Simulace plastů

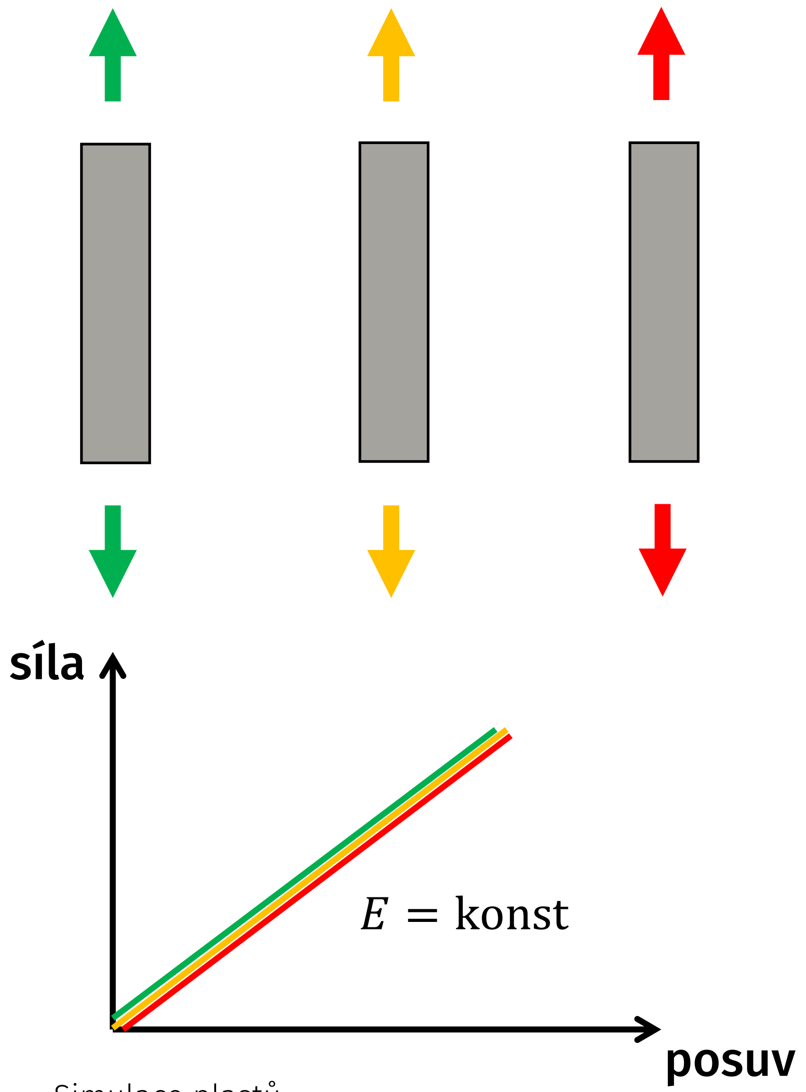
Tomáš Vítek

SVS FEM

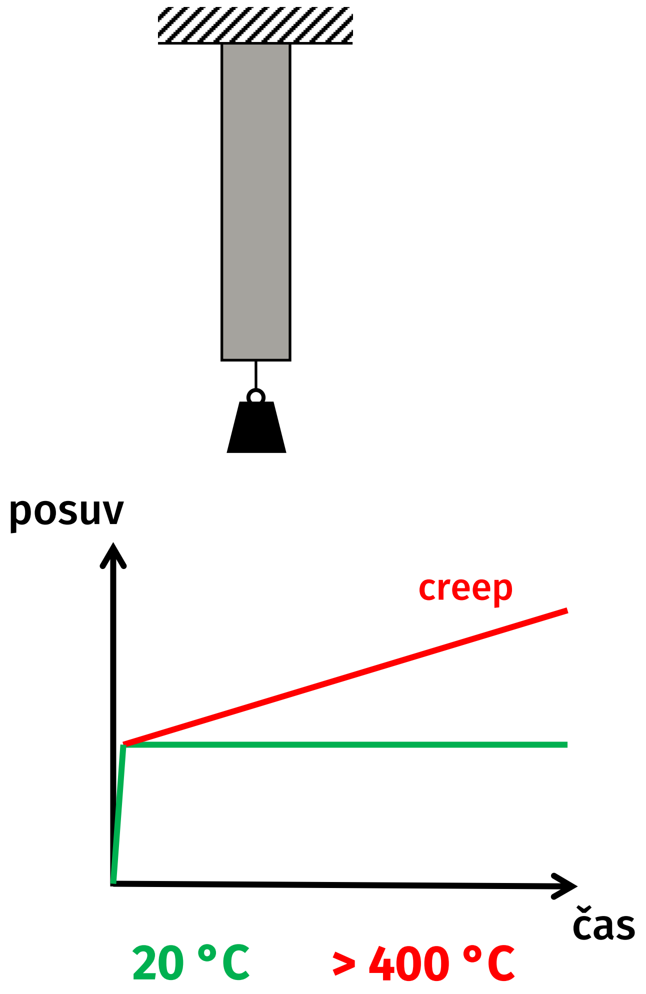
KOVY vs PLASTY

Kovy

- Rychlost deformace

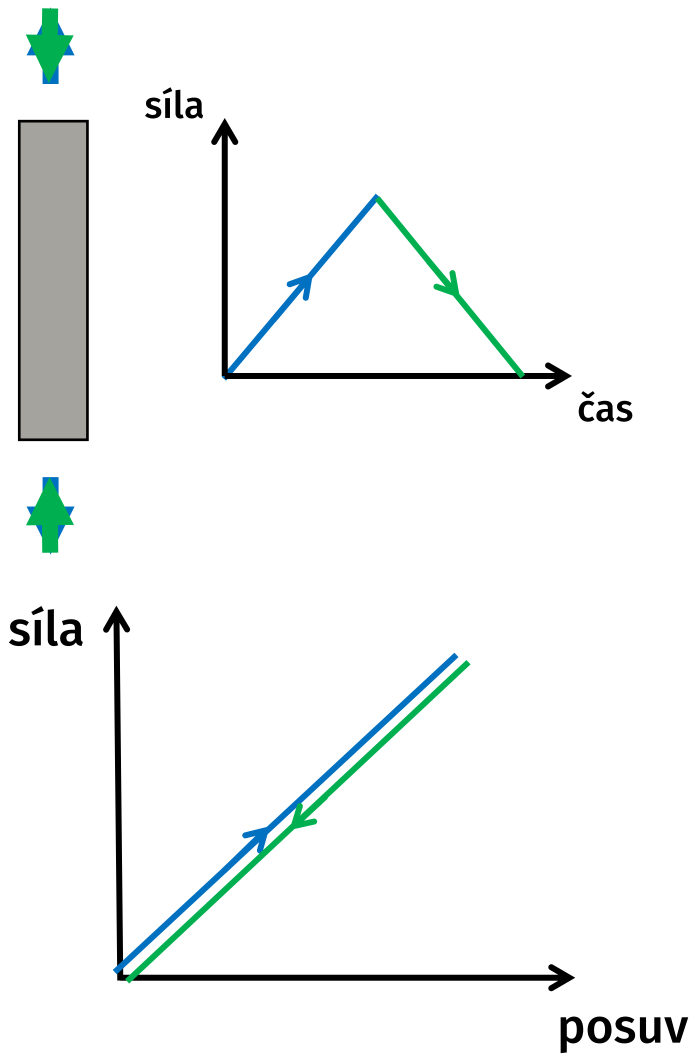


