Quantifying time-dependent mechanical behavior of visco-elastic materials or materials at elevated temperatures by nano-indentation

Marcus Fuchs, Nick Bierwisch, Norbert Schwarzer

Saxonian Institute of Surface Mechanics

Sächsisches Institut für Oberflächenmechanik

Motivation: knowledge-based optimization of surfaces structures

- optimization of arbitrarily structured surfaces on the basis of **physical knowledge** about its mechanics and tribology
- requires physical-mechanic material and interface parameters (e.g. elastic modulus, yield strength, tensile strength, shear strength, adhesion, but not hardness!)
- requires physical analysis of mechcanical contact experiments [3-5]
- allows proper modeling of complex conditions:
  - ✓ up to 100 layers
  - ✓ visco-elasticity / creep / time-dependency
  - ✓ surface or interface roughness
  - ✓ (poor) adhesion
  - ✓ friction, nano-structures, debris
  - ✓ and many more

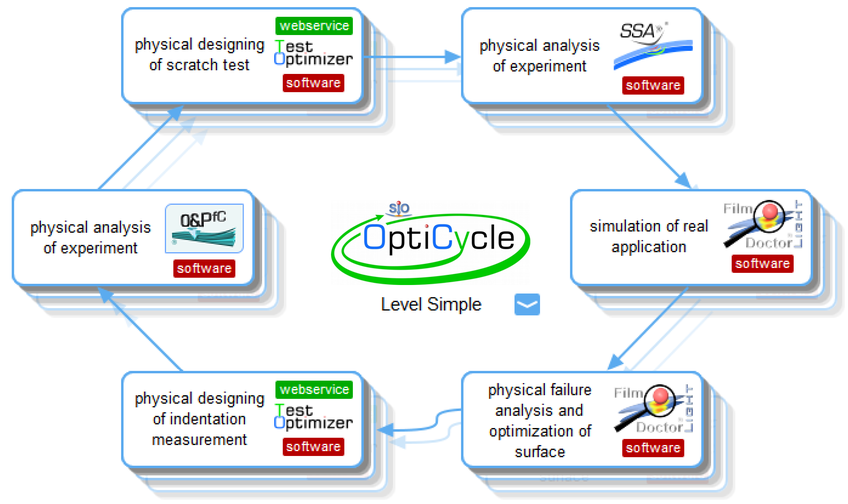


Fig. 1: The SIO OptiCycle [1, 2] – the quasi standard for mechanical or tribological optimization of arbitrarily structured surfaces – can be applied universally to all material classes and areas of application.

Fig. 2: The software FilmDoctor [6] is based on an analytical contact model which meets all these requirements correctly.

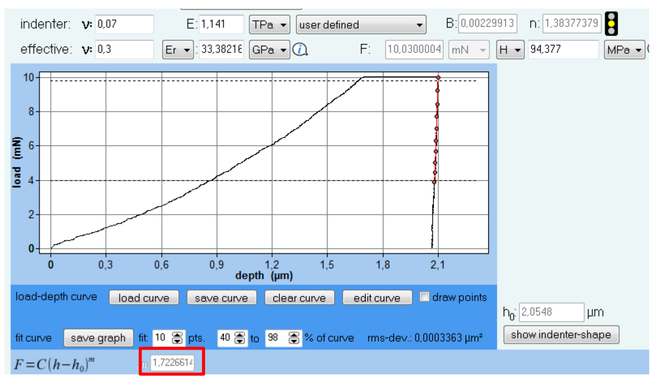
Finding an Adequate Analysis Model for Nano-Indentations Accounting for Time-Dependency

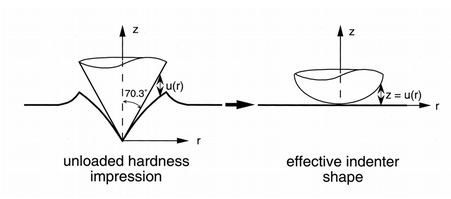
The well-know classic Oliver&Pharr method [7-8]?

