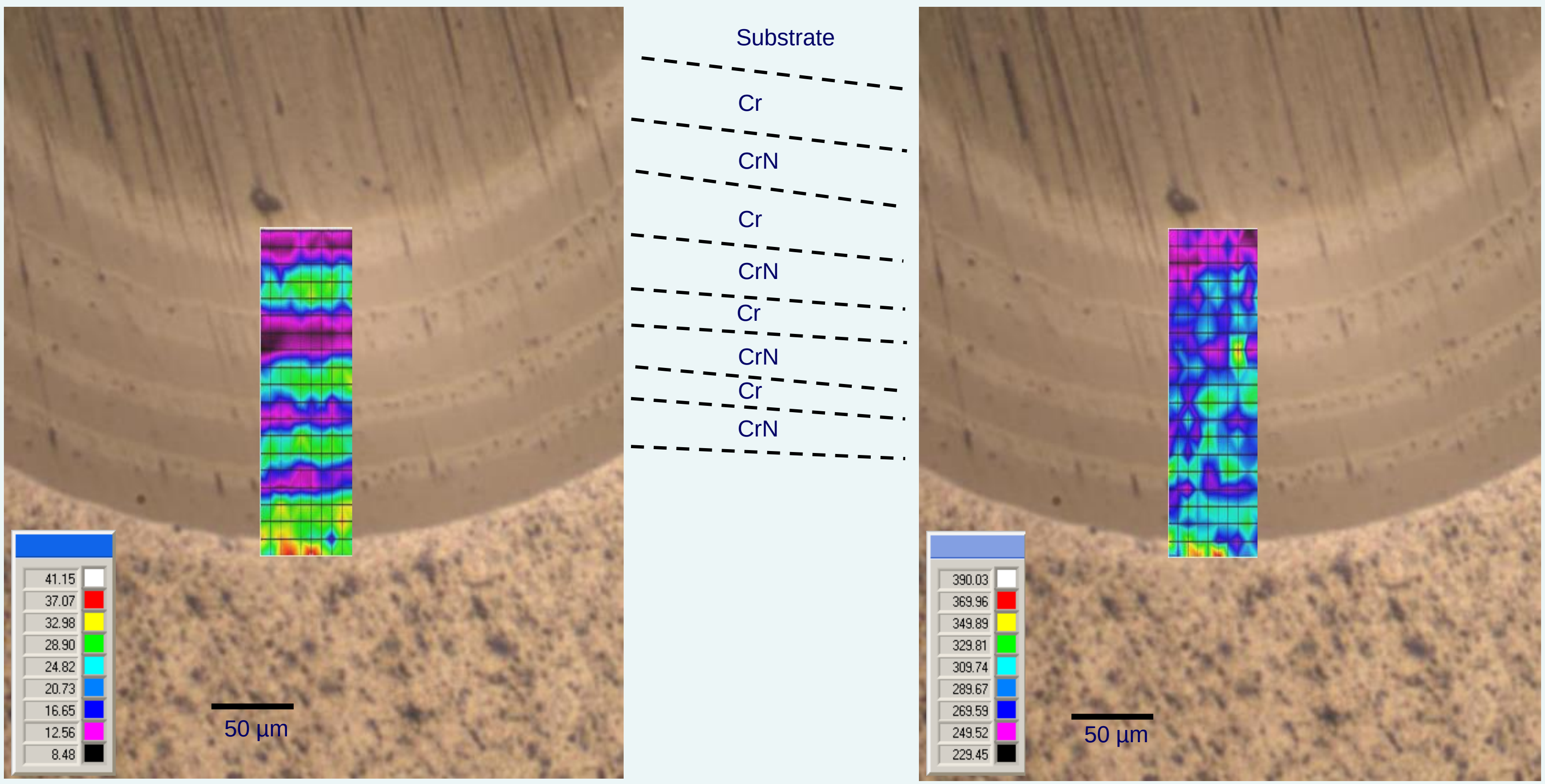
youtube

Now perform a series of indentation measurements inside and outside of the crater
Reference indent could be anywhere



Nanoindentation of multi-layer coating

Hardness and modulus maps are created automatically in most actual indentation device software packages. The manufacturers put a lot of efford in faster measurement procedures.



Stress profiles

Example: 4.5 µm dlc coating on a metal substrate

material | curves | load | fit | results | close residual stress reference module

