About the identification of generic tribological parameters

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Introduction

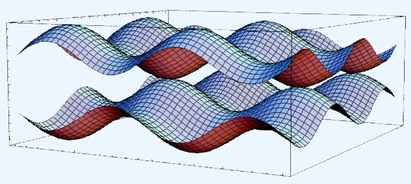
mechanical contact tests are real life

→ cannot be simplified

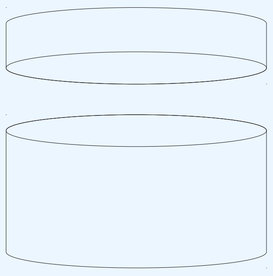
→ difficult to model correctly

→ theory for physical analysis is not trivial

real world contact: curved surfaces

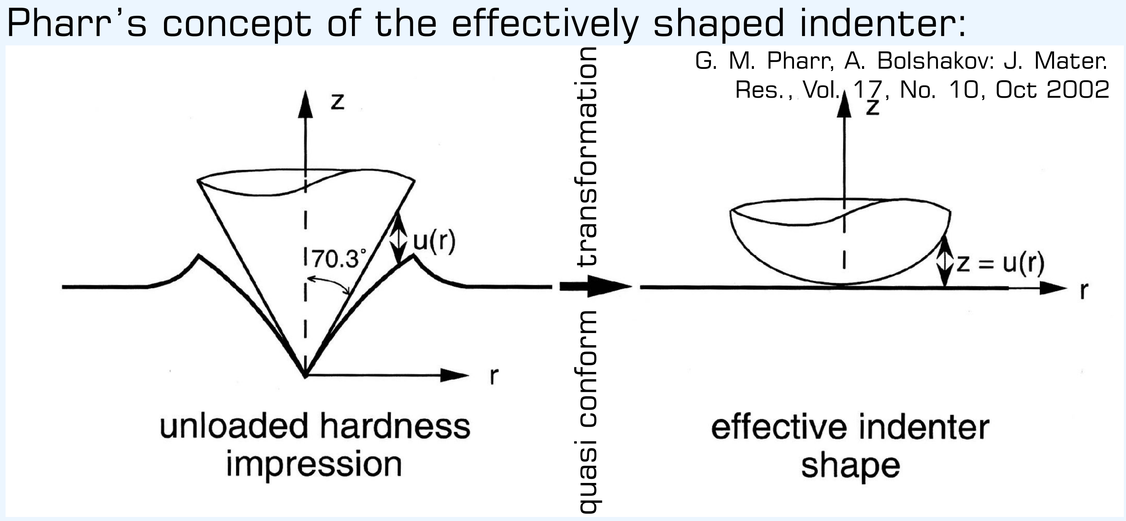


currently applied theory: flat surfaces



About the model – classic basis

Pharr's concept of the effectively shaped indenter:

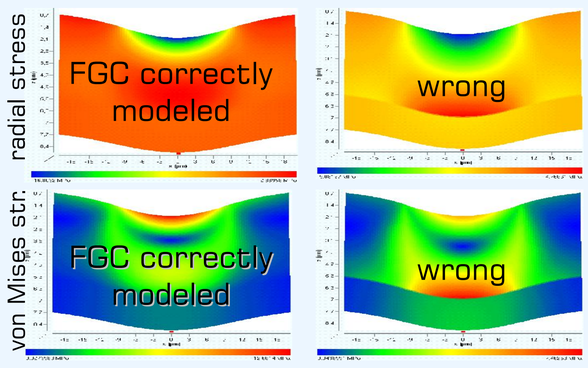


- mixed residual and elastic indenter stresses
- no analytical description possible

