Predictive Wear Model

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Motivation: Computer-Aided Design/Optimization of Wear-Resistant Surfaces

There are more then 100 wear laws in the literature. This is no surprise as wear can be the result of several different mechanisms acting in combination like:

- adhesive wear
- abrasive wear
- fatigue
- fretting wear
- erosive wear

However, in order to achieve the objective of an Computer-Aided Design of Multi-Scale Surface Structures as proposed in 2010 (see Fig. 1) one has to account for the complex nature of wear by introducing a general wear law. Such an approach would facilitate an application-tailored design or optimization of arbitrarily structured surfaces by means of model-based simulations saving a lot of money for scarce raw materials and time for time-consuming trial-and-error testing (Fig. 2).

Fig. 1 (c.f. [1])

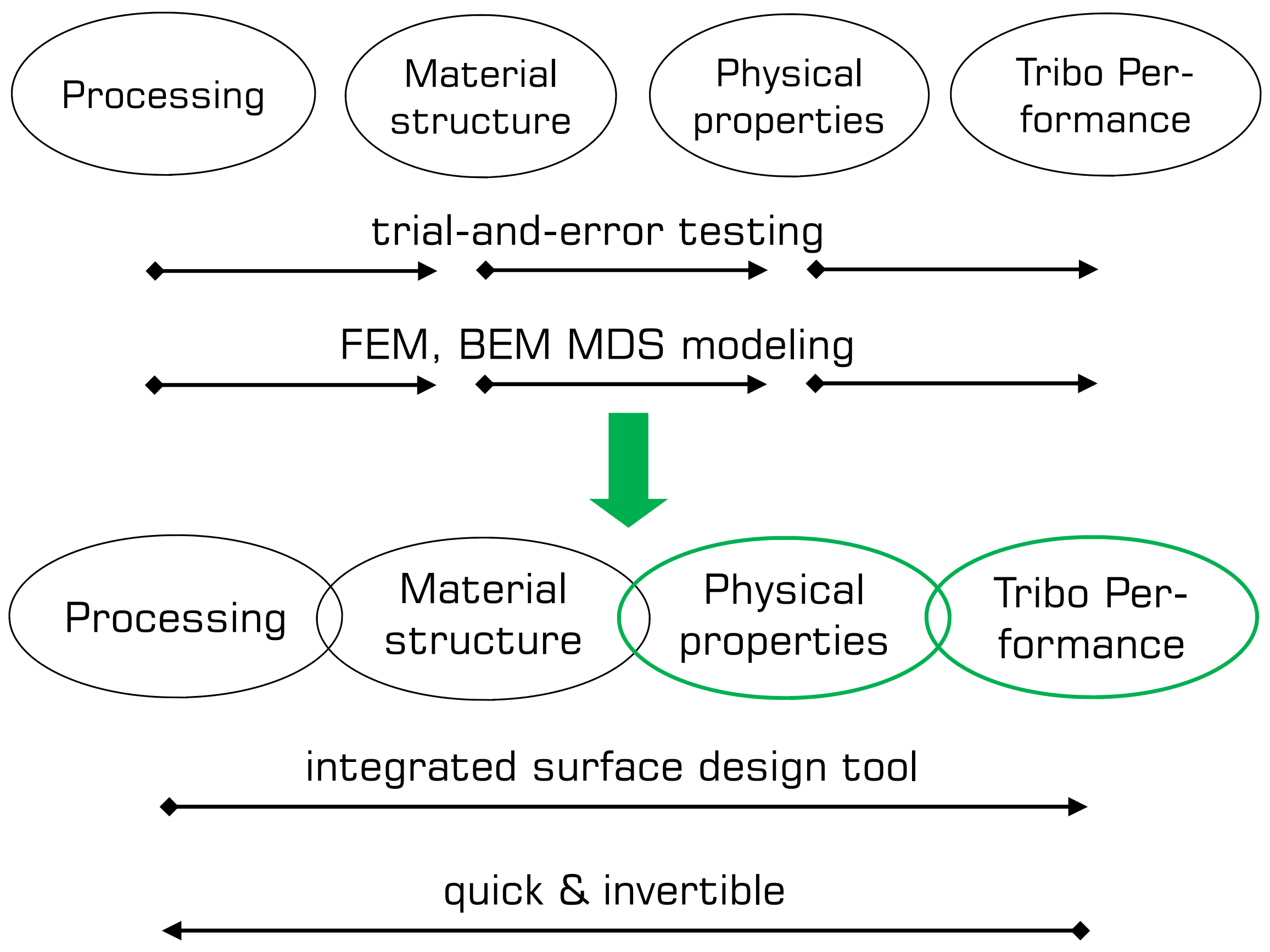
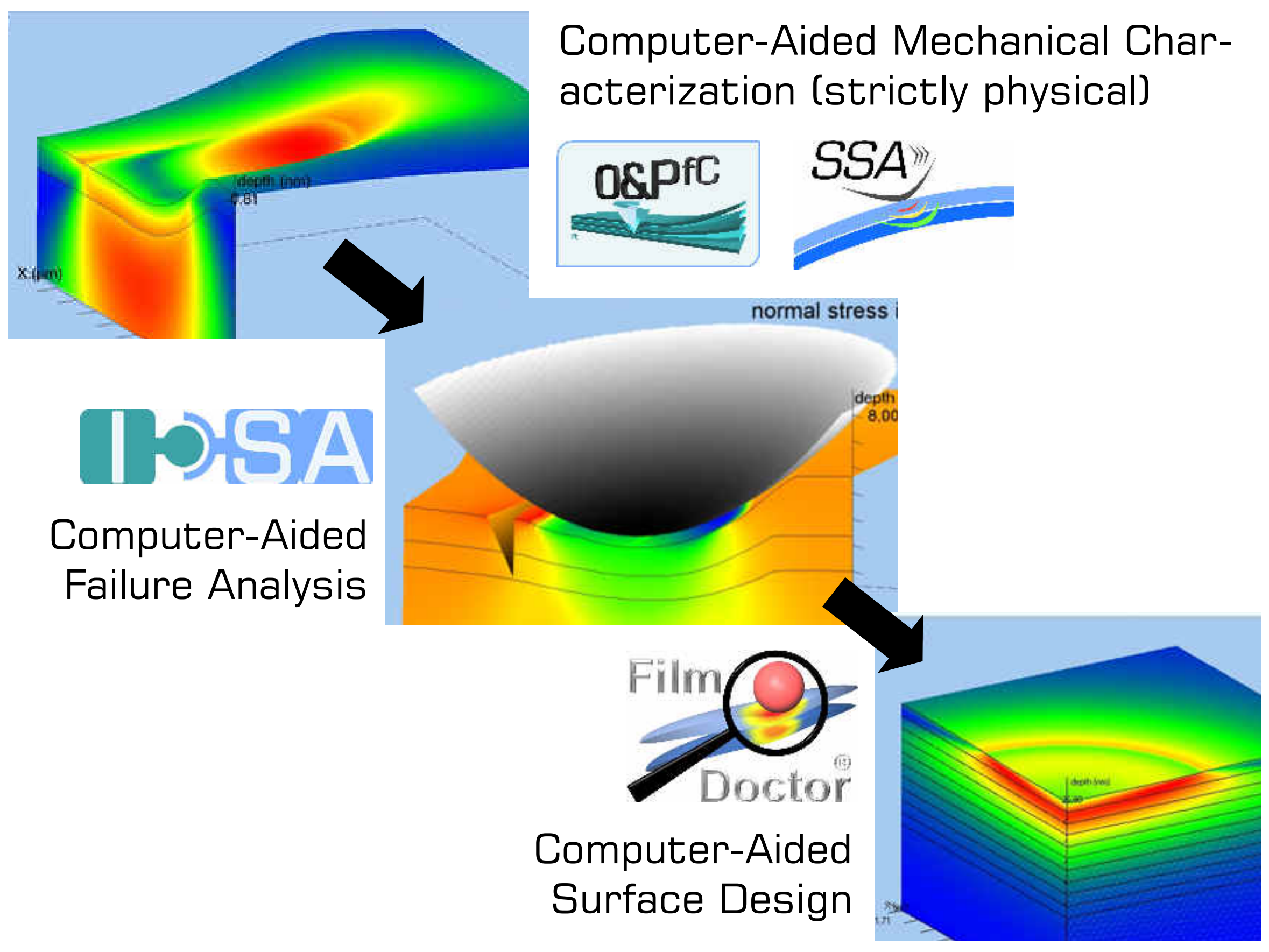