Underlying model: effective indenter concept

applying to example: gold coating on pin

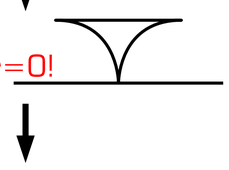
m=2.17 → $m=1+\frac{1}{n}$ → n=0.85





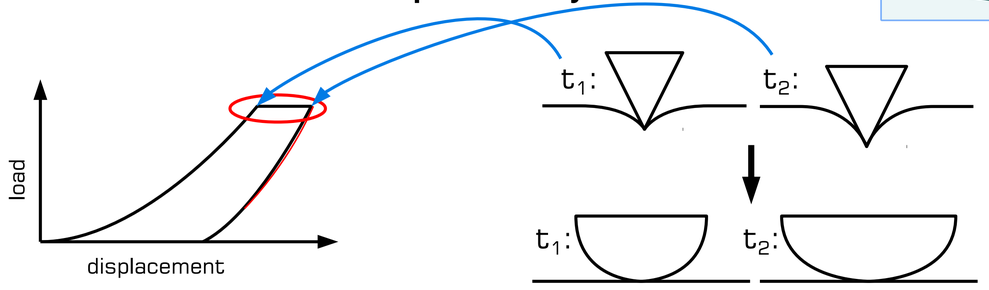
$$F=C(h-h_0)^m \Rightarrow Z(r)=B\cdot r^n$$

If m>2, then singularity at r=0!



Inappropriate!

Oliver&Pharr method extended for time-dependency [XXX]?



possible solution:

time-dependent effective indenter: $F=C(t)(h-h_0(t))^{m(t)} \Leftrightarrow Z(r,t)=B(t)r^{n(t)}$

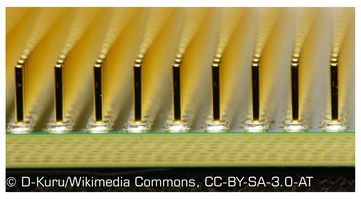
+ time-dependent material law: $E(t)=E_0+E_1 e^{-\frac{t}{\tau}}$

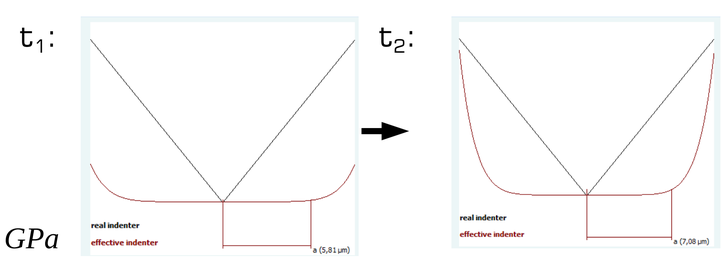
→ implemented in software O&PfC [9]:

Appropriate!

Results: Time-Dependent Mechanical Material Parameters by means of Physically Analized Nanoindentation

example: gold plated pin of CPU at operating temperature





$$E(t)=1{,}4\,GPa+7{,}68\,GPa\,e^{-\frac{t}{1{,}63\,s}} \; vs.\; E=31\,GPa$$

$E'=5.27\,GPa$

$E''=3.84\,GPa$

$H=63.8\,MPa$

$Y=50.8\,MPa$

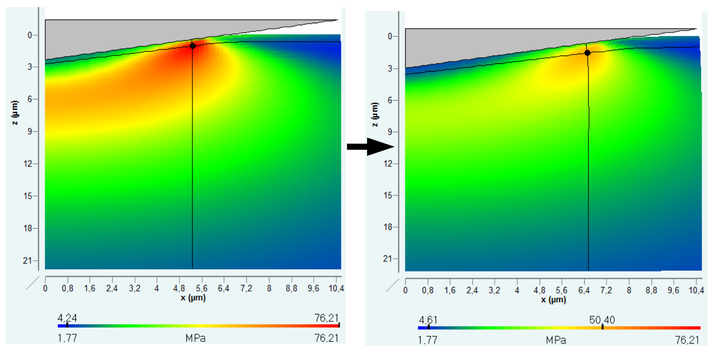


Fig. to the right: change of effective indenter shape (top) and respective von Mises stress (bottom) from beginning to end of hold period.

example: visco-elastic PMMA

$$E(t)=1{,}2\,GPa+0.294\,GPa\,e^{-\frac{t}{12.4\,s}} \; vs.\; E=3.08\,GPa$$

$E'=1.35\,GPa$

$E''=146.9\,MPa$

$H=106.4\,MPa$

$Y=50.4\,MPa$

All these results can be obtained **from a single indentation** – analyzed physically!