step 1: select your material

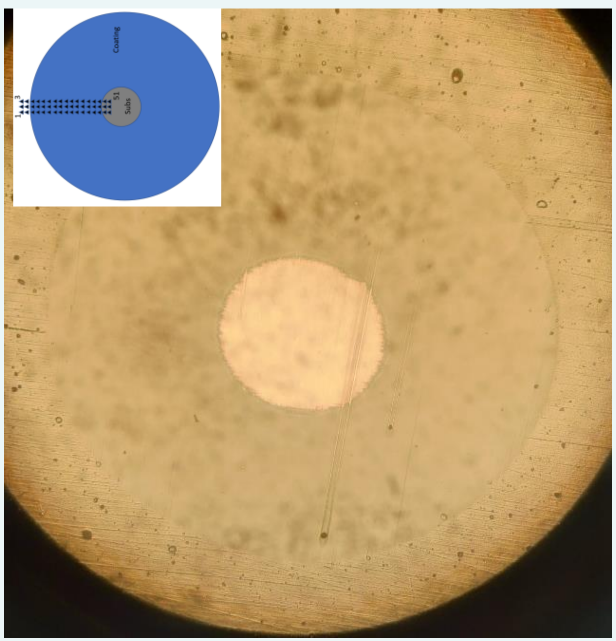
select all

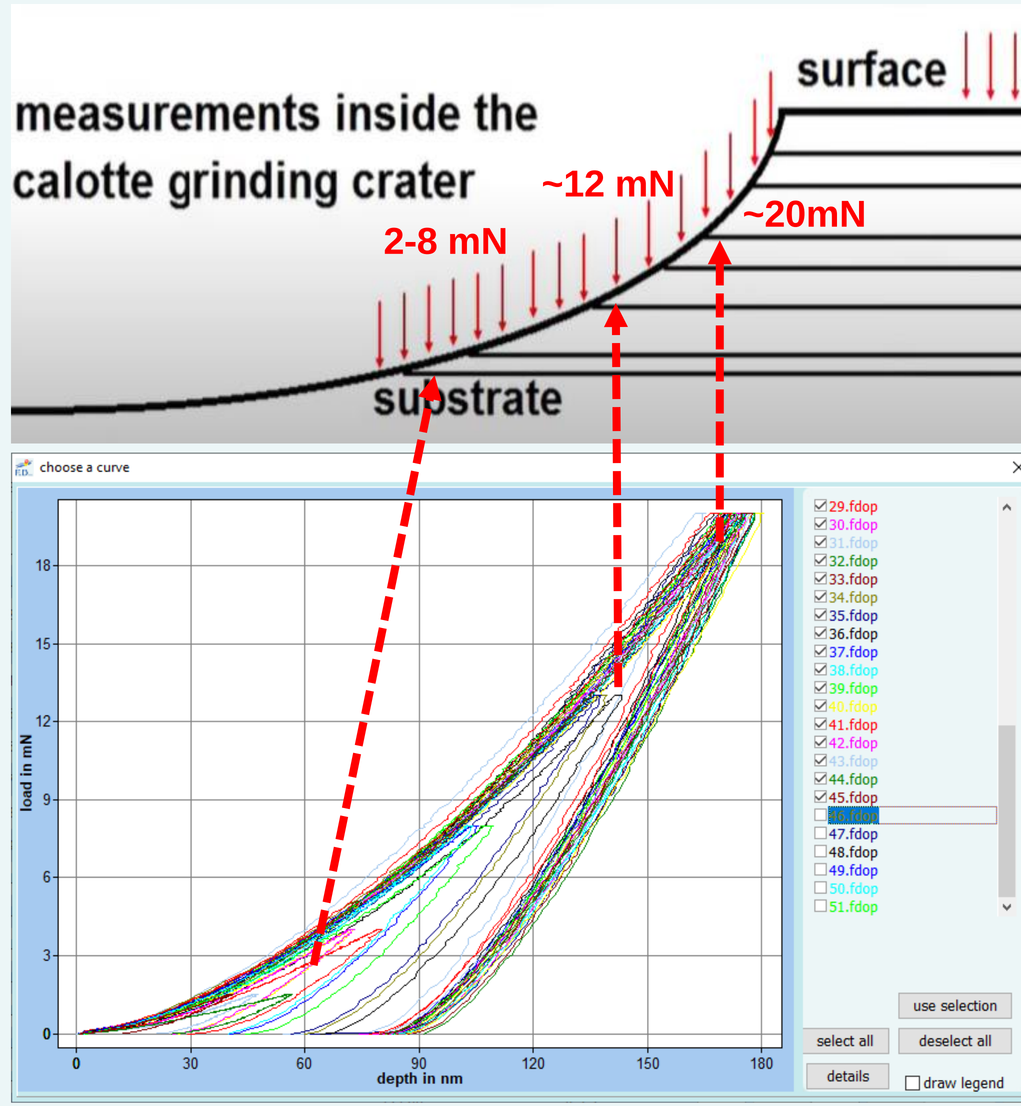
Layer	Poisson's ratio	Young's modulus (☐ gradient ☐ viscous)	select from database	layer thickness	intrinsic stresses (☐ gradient)	intrinsic stresses (☐ gradient)	
☑ layer 1:	V: 0,25	E: 440 GPa	user defined	h: 4,5 µm	in x: 0 GPa	in y: 0 GPa	more
☐ layer 2:	V: 0,22	E: 450 GPa	user defined	h: 1 µm	in x: 0 GPa	in y: 0 GPa	more
☐ layer 3:	V: 0,321	E: 115,7 GPa	user defined	h: 1 µm	in x: 0 GPa	in y: 0 GPa	more
☐ layer 4:	V: 0,22	E: 450 GPa	user defined	h: 1 µm	in x: 0 GPa	in y: 0 GPa	more
☐ layer 5:	V: 0,321	E: 115,7 GPa	user defined	h: 1 µm	in x: 0 GPa	in y: 0 GPa	more
☐ layer 6:	V: 0,22	E: 450 GPa	user defined	h: 1 µm	in x: 0 GPa	in y: 0 GPa	more
☐ layer 7:	V: 0,321	E: 115,7 GPa	user defined	h: 1 µm	in x: 0 GPa	in y: 0 GPa	more
☐ layer 8:	V: 0,22	E: 450 GPa	user defined	h: 1 µm	in x: 0 GPa	in y: 0 GPa	more
☐ layer 9:	V: 0,321	E: 115,7 GPa	user defined	h: 1 µm	in x: 0 GPa	in y: 0 GPa	more
☐ layer 10:	V: 0,22	E: 450 GPa	user defined	h: 1 µm	in x: 0 GPa	in y: 0 GPa	more
☐ layer 11:	V: 0,321	E: 115,7 GPa	user defined	h: 1 µm	in x: 0 GPa	in y: 0 GPa	more
☐ layer 12:	V: 0,22	E: 450 GPa	user defined	h: 1 µm	in x: 0 GPa	in y: 0 GPa	more
☐ layer 13:	V: 0,321	E: 115,7 GPa	user defined	h: 1 µm	in x: 0 GPa	in y: 0 GPa	more
☐ layer 14:	V: 0,22	E: 450 GPa	user defined	h: 1 µm	in x: 0 GPa	in y: 0 GPa	more
☐ layer 15:	V: 0,321	E: 115,7 GPa	user defined	h: 1 µm	in x: 0 GPa	in y: 0 GPa	more