Fig. 2 (c.f. [2])



Computer-Aided Mechanical Characterization (strictly physical)

Computer-Aided Failure Analysis

Computer-Aided Surface Design

Yet Another Wear Law? No, a General Approach.

All the many types of wear can be incorporated into a single tribology law by extracting decomposition limits from first principle approaches [3-4] and comparing them to the contact fields of the complex multi-physics multi-body model describing the tribological effect. In the most simple case, any tribological process can be generalized as (c.f. [5-6]):

$$tribo-effect_{ij}=\hat{k}^{\sigma}_{ijkl}\,\sigma^{kl}+\hat{k}^{\varepsilon}_{ijkl}\,\varepsilon^{kl}+\hat{k}^{u}_{ijkl}\,u^{k}u^{l}+\sum_{n=1}^{N}\hat{k}^{S_n}\delta_{ij}S_n$$

Luckily, in most cases it is sufficient to consider only the stresses of the tribological contact, yielding:

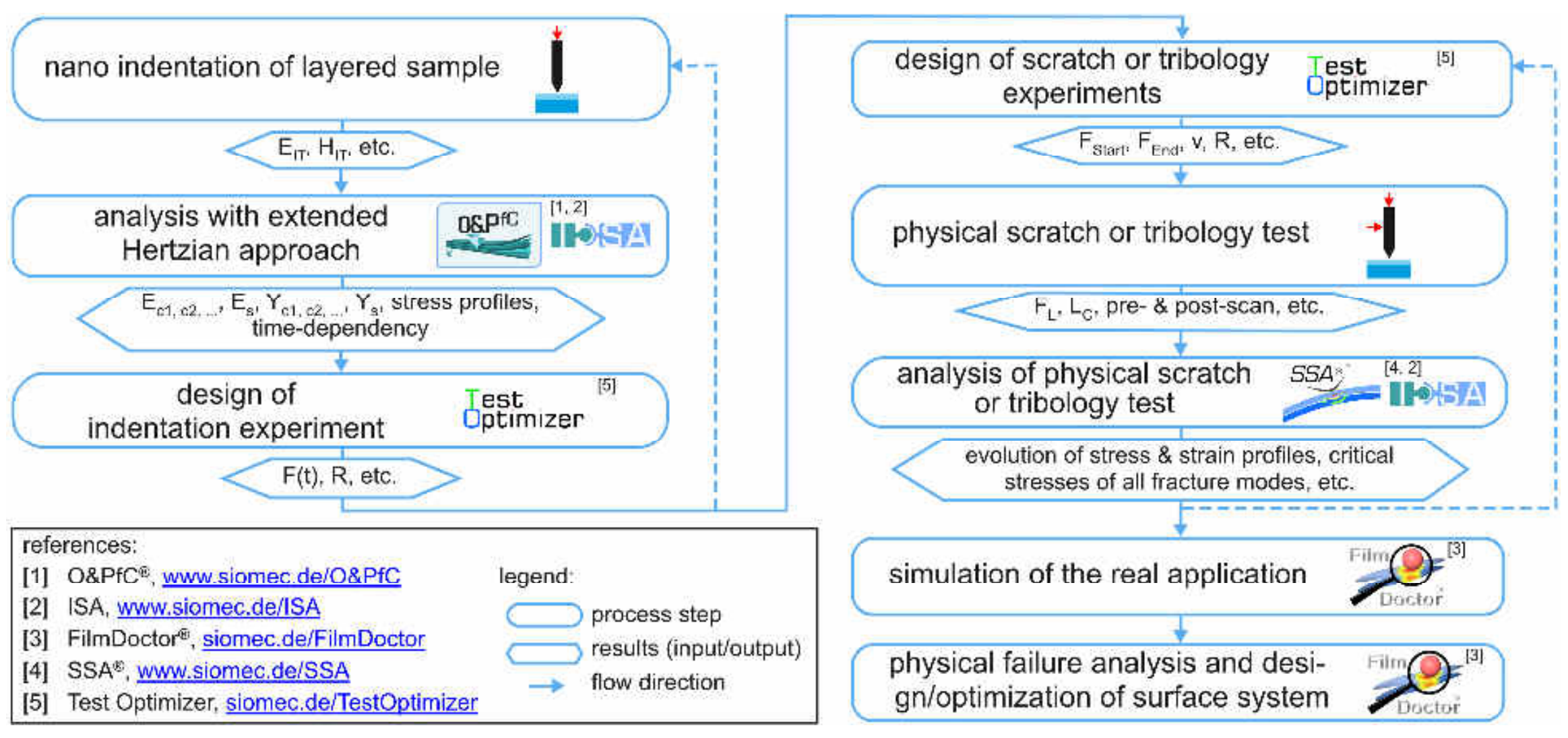
$$tribo-effect_{ij}\equiv w_{ij}=\hat{k}_{ijkl}\,\sigma^{kl}\quad\equiv\quad\delta_{ij}\left(k_{dvM}\frac{\sigma_{vM}}{Y(T)}\cdot e^{-\lambda_k\vec{r}\cdot\vec{r}}\right)$$

However, in order to not only properly calculate the contact fields of tribo experiments or applications but also correctly determine the wear moduli k_{ijkl} one has to overcome some obstacles:

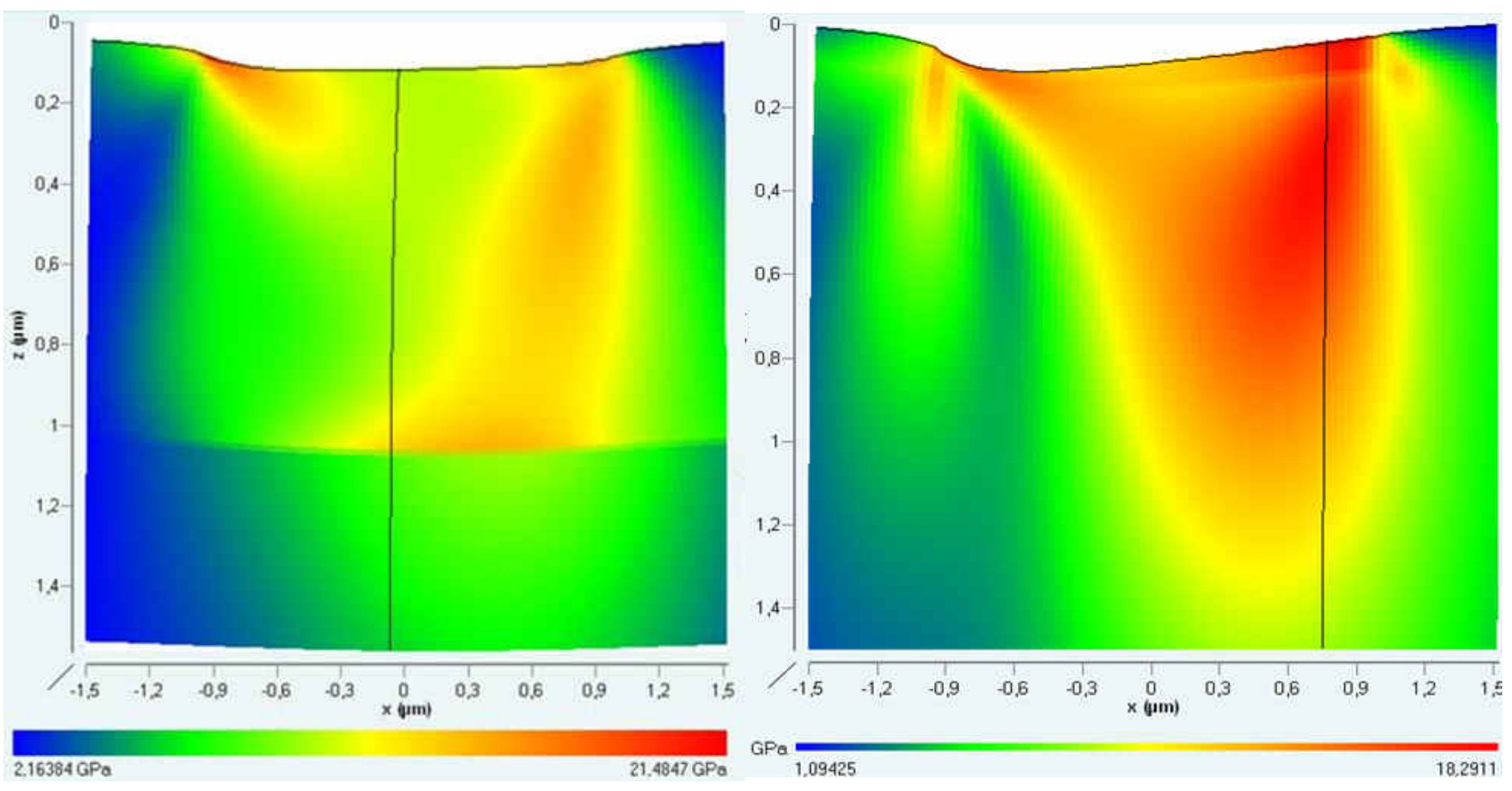
- mechanical characterization strictly physical
- quasi-static experiments → dynamic contacts
  - friction → temperature fields
  - phonons, shock waves
  - time-dependent material behavior
- non-linearity
- inhomogeneity (not only due to layered structure)
- from mechanical properties to wear performance

Tools from absolutely different fields of physics will be necessary to overcome these obstacles.