- extraction of the elastic indenter stresses

About the model – extensions

- extended to general structures, e.g.:
  - layers
  - gradients (see fig.)
  - defects
  - inclusions
  - etc.
  - surface curvature:



solution in paraboloidal (for curved space model)

$$\phi(\xi,\eta) = J_0(c*\xi)*Y_0(-i*c*\eta)$$

&

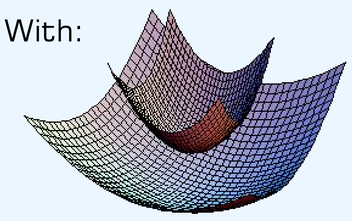
cylindrical coordinates (for half space model)

$$\phi(r,z) = J_0(c*r)*\exp(c*z)$$

$$r = \sqrt{x^2 + y^2}$$

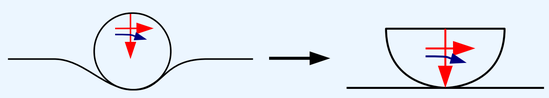
$$x = \xi*\eta*\cos\varphi;\quad y = \xi*\eta*\sin\varphi;\quad z = \left(\xi^2 - \eta^2\right)/2$$

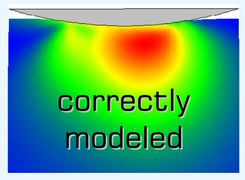
With:



constant η gives surface of paraboloid

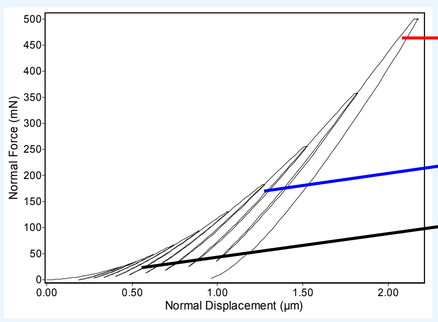
- extended to multi-axial loads

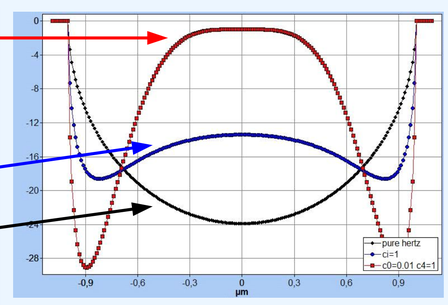




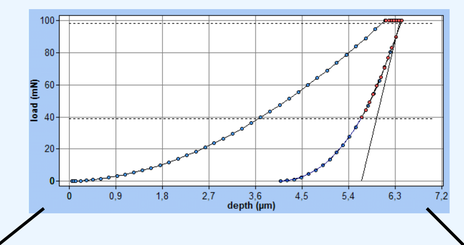
- extended Hertz

Schwarzer, Phil. Mag. 86(33-35) 21 Nov - 11 Dec 2006 5153 – 5767

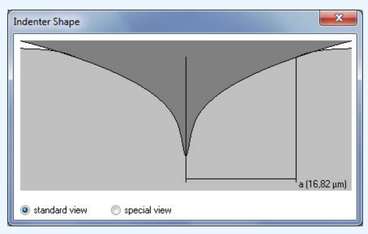




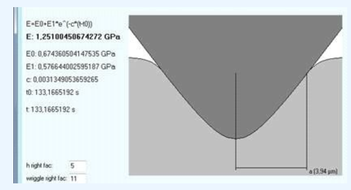
- extended for time dependency



indentation into Au sample



classic O&P gives phyiscal Nonsense (singularity)