upgrade to more layers

substrate:	V: 0,3	E: 240 GPa	user defined		in x: 0 GPa	in y: 0 GPa	more

Load a series of indentation measurements

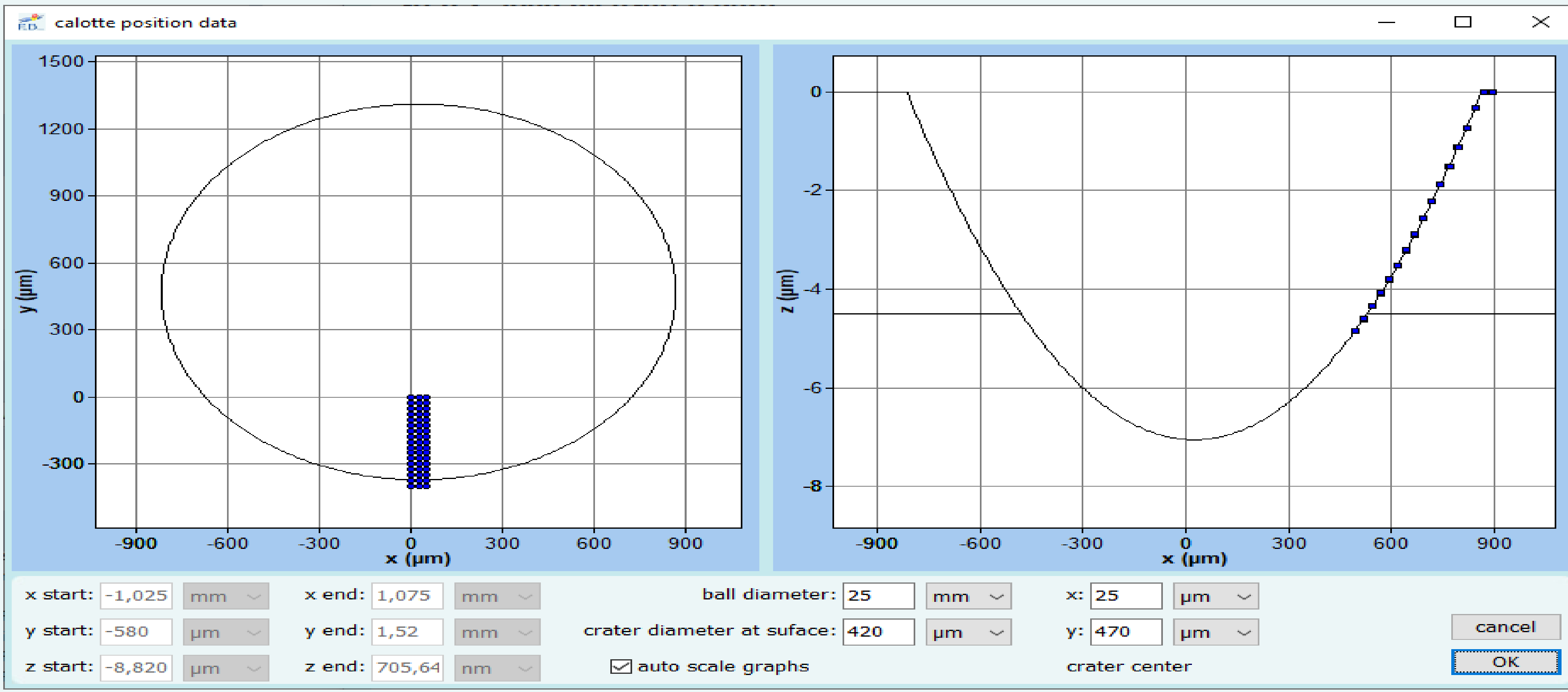




Stress profiles

Define the position of each measurement

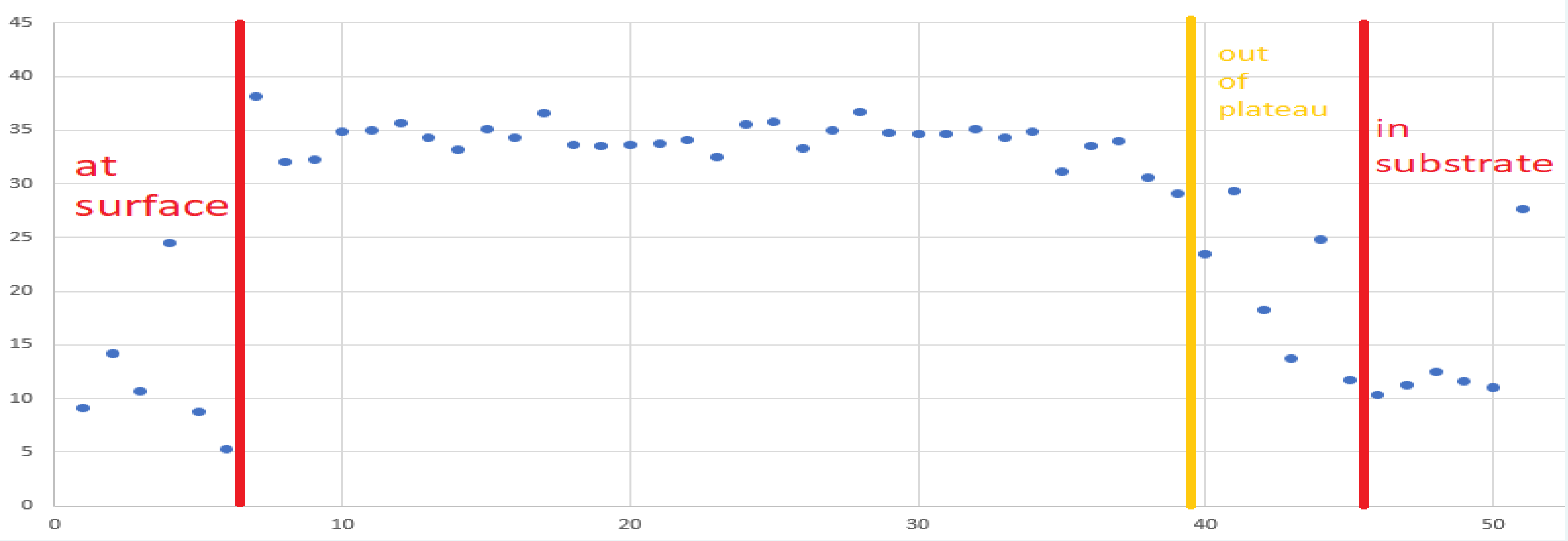
Define the calotte crater parameters



Stress profiles

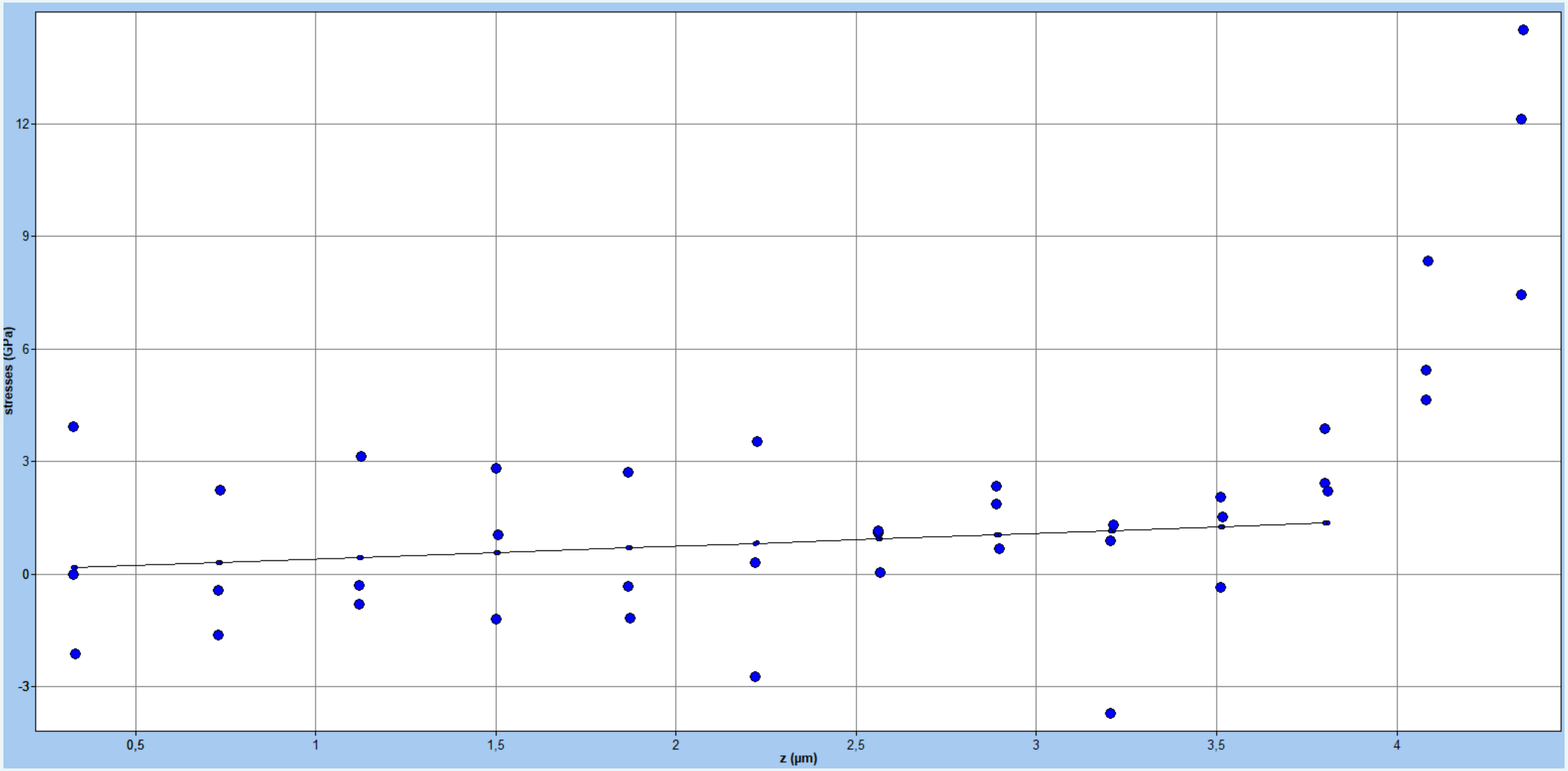
Measurements were performed from the surface to the substrate

Nice hardness plateau in most of the coating



Stress profiles

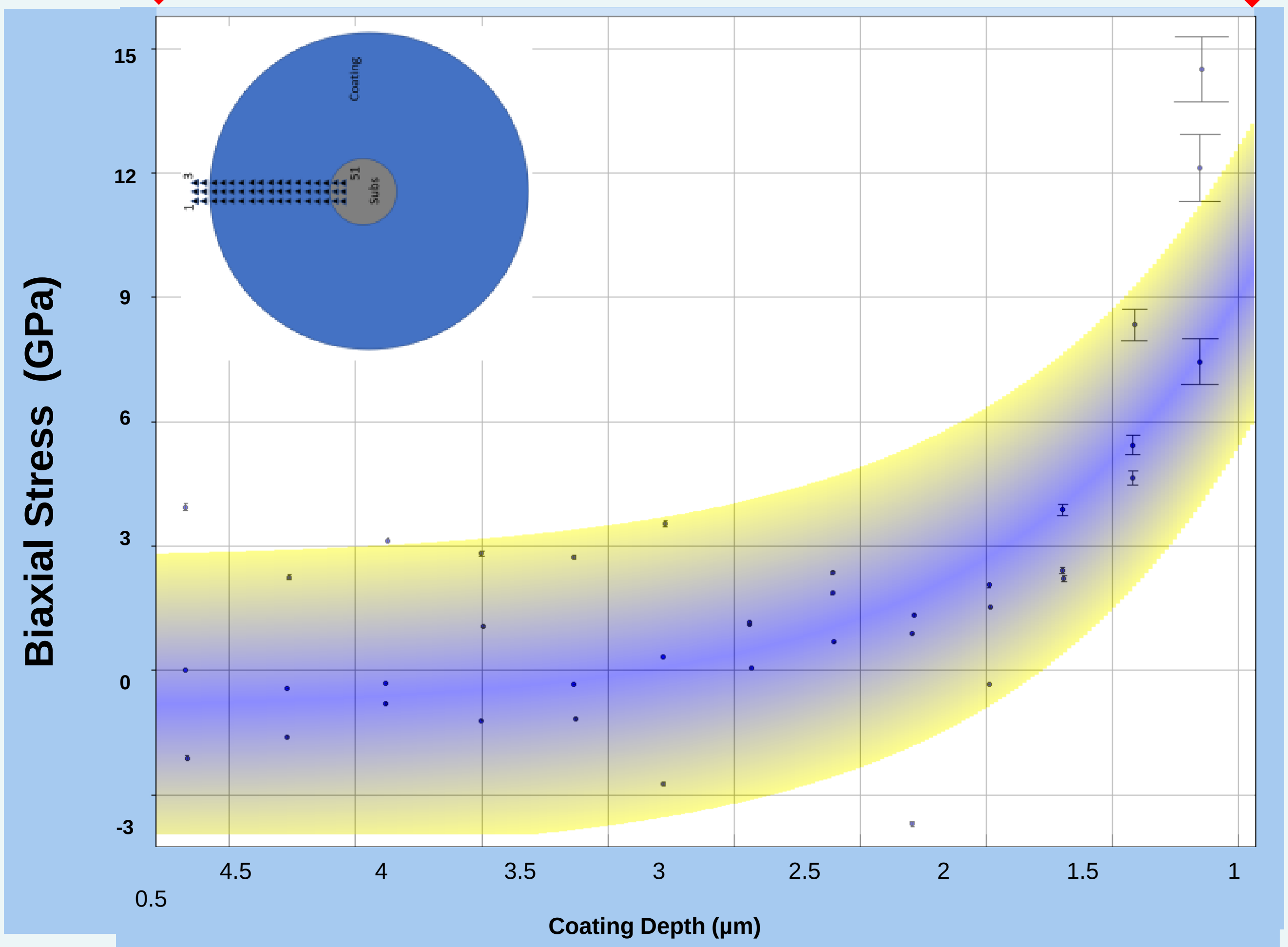
Nice residual stress plateau in most of the coating was found



