Numerical prediction of mechanical and dry/wet tribological behaviour of viscoelastic bodies (rubber-like materials, polymer foams, polymer/elastomer composites)

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Numerical methods applied: Finite Element Method (FEM), Discrete Element Method (DEM), Finite Difference Method (FDM)

Computer codes developed: 3D discrete element software (implemented in C++), Mixed friction simulation code for reciprocating rod seals (implemented in C++)

Introduction

The research area is directly related to numerical tribology. It helps engineers to understand the causes and consequences of friction and to develop design tools with which the tribological aspects can be taken into consideration even in the design phase. Similar to other fields of sciences, nowadays, the tribology as the science of friction, wear and lubrication cannot be imagined without computer simulations. The topic is of great practical importance because many everyday life-related components (tires, shoe soles, windscreen wipers, etc.) and important machine elements (seals, gaskets, rollers, conveyor belts, guiding shoes, etc.) are made of viscoelastic material. The behavior of these components affects, among others, the energy consumption, fuel consumption, CO_2 emission, amount of lubricant needed, slip and fall accidents causing human injuries/deaths, occupational safety and health, traffic safety, friction related control and service problems, friction related vibration and noise generation, environment friendly design of rubber products, reduction of environmental impact, etc.

Material characterization and identification of constitutive constants

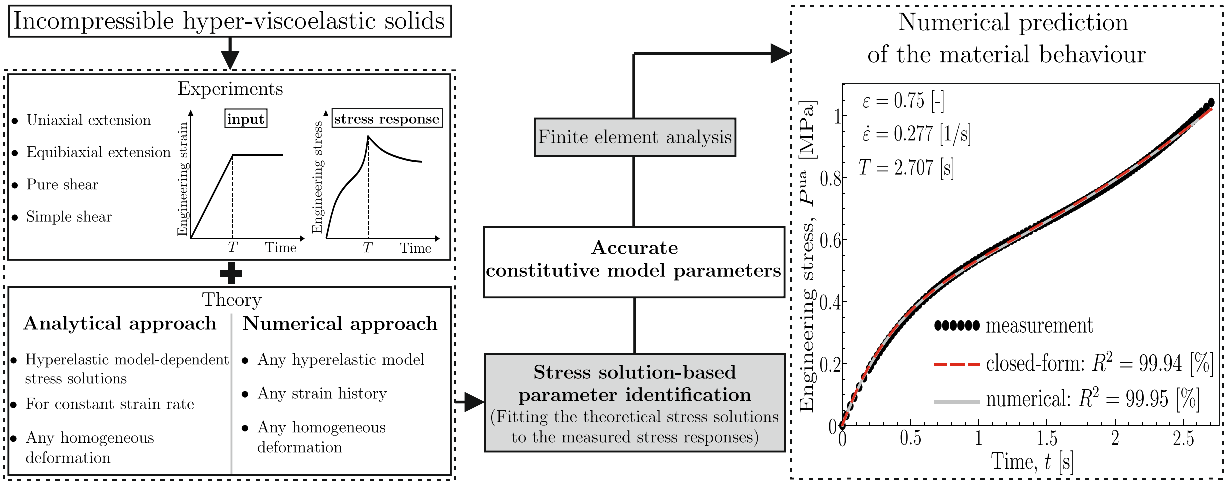
Rubber-like materials exhibit large deformation, highly nonlinear stress-strain relation and time-and temperature dependent material properties. One of our main aims is to determine the constitutive constants of different material models with high accuracy. The most commonly used approach to model the macroscopic behaviour of these materials is based on the finite element method and the so-called hyper-viscoelastic material models. In the latter, the nonlinear elastic response is described by a hyperelastic model while the time-dependent behaviour is taken into consideration through a viscoelastic model. Although the studies dealing with computational modelling use frequently these hyper-viscoelastic models, the determination of reliable model parameters remains a challenge. To overcome this difficulty, as a first step, numerical stress solutions have been worked out for compressible/incompressible hyper-viscoelastic solids subjected to uniaxial loading. Then, closed-form and numerical stress solutions have been developed for rubber-like materials subjected to uniaxial and equibiaxial tension/compression, pure shear and simple shear. These stress solution-based parameter identification methods make the accurate FE modelling of compressible/incompressible viscoelastic solids possible.

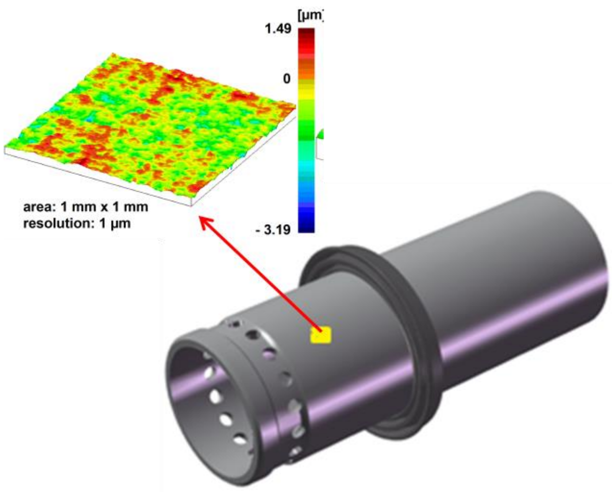
Numerical tribology: continuum mechanics approach