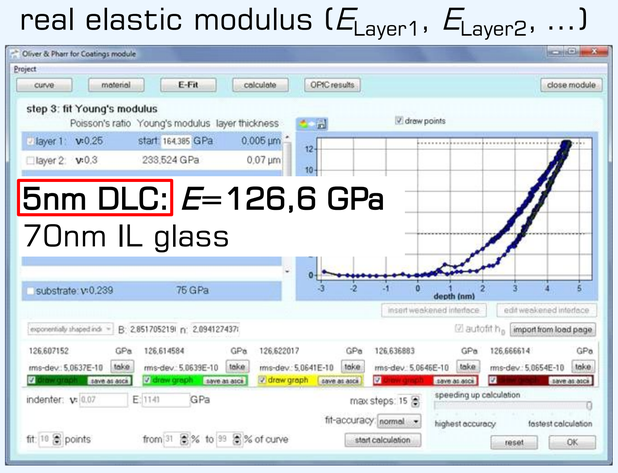


O&P extended for time-dependency → physically reasonable effective indenter

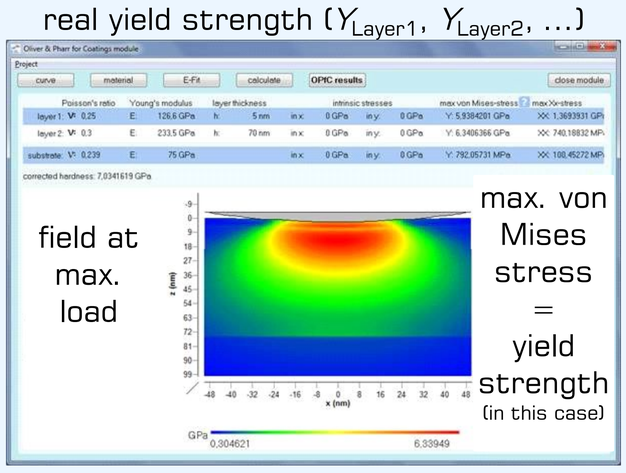
Resulting possible applications

- calculation of basic generic material parameters

real elastic modulus (E_{Layer1}, E_{Layer2}, …)



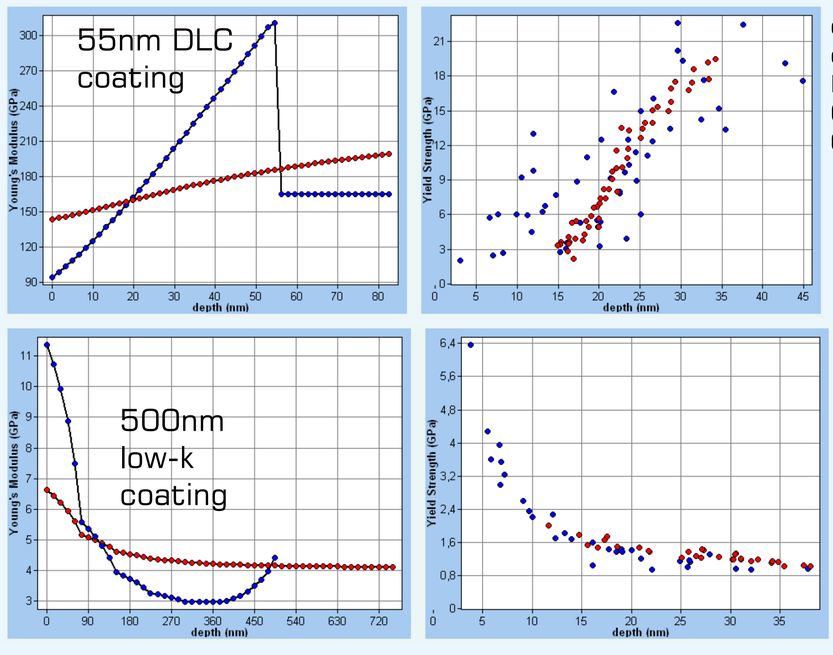
real yield strength (Y_{Layer1}, Y_{Layer2}, …)



Be careful with ultra-hardness results!

Visit www.siomec.de/The-Saga-of-Ultra-Hard-Coatings for more information.

- profiling



data courtesy of Dr. Hangen, Hysitron Inc., Cologne, Germany

Young's modulus profile and yield strength profile as function of real depth

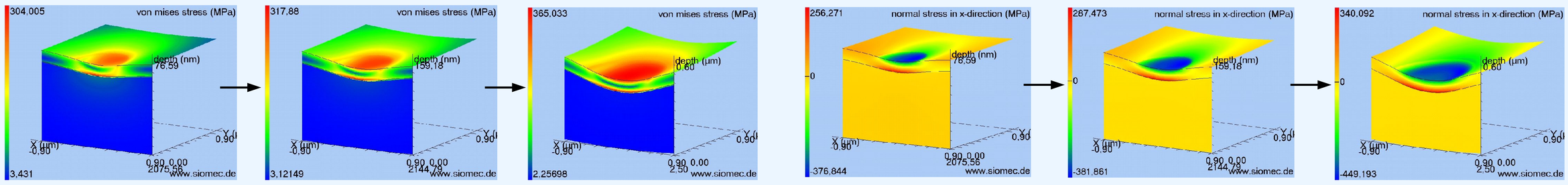
www.siomec.de

Please turn over!

Continued on reverse.