Stress Profiles From Nanoindentation

Surface

Substrate Interface



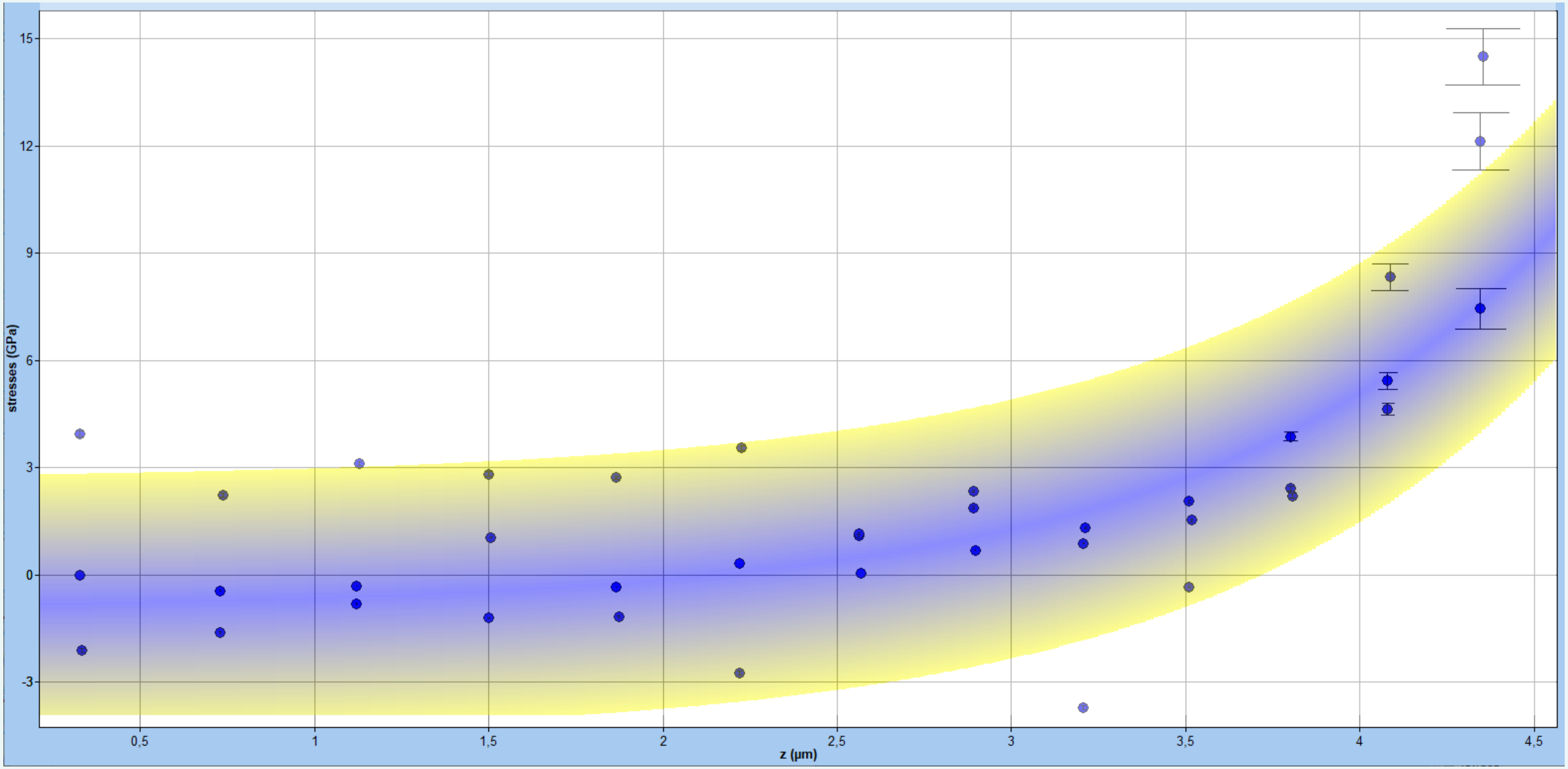
Tensile direction

Compressive direction

DLC coating by PECVD with a doped interface on A2 Tool Steel

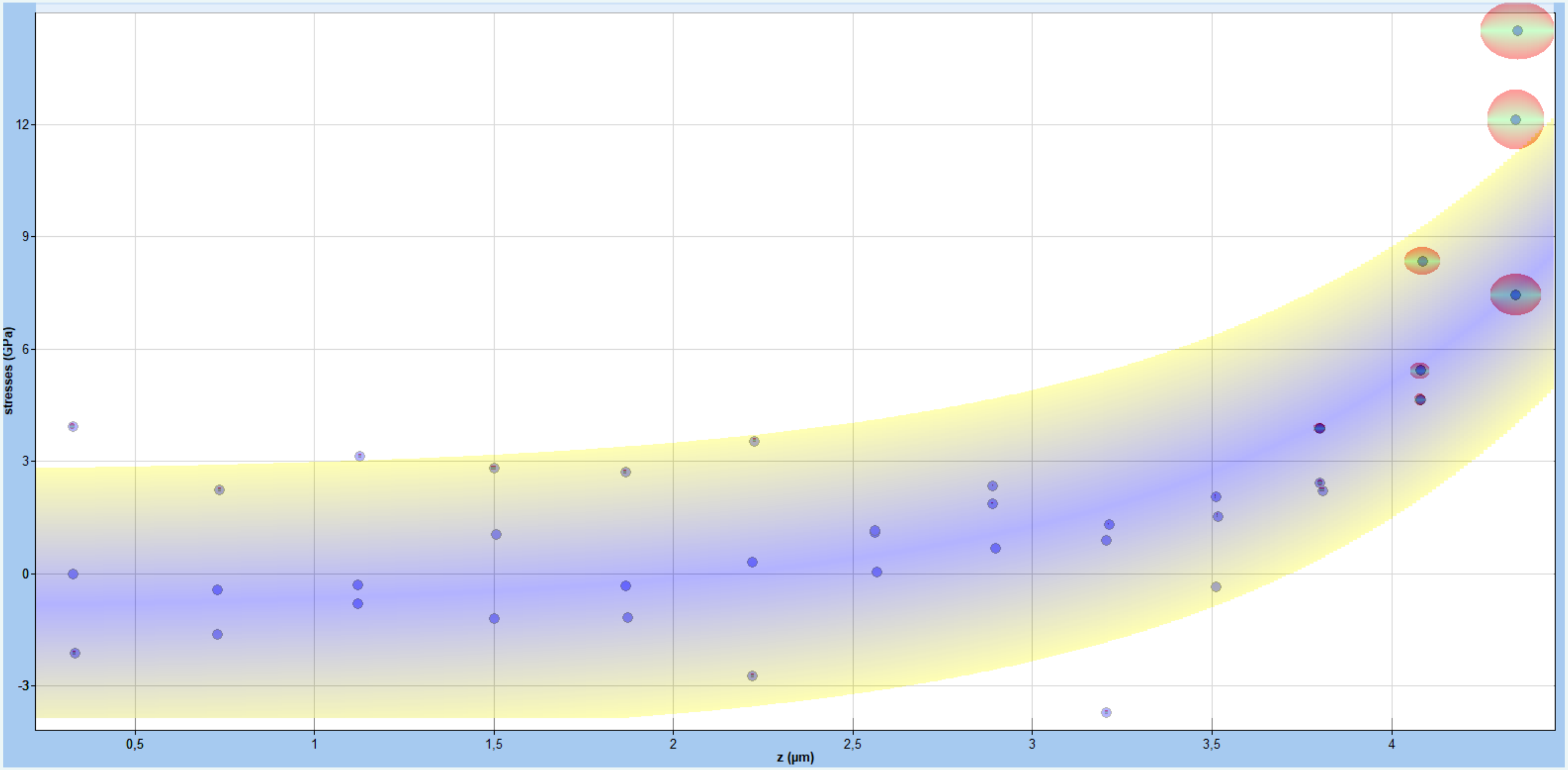
Stress profiles

Errors are higher for the substrate near measurements, because a much lower load was used due to the very thin remaining coating