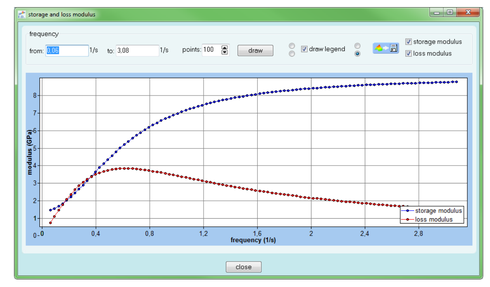
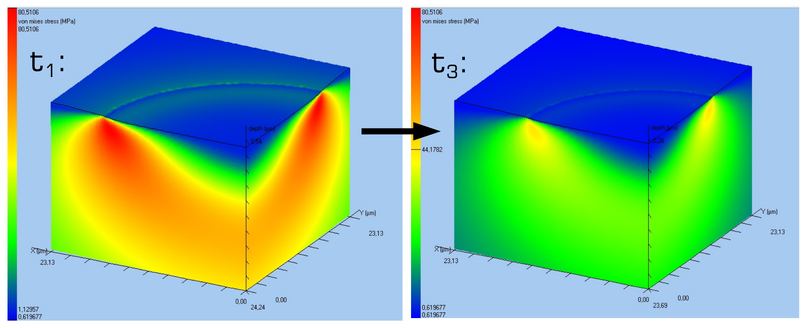


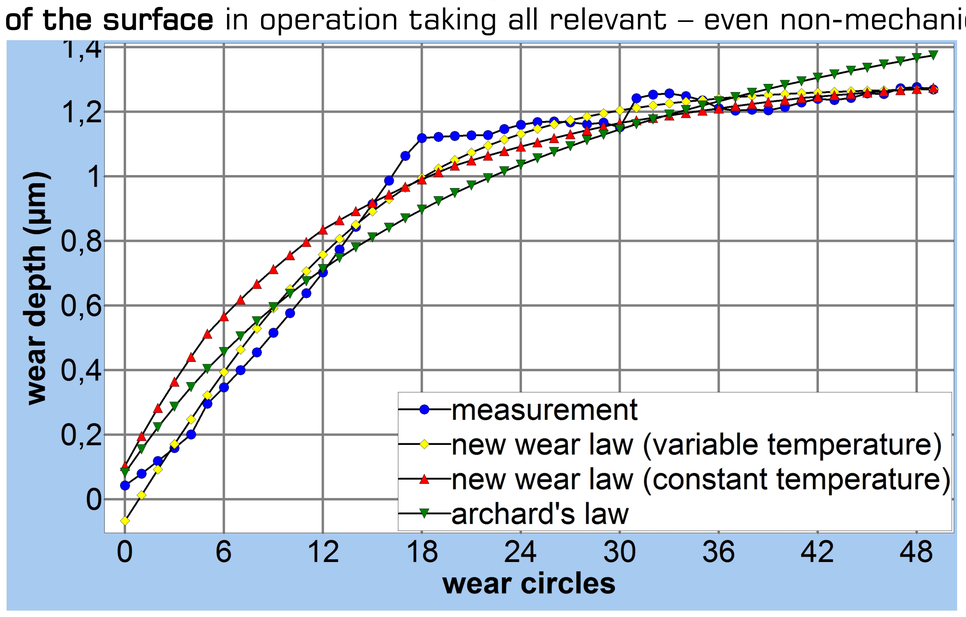
Fig. top right corner: storage (E') and loss modulus (E") as function of frequency

Fig. to the right: von Mises stress at the beginning of hold period (left) and at 40% of unloading part.