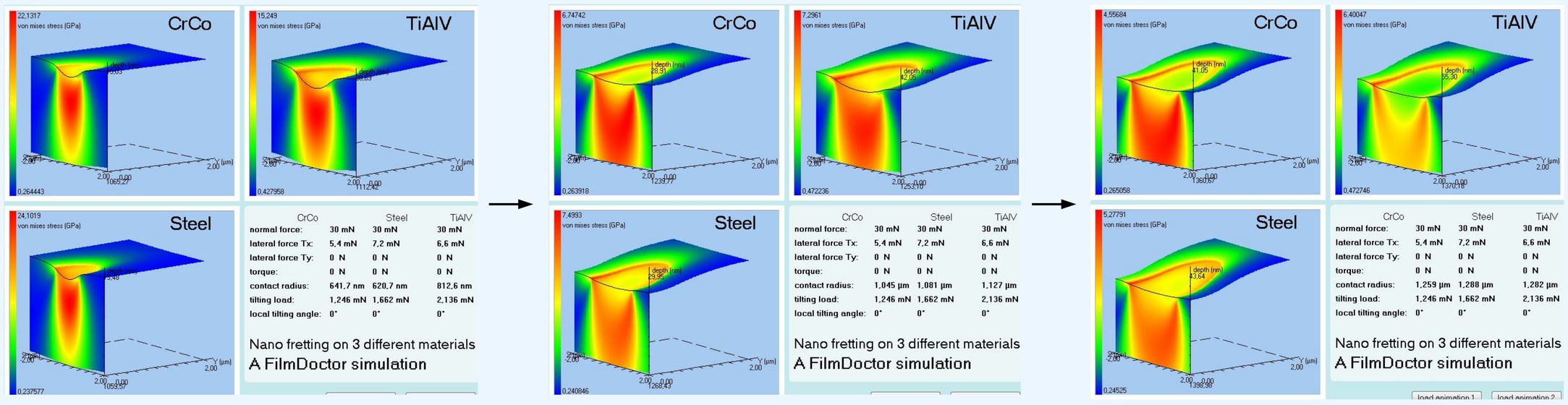
Resulting possible applications (continuation)

- time-dependent scratch testing



Evolution of von Mises stress (left) and normal stress in scratch direction (right) during scratch test on a AR coating on polymer coating (viscose).

- nano fretting testing



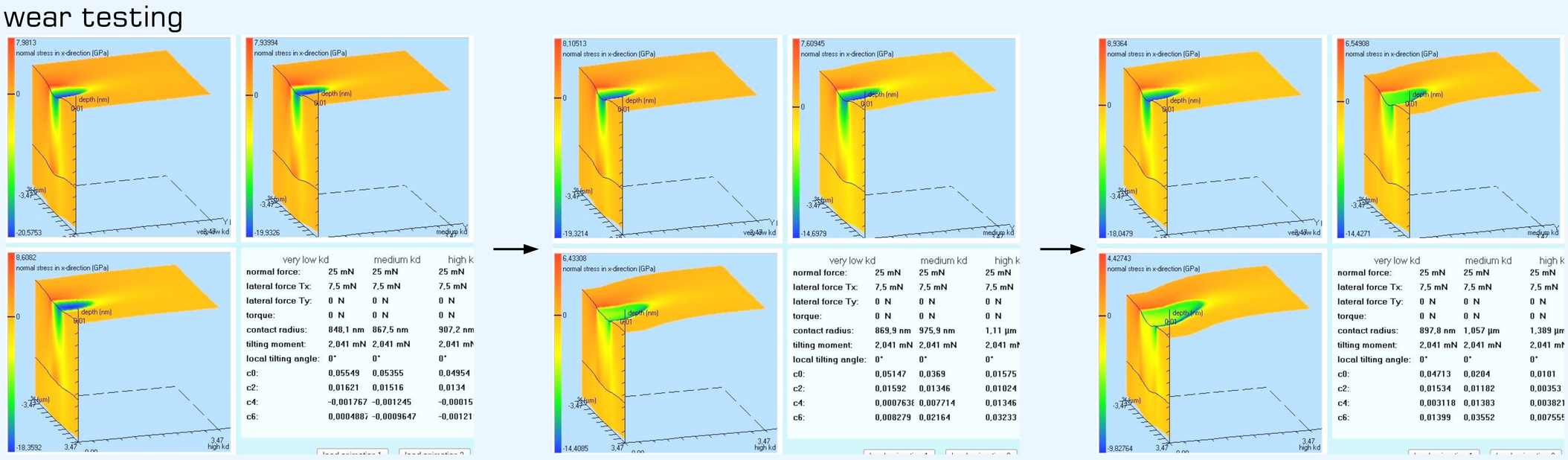
	CrCo	Steel	TiAlV
normal force:	30 mN	30 mN	30 mN
lateral force Tx:	5,4 mN	7,2 mN	6,6 mN
lateral force Ty:	0 N	0 N	0 N
torque:	0 N	0 N	0 N
contact radius:	641,7 nm	620,7 nm	812,6 nm
tilting load:	1,246 mN	1,662 mN	2,136 mN
local tilting angle:	0°	0°	0°