Stress profiles

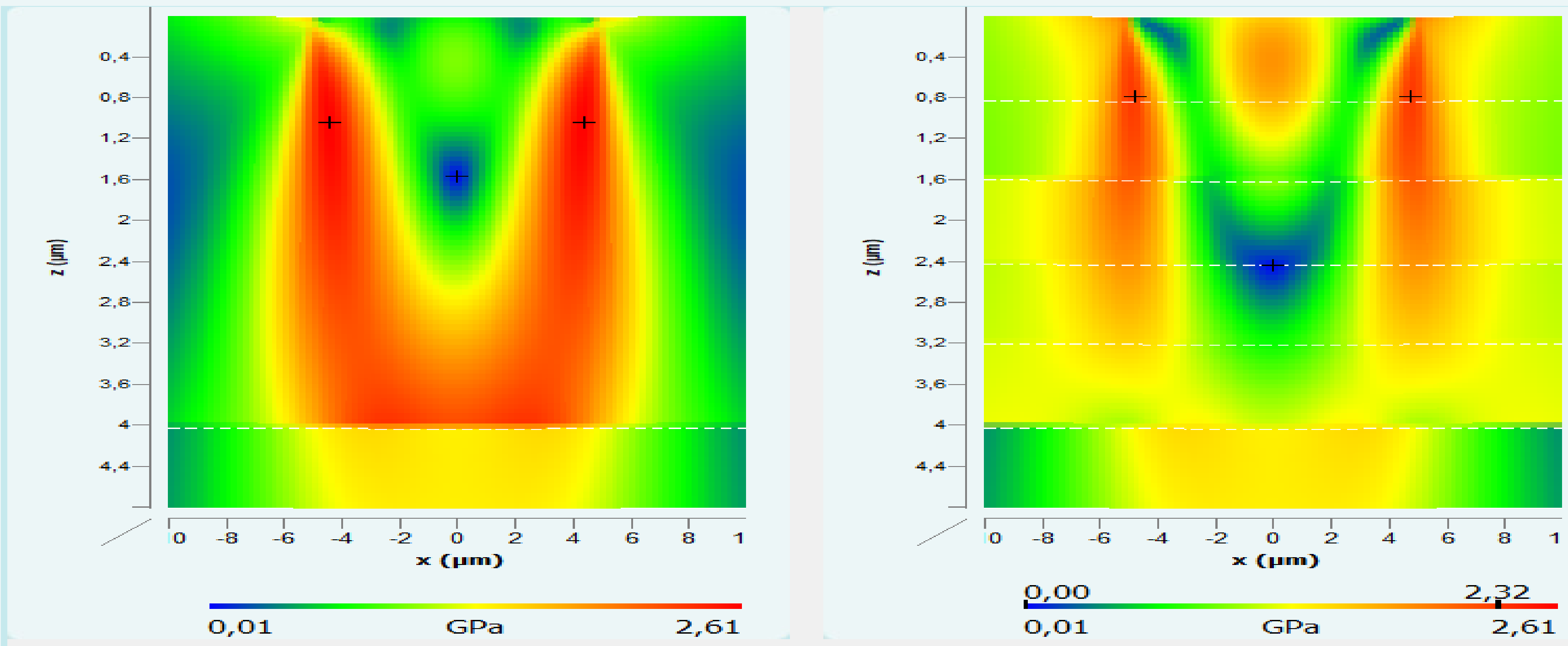
The increased stress values close to the interface were in good correlation with the observed failure mechanism



Stress optimization

Improve performance by steering (e.g. bias changes) intrinsic stresses during the deposition process

No material changes or new materials needed



https://worldformulaapps.com/portfolio/intrinsic-stress

OstriA

Better understanding of tribological properties of polymers

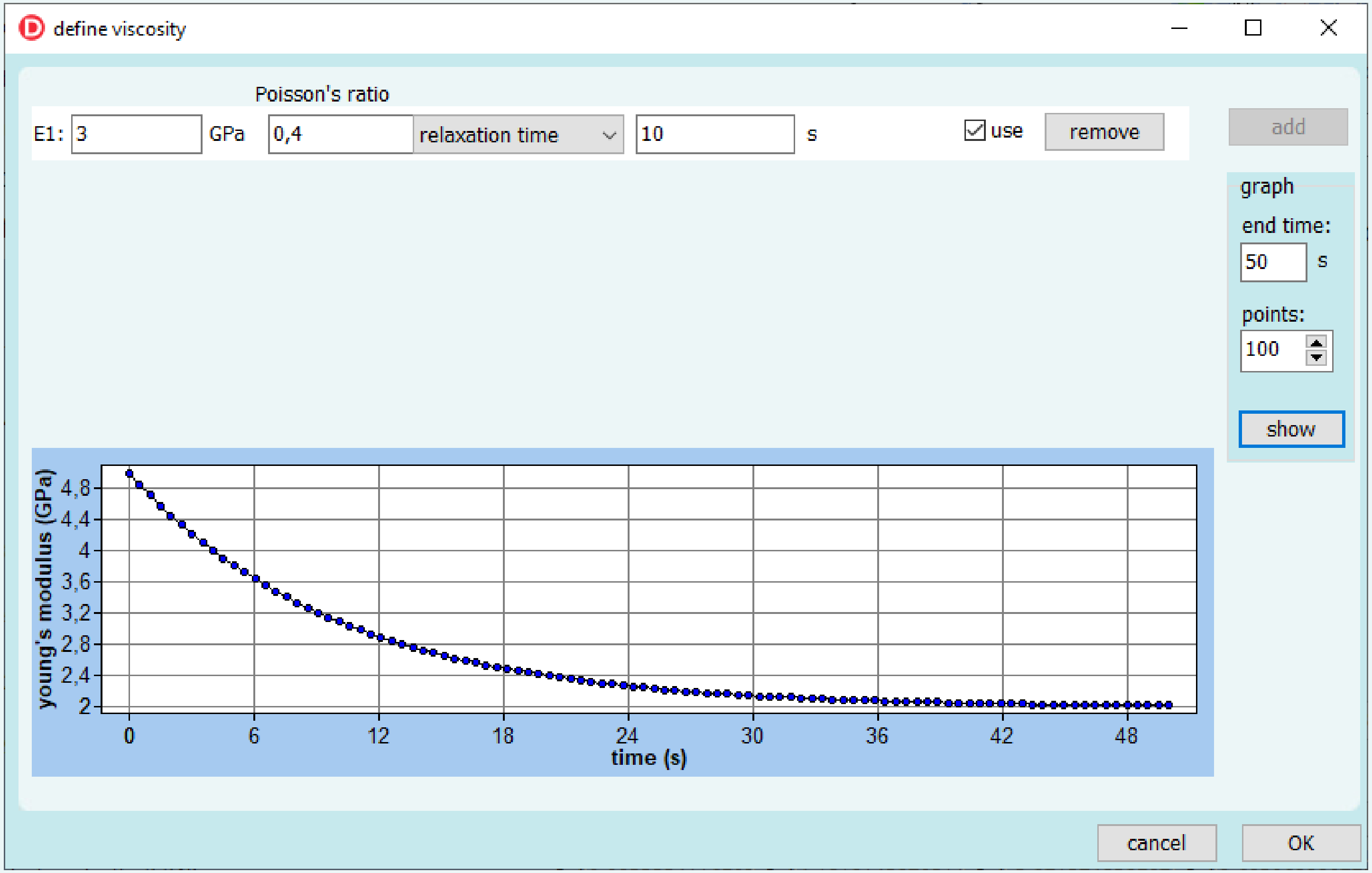
https://fbmk.h-da.de/forschung/institut-fuer-kunststofftechnik/aktuelle-projekte-am-ikd