Obstacle #1: Physical characterization of mechanic material behaviour



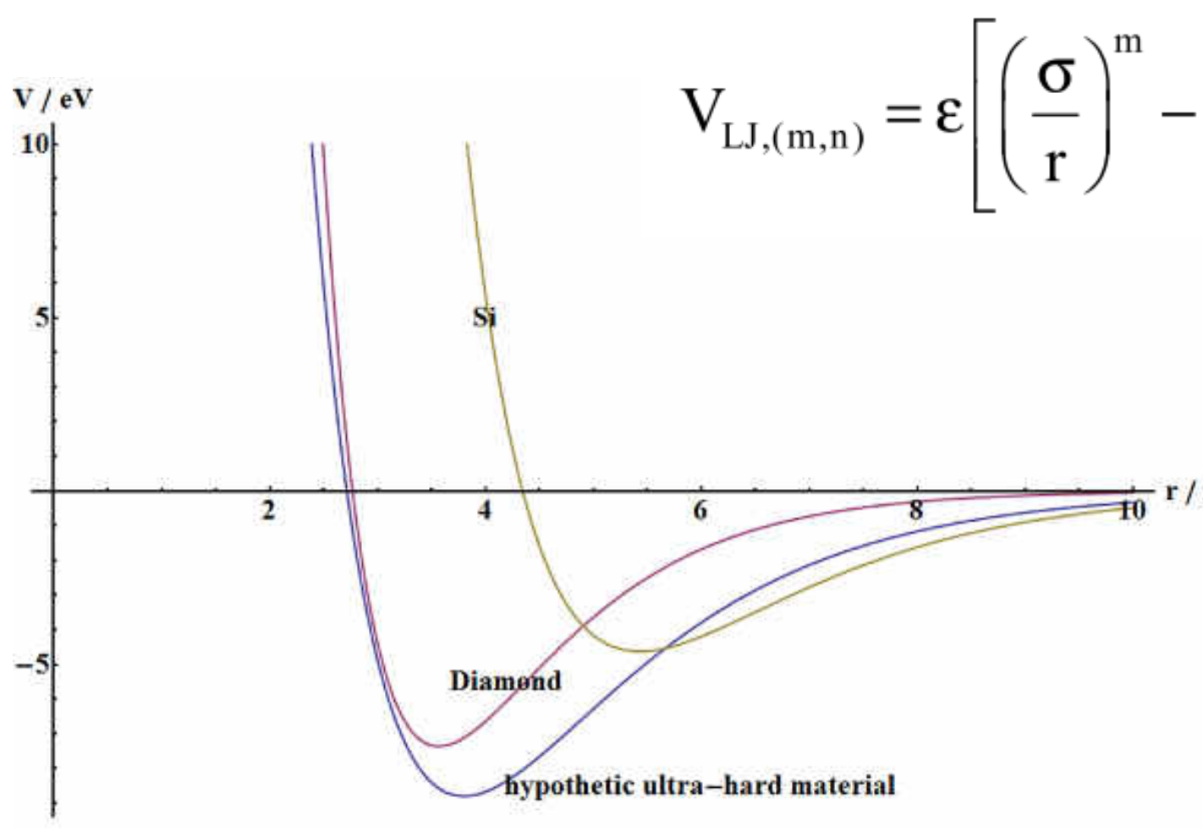
Obstacle #2: Friction → Temperature



temperature field not taken into account

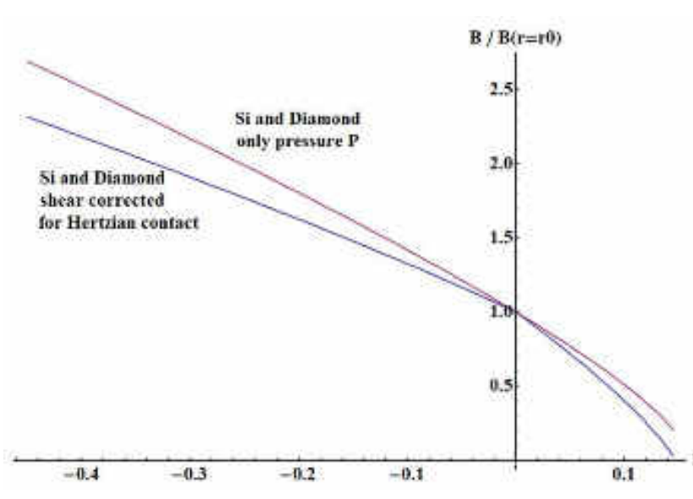
temperature field taken into account

Obstacle #4: From mechanical properties to tribo performance

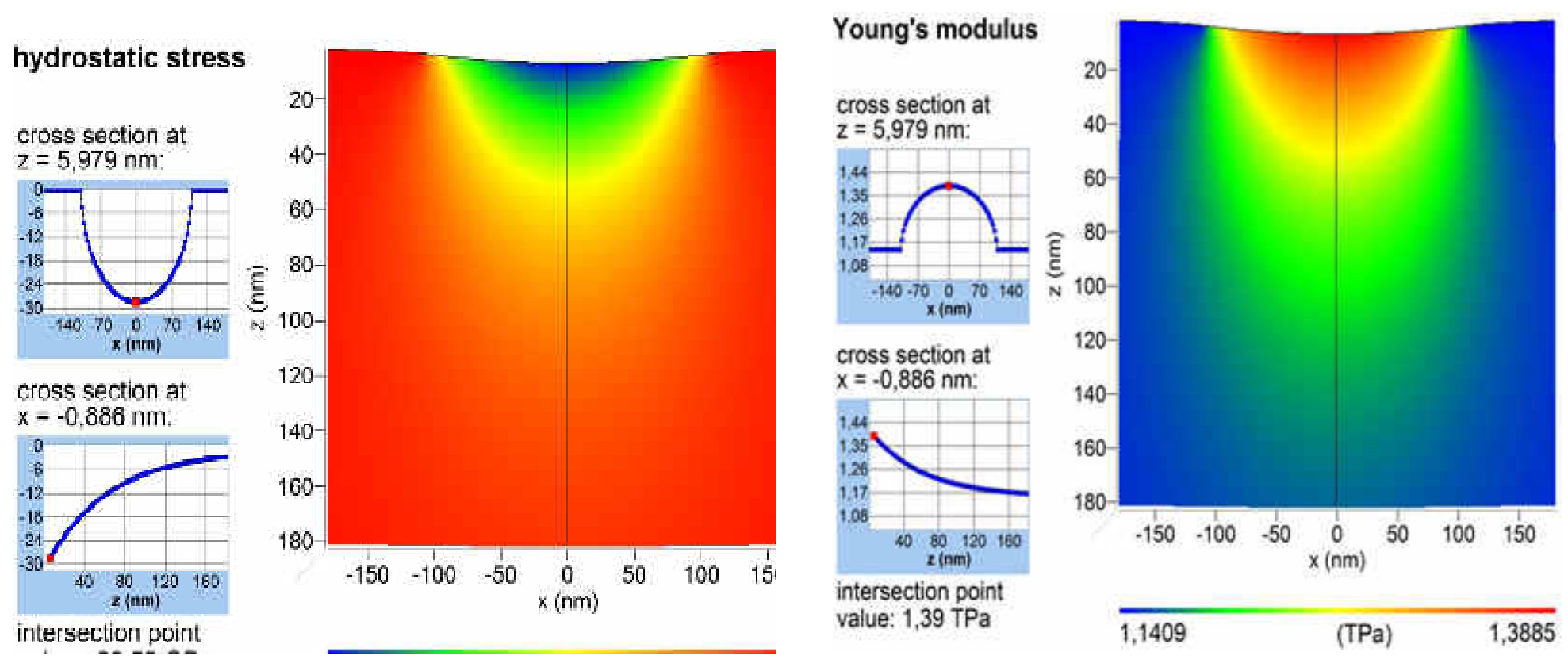


$$V_{LJ,(m,n)}=\varepsilon\left[\left(\frac{\sigma}{r}\right)^{m}-\left(\frac{\sigma}{r}\right)^{n}\right]$$

pressure-dependency of mechanical properties



decomposition parameters (decomposition strength)



Obstacle #3: Time-Dependency