	CrCo	Steel	TiAlV
normal force:	30 mN	30 mN	30 mN
lateral force Tx:	5,4 mN	7,2 mN	6,6 mN
lateral force Ty:	0 N	0 N	0 N
torque:	0 N	0 N	0 N
contact radius:	1,045 µm	1,081 µm	1,127 µm
tilting load:	1,246 mN	1,662 mN	2,136 mN
local tilting angle:	0°	0°	0°

	CrCo	Steel	TiAlV
normal force:	30 mN	30 mN	30 mN
lateral force Tx:	5,4 mN	7,2 mN	6,6 mN
lateral force Ty:	0 N	0 N	0 N
torque:	0 N	0 N	0 N
contact radius:	1,259 µm	1,288 µm	1,282 µm
tilting load:	1,246 mN	1,662 mN	2,136 mN
local tilting angle:	0°	0°	0°

Evolution of von Mises stress during nano fretting tests on CrCo, TiAlV, and steel.

- wear testing



	very low kd	medium kd	high k
normal force:	25 mN	25 mN	25 mN
lateral force Tx:	7,5 mN	7,5 mN	7,5 mN
lateral force Ty:	0 N	0 N	0 N
torque:	0 N	0 N	0 N
contact radius:	848,1 nm	867,5 nm	907,2 nm
tilting moment:	2,041 mN	2,041 mN	2,041 mN
local tilting angle:	0°	0°	0°
c0:	0,05549	0,05355	0,04954
c2:	0,01621	0,01516	0,0134
c4:	-0,001767	-0,001245	-0,00015
c6:	0,0004887	-0,0009647	-0,00121