https://fbmk.h-da.de/forschung/institut-fuer-kunststofftechnik

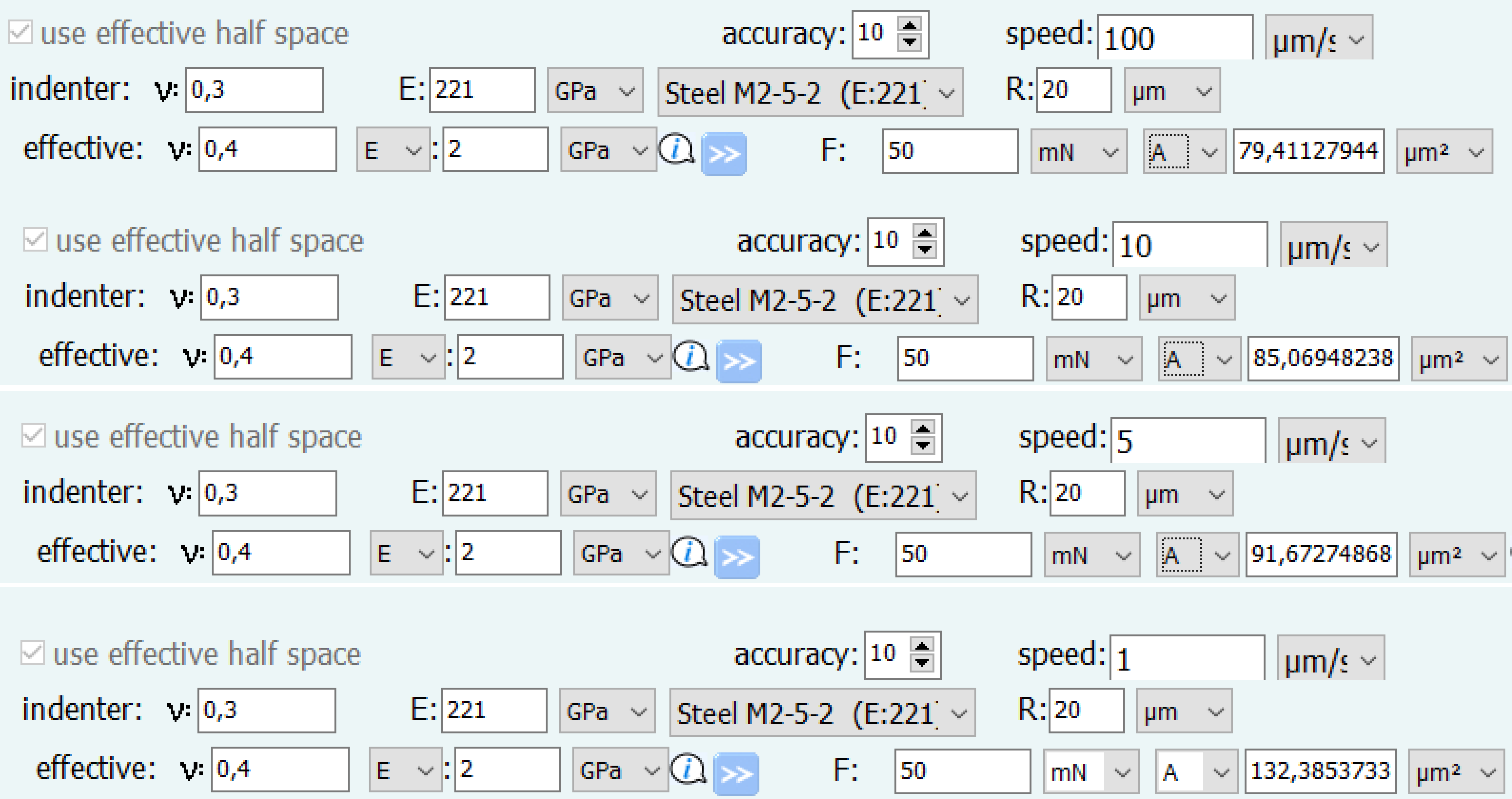
https://www.tu-chemnitz.de/mb/FoerdTech/startseite.php

Extend material parameters

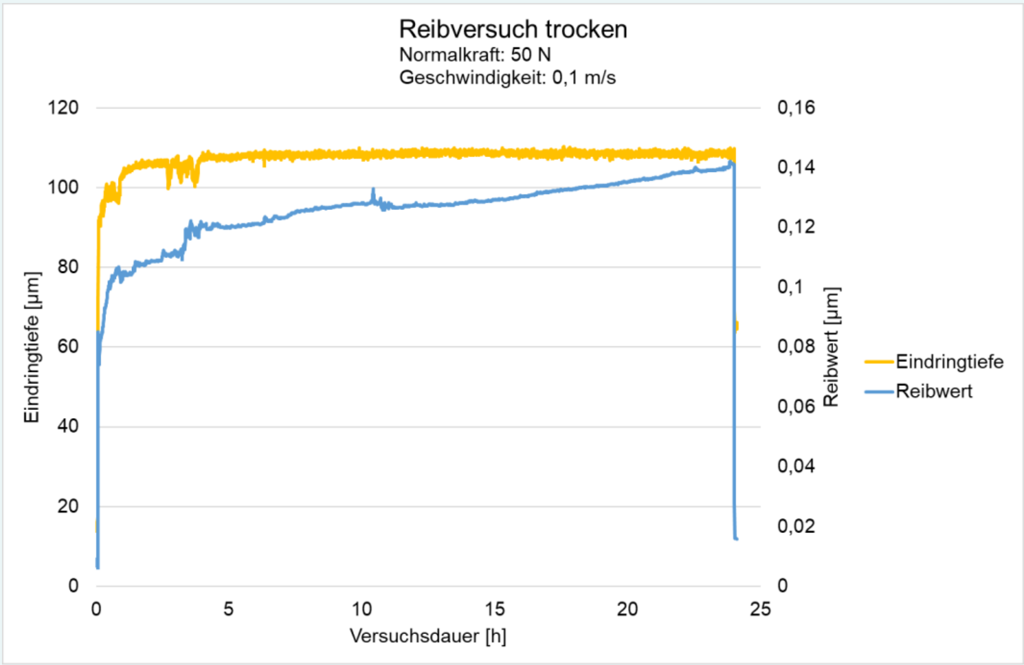
Young‘s modulus can now be time dependent. E=E0+E1*exp(-c/t)