Wear Prediction and Estimation of Durability by means of the Predictive Wear Models [10-12]

Determination of physical-tribological wear parameters by means of nanofretting experiments and subsequent simulation-driven **prediction of wear and life span of the surface** in operation taking all relevant – even non-mechanical – operation conditions into account.



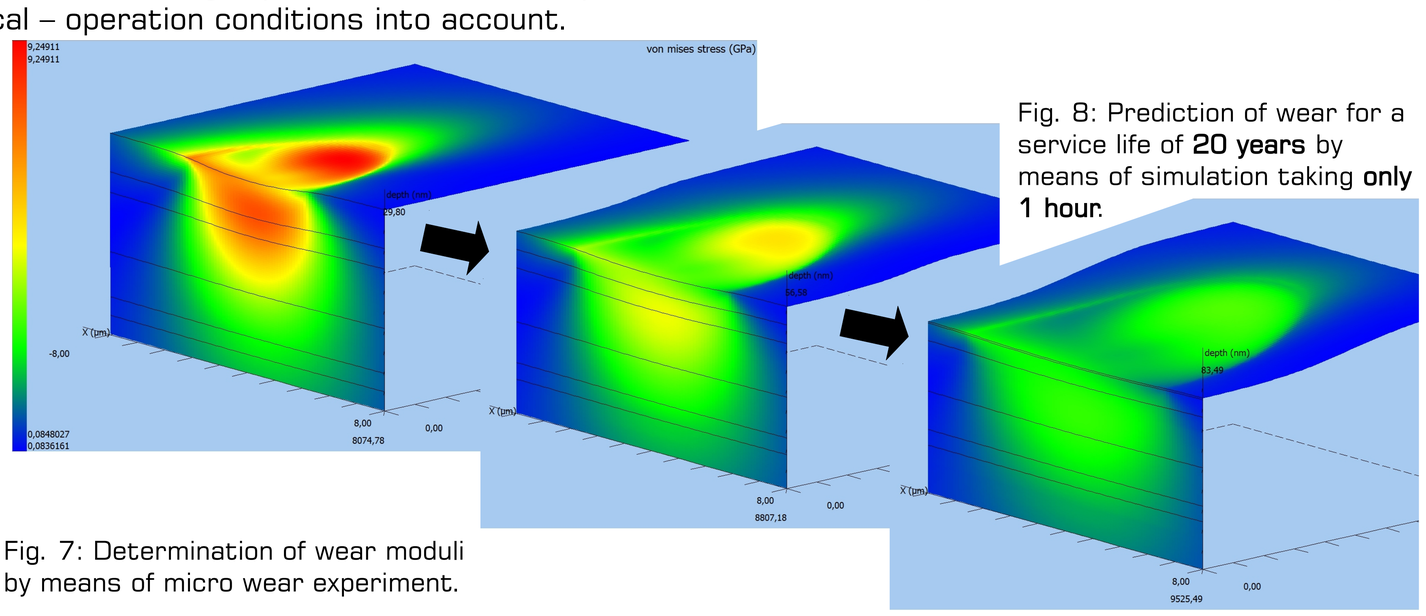


Fig. 7: Determination of wear moduli by means of micro wear experiment.

Fig. 8: Prediction of wear for a service life of **20 years** by means of simulation taking **only 1 hour**.

www.siomec.de

[1] Schwarzer et al., Surface and Coatings Technology 206 (2011) 6.
[2] SIO OptiCycle, www.siomec.de/OptiCycle.
[3] Schwarzer, Journal of Tribology 122 (2000) 4.
[4] Schwarzer, Journal of Physics: Applied Physics 37 (2004) 19.
[5] Schwarzer, Philosophical Magazine 86 (2006) 33-35.
[6] Software FilmDoctor, www.siomec.de/FilmDoctor.
[7] Oliver, Pharr, J. of Mat. Res. 7 (1992) 6.
[8] Bolshakov et al., Mat. Res. Soc. Proc. (1995) 356.
[9] Software O&PfC, www.siomec.de/O&PfC.
[10] Schwarzer , Materials Research Express 1 (2014) 1.
[11] Schwarzer, Coatings 4 (2014) 2.
[12] Fuchs, Schwarzer, www.siomec.de/docs/2014/002.