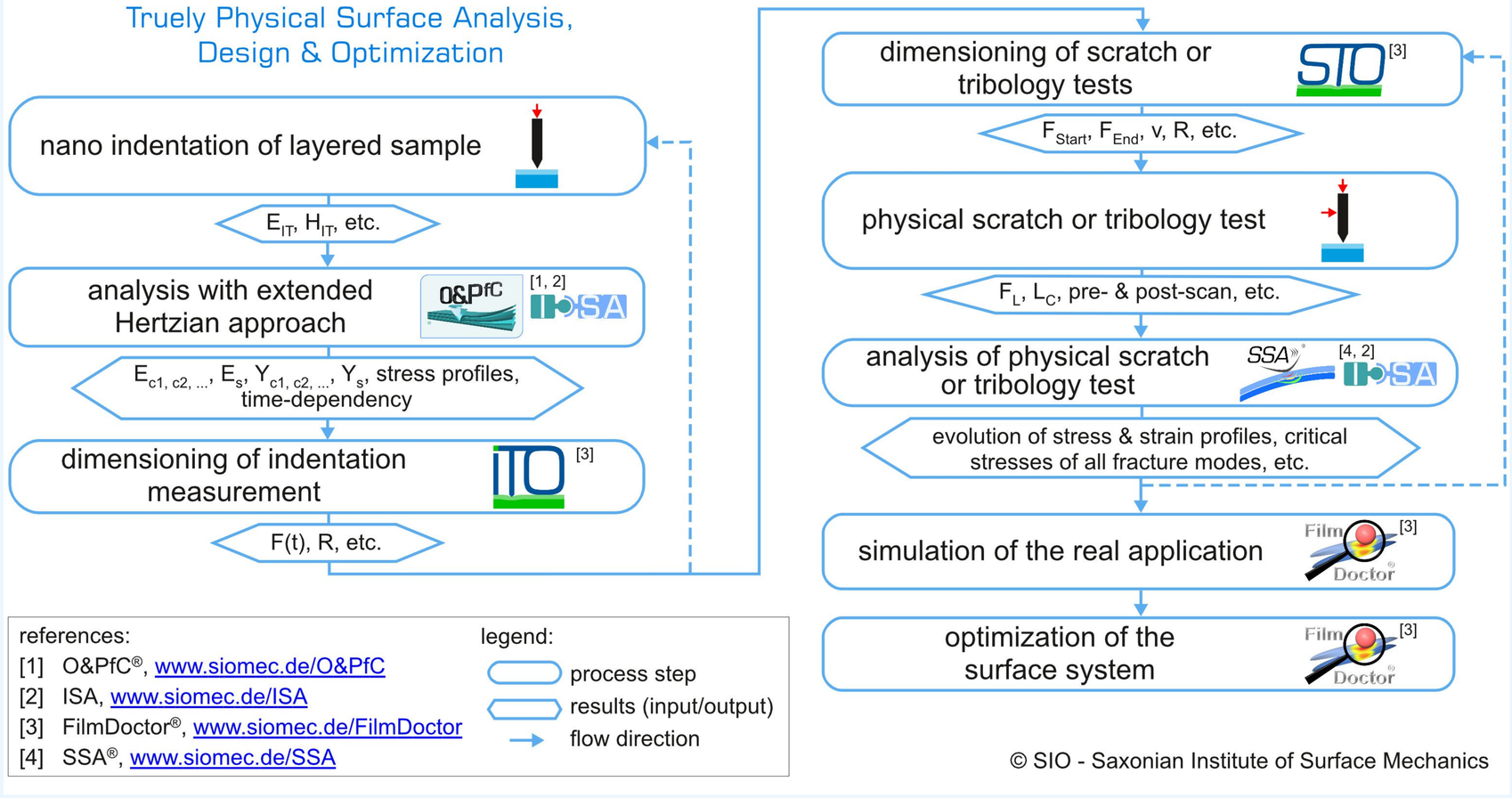
	very low kd	medium kd	high k
normal force:	25 mN	25 mN	25 mN
lateral force Tx:	7,5 mN	7,5 mN	7,5 mN
lateral force Ty:	0 N	0 N	0 N
torque:	0 N	0 N	0 N
contact radius:	869,9 nm	975,9 nm	1,11 µm
tilting moment:	2,041 mN	2,041 mN	2,041 mN
local tilting angle:	0°	0°	0°
c0:	0,05147	0,0369	0,01575
c2:	0,01592	0,01346	0,01024
c4:	0,0007638	0,007714	0,01346
c6:	0,008279	0,02164	0,03233

	very low kd	medium kd	high k
normal force:	25 mN	25 mN	25 mN
lateral force Tx:	7,5 mN	7,5 mN	7,5 mN
lateral force Ty:	0 N	0 N	0 N
torque:	0 N	0 N	0 N
contact radius:	897,8 nm	1,057 µm	1,389 µm
tilting moment:	2,041 mN	2,041 mN	2,041 mN
local tilting angle:	0°	0°	0°
c0:	0,04713	0,0204	0,0101
c2:	0,01534	0,01182	0,00353
c4:	0,003118	0,01383	0,003821
c6:	0,01399	0,03552	0,007555

Evolution of normal stress in scratch direction during wear tests on three different coatings for automotive industry.

Conclusions

- physical tribology modeling requires generic tribo parameters (like wear or fretting parameters)
- such can be derived by ab initio modeling (c.f. Schwarzer: “Short note on the effect of pressure induced increase of Young's modulus”, Philosophical Magazine, 2012)
- this requires properly calculated generic mechanical material parameters
- those can be determined using the presented Oliver & Pharr method extended by Schwarzer in the following way for physical analysis of the appropriate contact measurements (e.g. nano indentation and scratch testing):



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