Contact conditions change for different application/test speeds



OstriA


Reibversuch trocken
Normalkraft: 50 N
Geschwindigkeit: 0,1 m/s
Eindringtiefe [µm]
Reibwert [µm]
Versuchsdauer [h]
0
20
40
60
80
100
120
0
0,02
0,04
0,06
0,08
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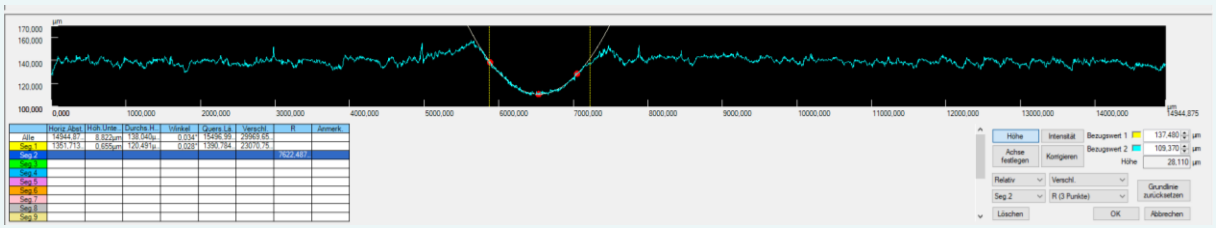
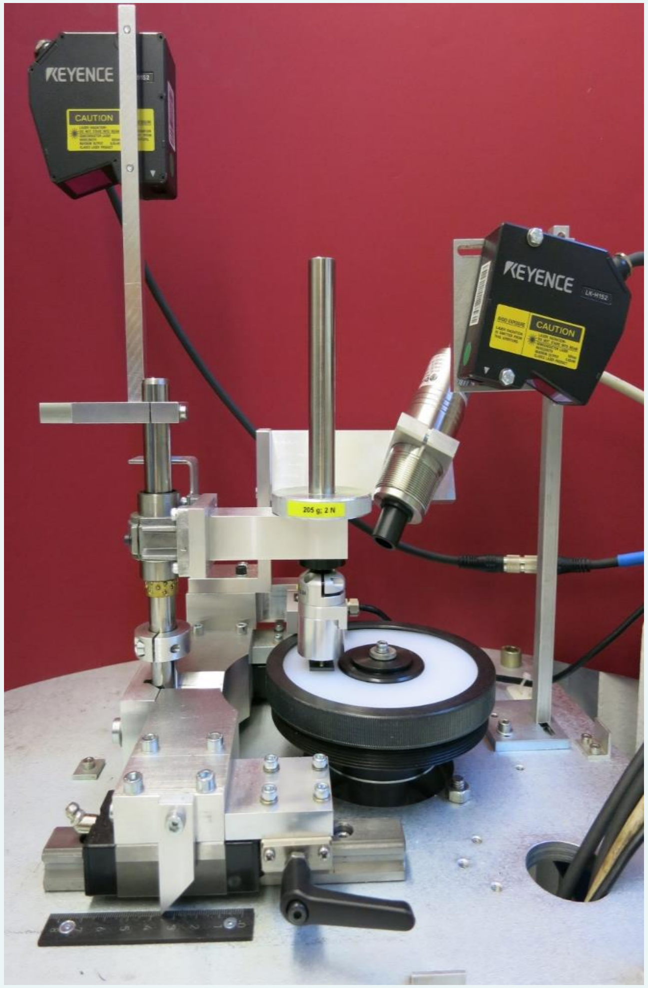
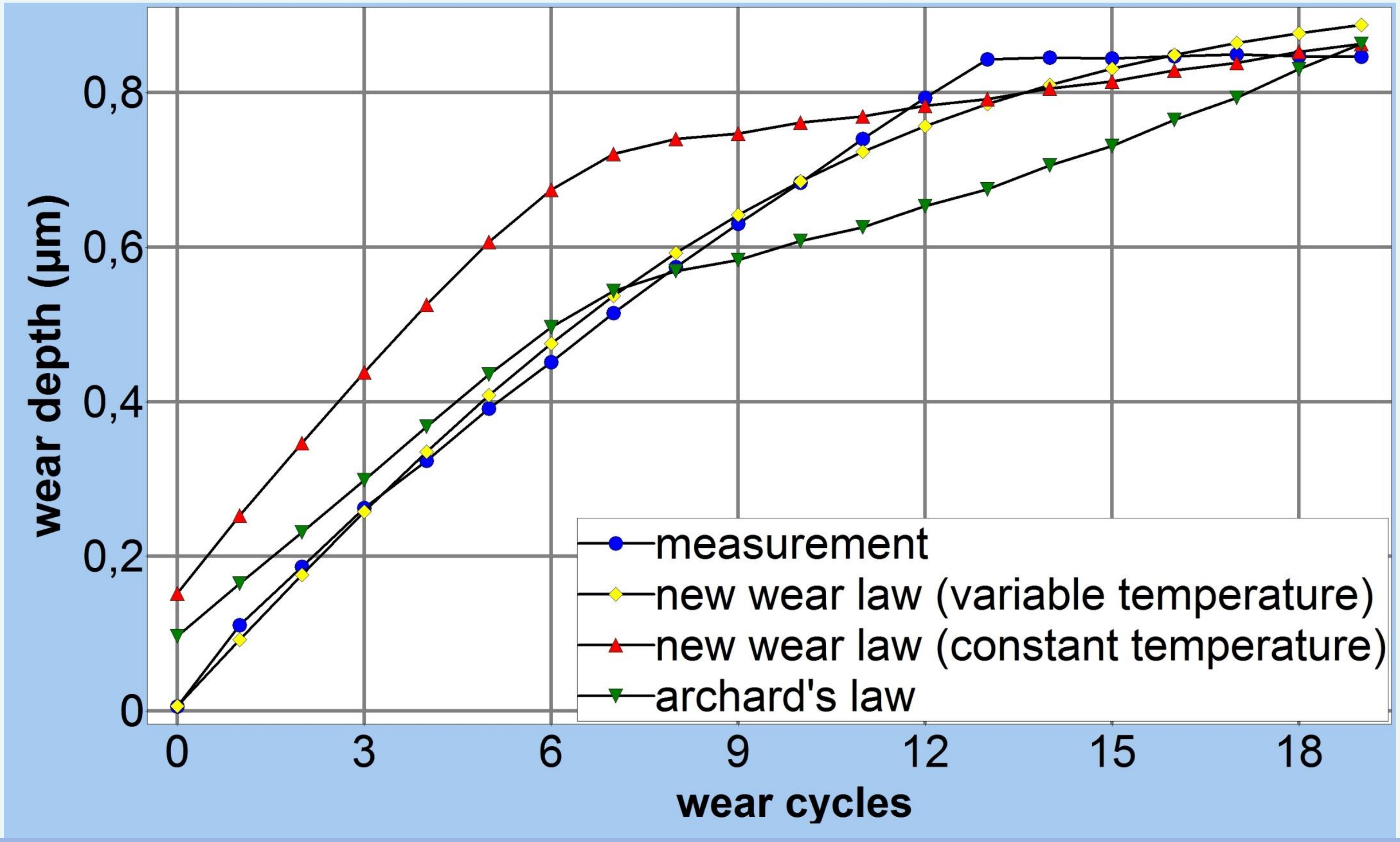