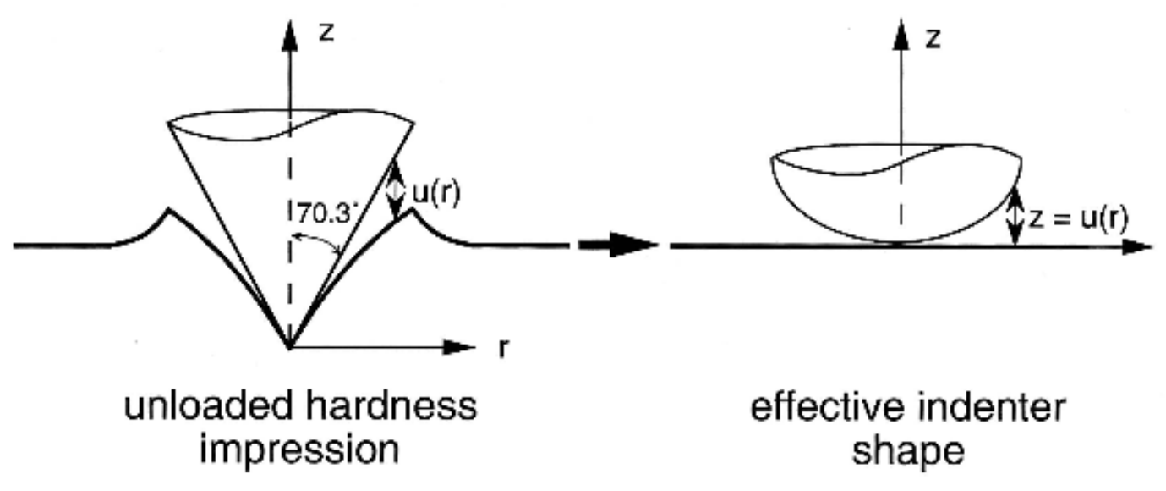
Classic standard linear solid for individual interactions:

$$E(t)\;=\;E_0+E_1e^{\frac{-t}{\tau\left(T_j(r,z),\mu\right)}}$$

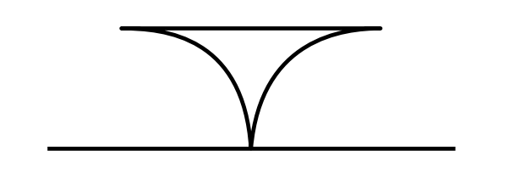
Resulting phenomenological time-dependent E:

$$E(t)\;=\;E_0+E_1e^{\frac{-t}{\tau\left(T_j(r,z),\mu\right)}}+\vec{r}\cdot E_1e^{\frac{-t}{\tau\left(T_j(r,z),\mu\right)}}\frac{t}{\tau^2}\frac{d\tau}{d\vec{r}}+\vec{r}\cdot\vec{r}\frac{\left(E_1e^{\frac{-t}{\tau\left(T_j(r,z),\mu\right)}}\frac{t}{\tau^2}\frac{d\tau}{d\vec{r}}\right)^2}{4\left(E_0+E_1e^{\frac{-t}{\tau\left(T_j(r,z),\mu\right)}}\right)}.$$