- Dlouhodobé zatížení

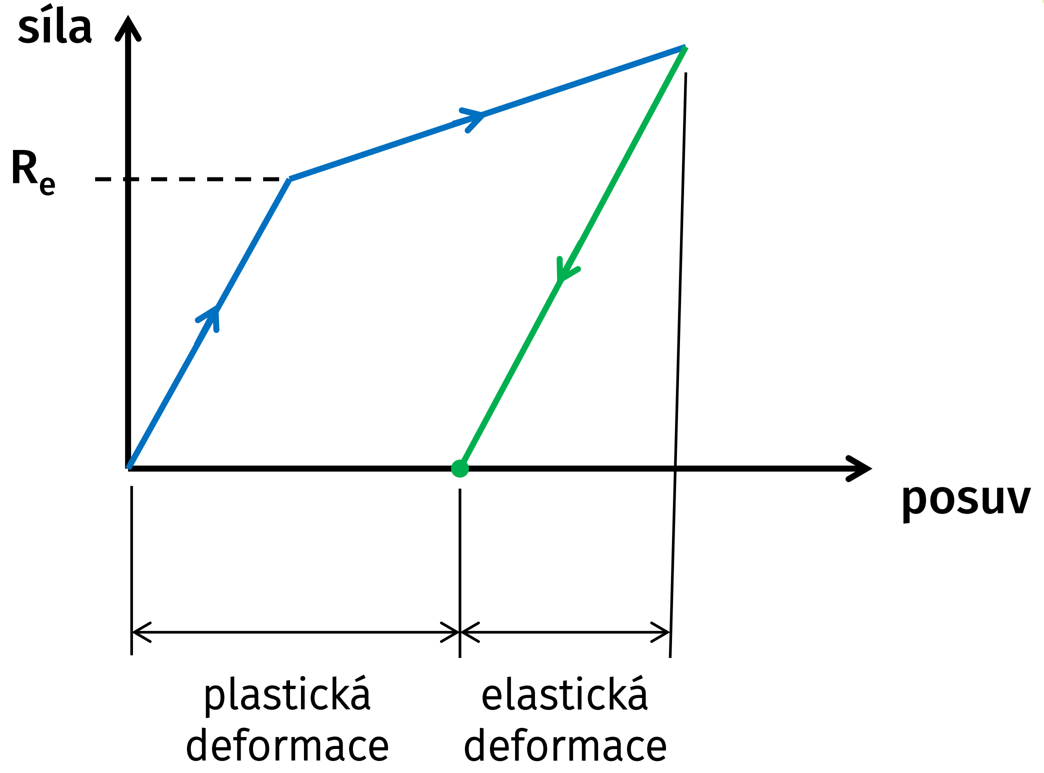


Kovy

- Elasticita

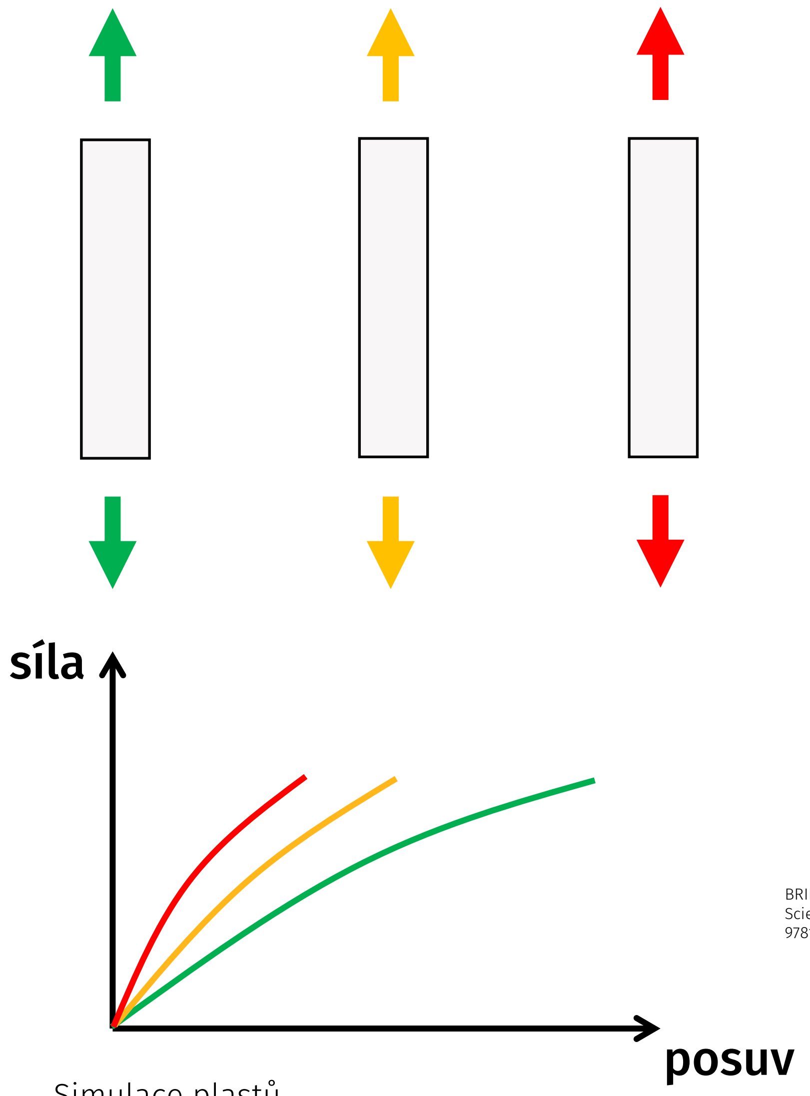


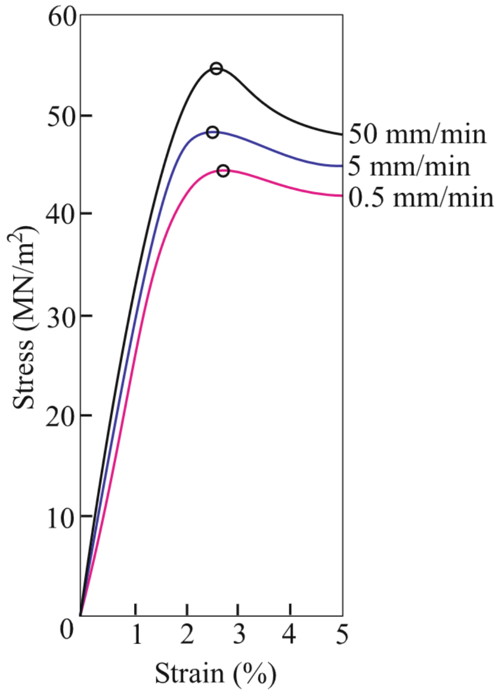