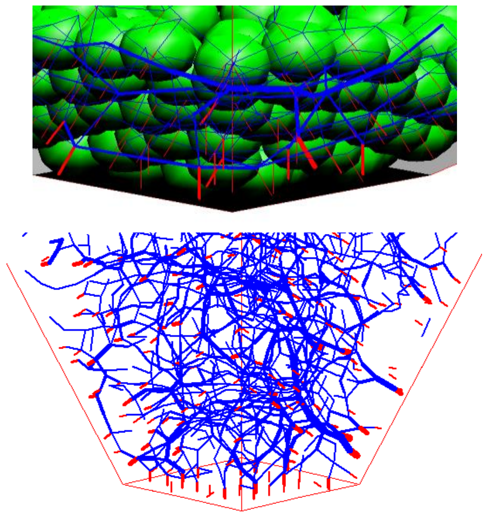
Although rubber friction has wide literature relative little information is available on apparently smooth surface generated viscoelastic friction. Majority of studies dealing with hysteresis friction focuses on tire friction where the RMS roughness of the road surface is bigger with orders of magnitude than that of apparently smooth surfaces frequently used in sealing applications. In case of seals, however, one of the main uncertainties is the friction-connected energy loss contribution arising from micro hysteresis. Consequently it is essential to get better insight into the mechanism of hysteresis friction and give reliable prediction for the hysteresis component of rubber friction. Accurate prediction of micro hysteresis friction makes the differentiation and quantification of other friction mechanisms (contribution to rubber friction from macro hysteresis, adhesion, rubber wear, etc.) possible. Additionally, the knowledge gained from theoretical and/or experimental works will enable engineers to design sliding/rolling viscoelastic components with prescribed (decreased or increased) friction. To predict the tribological behavior of viscoelastic bodies engineers need effective and accurate models and algorithms (design tools) with which they can test different what-if scenarios and geometries, perform sensitivity analysis, optimize the geometry, surface roughness and surface treatment of the viscoelastic component and its counterpart, eliminate or minimize time consuming and expensive measurements, reduce the number of prototypes, simulate real engineering problems, and understand the effect of different physical processes on the tribological behavior. Our primary aim is to develop FE and mixed friction models which make the quantitative prediction of the friction force of reciprocating rod seals possible.

Numerical tribology: discrete modelling approach

In order to improve the tribological properties it is essential to understand the interrelation between tribological behavior at macro and micro/nano-scale. Due to the lack of knowledge on scale dependent tribological behavior, in the majority of cases, the so called "trial and error" approach prevails in the present design practice of sliding systems. Numerical methods of tribology, however, allow us to change this. To predict friction, study contact conditions and simulate wear at macro, micro and nano scale numerically both continuum (e.g. finite element method) and discrete methods (e.g. discrete element method) can be used. As there exists no a generally applicable simulation method for multi-scale (time- and space-scale) systems, in many cases, it is needed to couple these methods. The three-dimensional discrete element computation algorithm and program developed and implemented by one of us can be used even for multi-scale systems. At the same time it may be extended freely and with or without modifications can be used for wear simulation and for research in material science, fracture mechanics, rheology of particulate materials, soil mechanics, etc. Here the term Discrete Element Method refers to the three-dimensional Distinct Element Method, where the computational domain consists of rigid spheres (ball-type model) with compliant contacts. Consequently the interpenetration (overlapping) of rigid spheres is allowed („soft" particle model) which can be interpreted as local deformation of the contacting spheres.







Some publications:

[1] Fazekas, B., Goda, T.J., 2019. Closed-form and numerical stress solution-based parameter identification for incompressible hyper-viscoelastic solids subjected to various loading modes. International Journal of Mechanical Sciences. 151, 650–660. https://doi.org/10.1016/j.ijmecsci.2018.12.011

[2] Fazekas, B., Goda, T.J., 2018. Determination of the hyper-viscoelastic model parameters of open-cell polymer foams and rubber-like materials with high accuracy. Materials & Design. 156, 596–608. https://doi.org/10.1016/j.matdes.2018.07.010

[3] Goda, T.J., 2016. Effect of track roughness generated micro-hysteresis on rubber friction in case of (apparently) smooth surfaces. Tribology International. 93, 142-150. https://doi.org/10.1016/j.triboint.2015.09.018

[4] Bódai, G., Goda, T.J., 2014. Sliding friction of wiper blade: Measurement, FE modeling and mixed friction simulation. Tribology International. 70, 63-74. https://doi.org/10.1016/j.triboint.2013.07.013

[5] Goda, T.J., Ebert, F., 2005. Three-dimensional discrete element simulations in hoppers and silos. Powder Technology.158. 58-68. https://doi.org/10.1016/j.powtec.2005.04.019

[6] Friedrich, K., Goda, T., Váradi, K., Wetzel, B., 2004. Finite element simulation of the fiber-matrix debonding in polymer composites produced by a sliding indentor: Part I - Normally oriented fibers. Journal of Composite Materials. 38, 1583-1606. https://doi.org/10.1177/0021998304043759