With respect to analysis of indentation measurements:



If m>2: $F=C\cdot\left(h-h_0\right)^{m}$



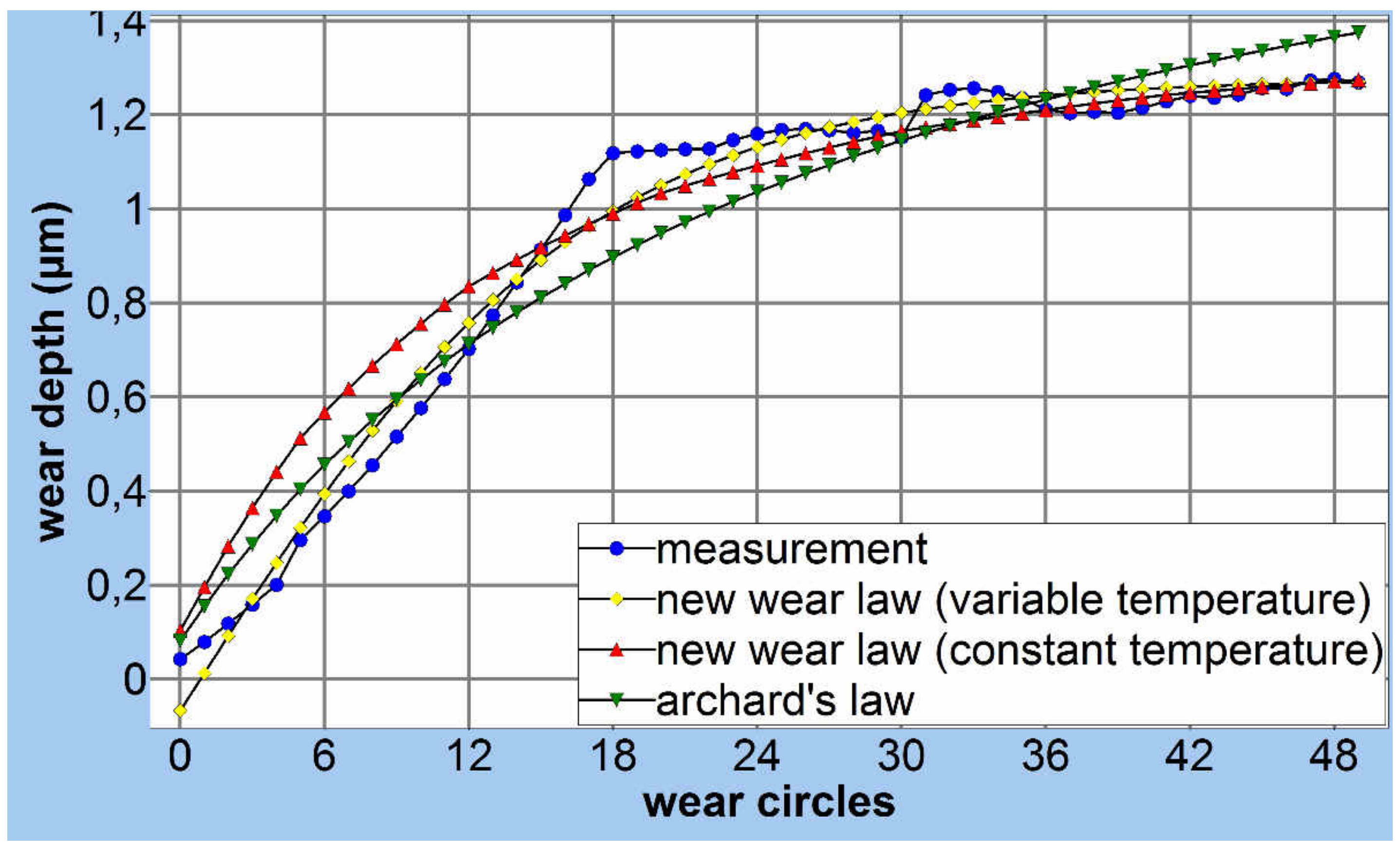
Sharper then real indenter!