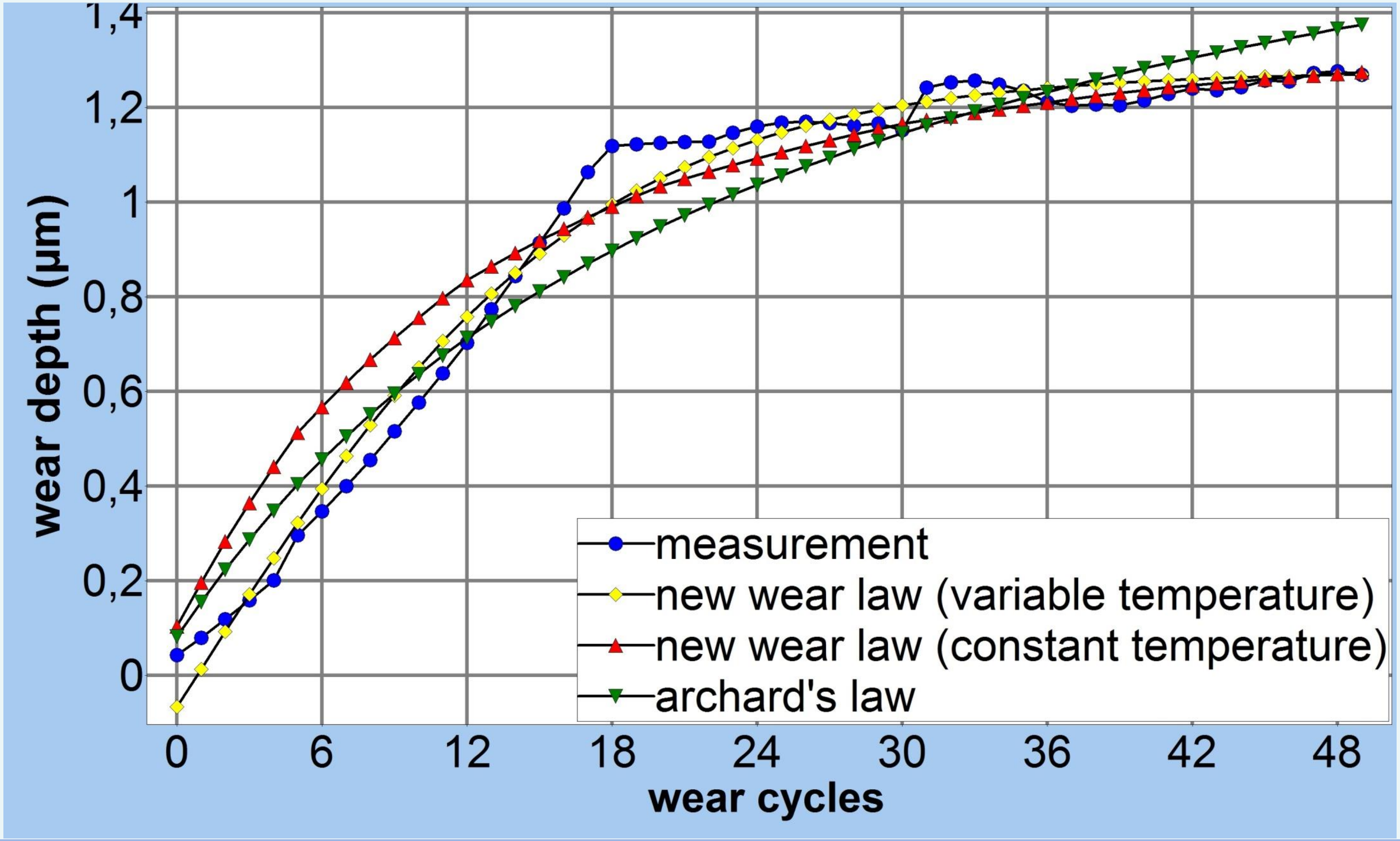

KEYENCE
KEYENCE
CAUTION

Predictive Wear Modelling



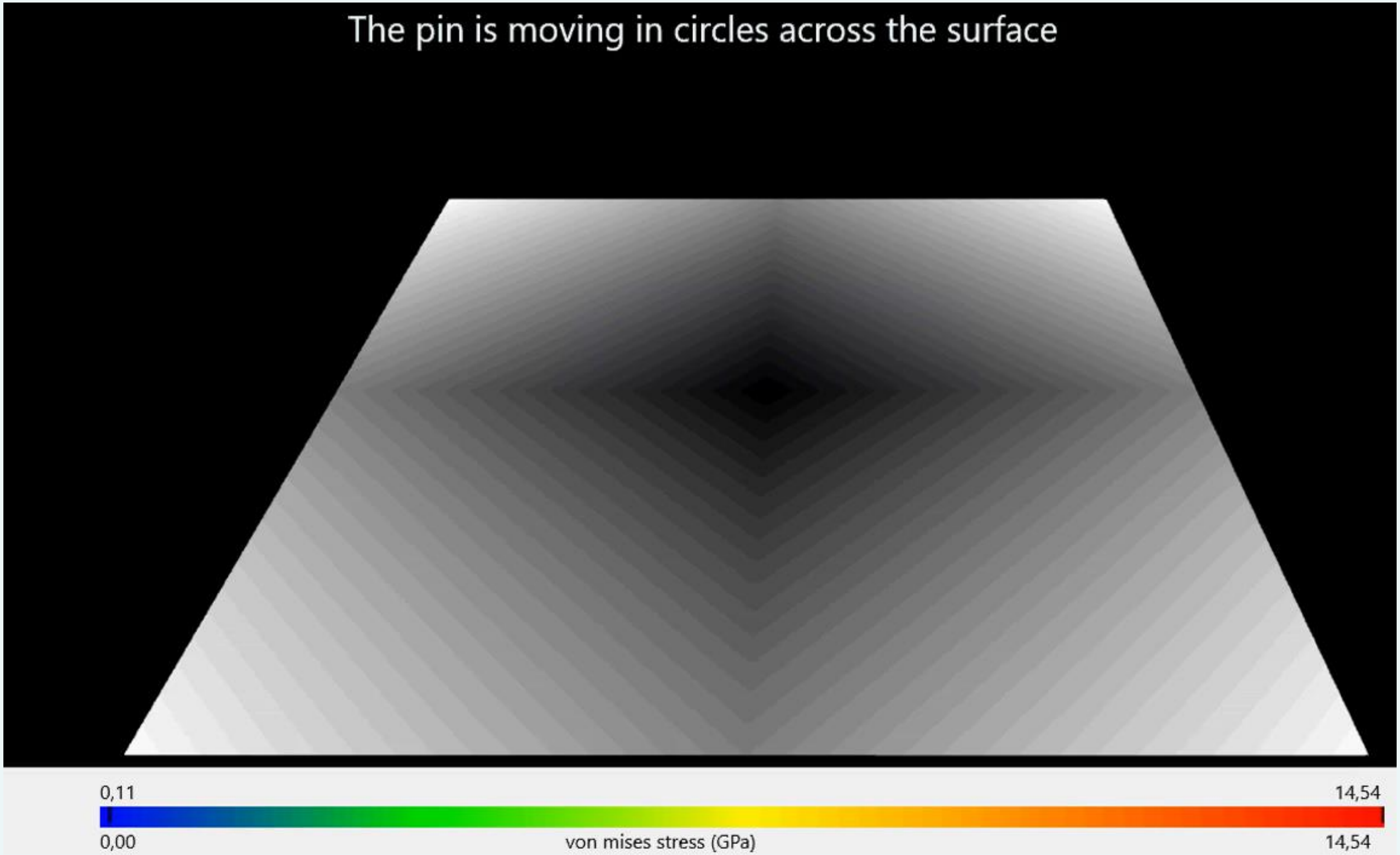
[13] A. Gies, T. Chudoba, N. Schwarzer, J. Becker: „Influence of the coating structure of a-C:H-W coatings on their wear-performance: a theoretical approach and its practical confirmation“, accepted for publication in ICMCTF 2013-proceedings

Predictive Wear Modelling



[14] T. Liskiewicz; B. Beake; N. Schwarzer; M. Davies: „ Short note on improved integration of mechanical testing in predictive wear models“, accepted for publication in ICMCTF 2013-proceedings

Predictive Wear Modelling



https://worldformulaapps.com/portfolio/pin-on-disc

Conclusion

Combining calotte grinding with indentation measurements offers a unique way to gather profile information from the coating.

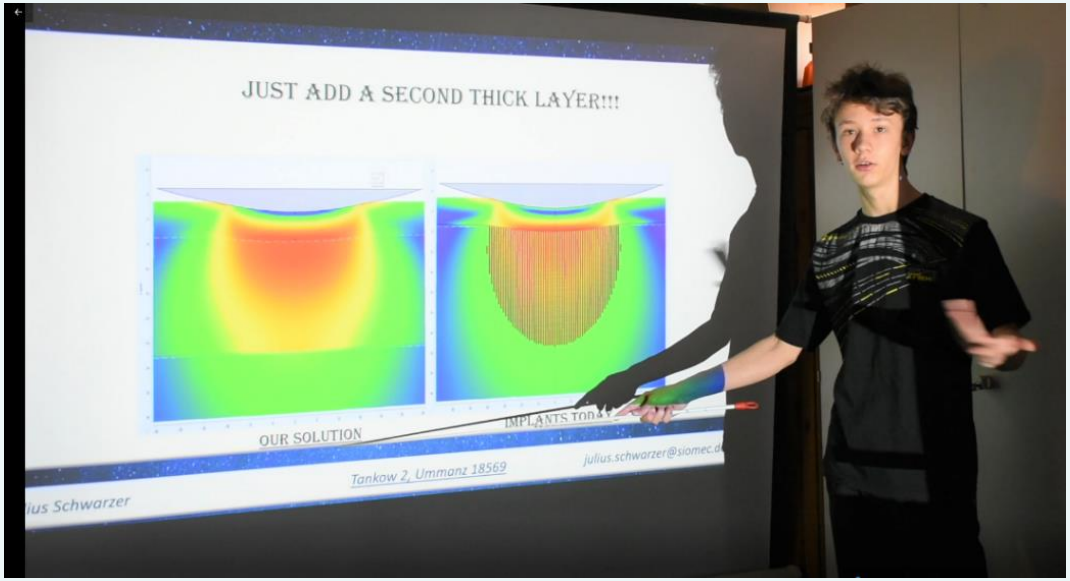
Results which couldn‘t be found with any other methods were obtained and could explain the failure.

Extension to time depending material behaviour offers a lot of new options.

In Summary

- <u>Locally</u> determined properties incl. stress.
- Quantified Errors at each location and for the ensemble of data.
- Surface roughness, load, tip-size and calo ball size optimized for the layered system.

Software that even a
14 year old intern used effectively
to optimize hip implants.



watch on youtube