Therefore: $F=C(t)\cdot\left(h-h_0(t)\right)^{m(t)}$ $\quad E(t)=E_0+E_1e^{-\frac{t}{\tau}}$

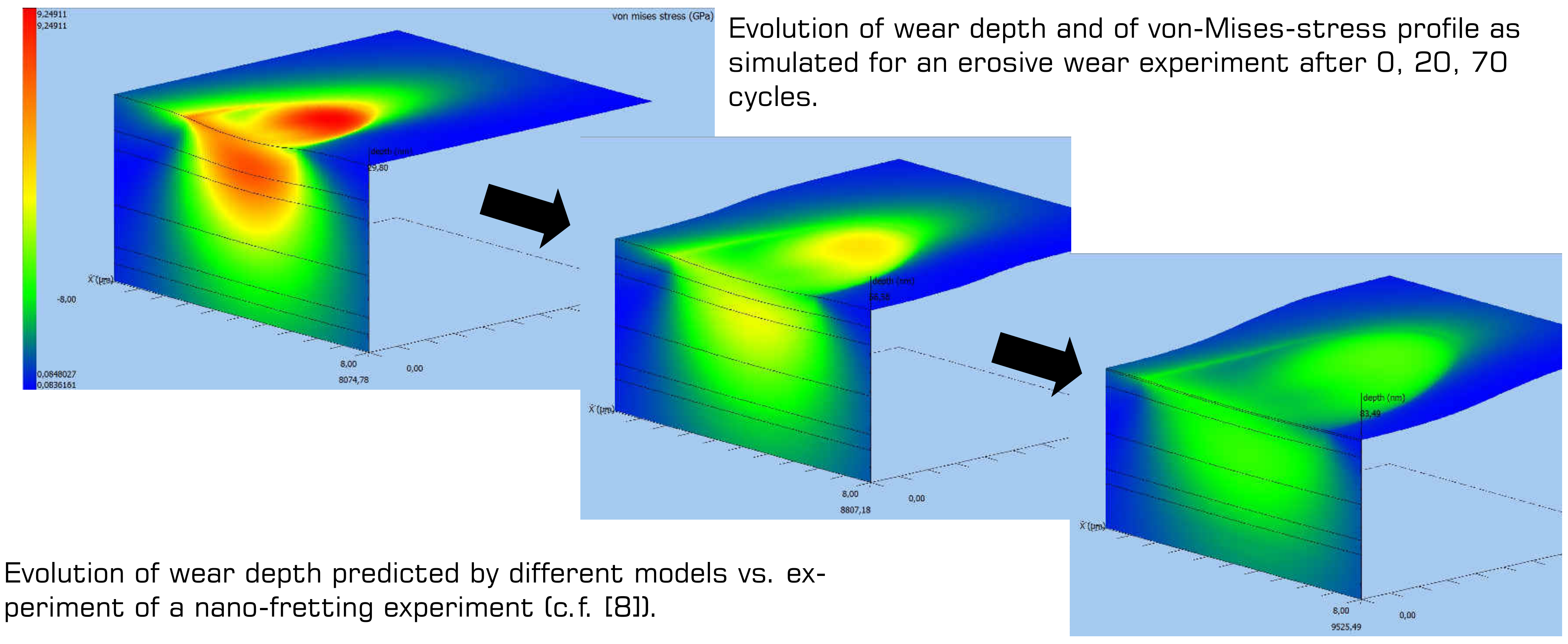
$$F\;=\;2\cdot\left(\frac{1-\nu_i^2}{E_i}+\frac{1-\nu_s^2}{E_{s0}+E_{s1}\cdot e^{-\frac{t}{\tau}}}\right)^{-1}\cdot\left[\frac{n}{n+1}\right]\cdot\left(\frac{1}{D^{tot}}\cdot\left[1-\varepsilon(n)\cdot\frac{n}{n+1}\right]\right)^{\frac{1}{n}}*(h-h_0)^{\left(1+\frac{1}{n}\right)}$$

According to [7], this method is the only reliable and stable found in literature which also yields reproducible results.

Results: Physical-Tribological Parameters + Model-Based Wear Predictions



Evolution of wear depth predicted by different models vs. experiment of a nano-fretting experiment (c.f. [8]).



Evolution of wear depth and of von-Mises-stress profile as simulated for an erosive wear experiment after 0, 20, 70 cycles.

References

[1] M. Fuchs et al., SIO Online Archive of Publications, 2010, siomec.de/pubs/2010/006.
[2] N. Schwarzer et al., Surface and Coatings Technology 2011, 206 (6).
[3] N. Schwarzer, Phil. Mag. 2012, 92 (13).
[4] N. Schwarzer, Materials Research Express 2014, 1 (1).
[5] N. Schwarzer, SIO Online Archive of Publications, 2013, siomec.de/pubs/2013/001.
[6] N. Schwarzer, Coatings 2014, 4 (2).
[7] M. Davies, PhD thesis, University of Nottingham, 2013.
[8] T. Liskiewicz et al., SCT 2013, 237.

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