- Plasticita



Plasty

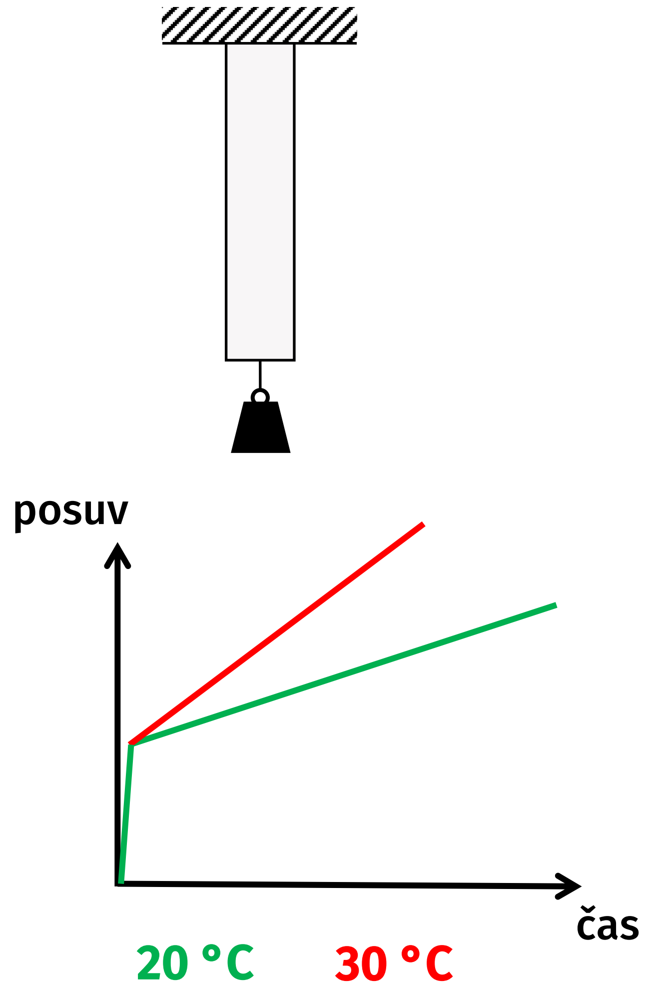
- Rychlost deformace





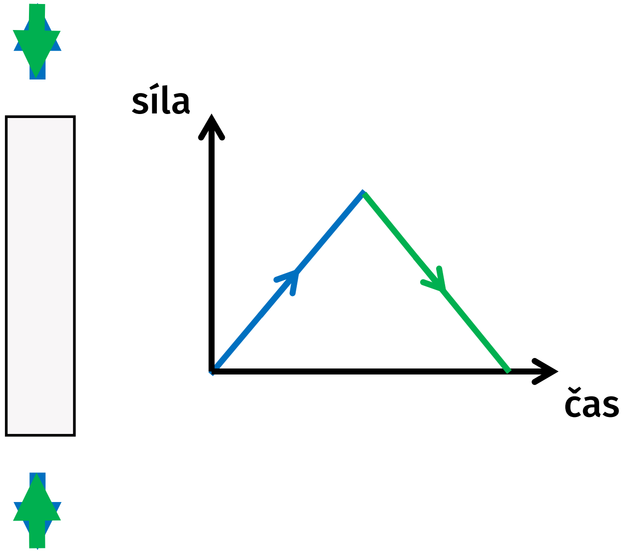
BRINSON, Hal F. and BRINSON, L. Catherine, 2015. Polymer Engineering Science and Viscoelasticity: An Introduction. Online. ISBN 9781489974846. Available at: https://doi.org/10.1007/978-1-4899-7485-3.

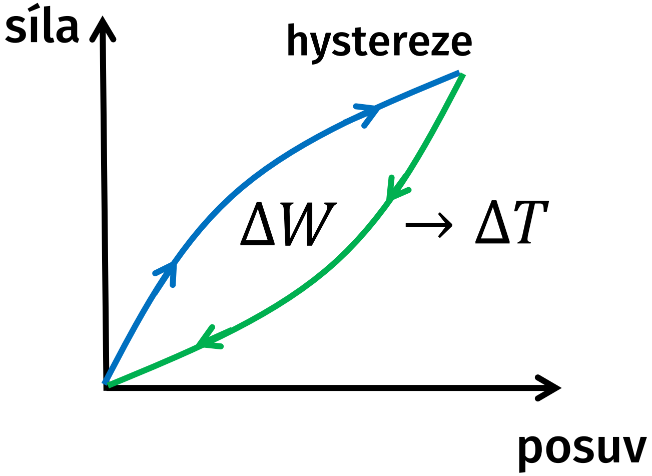
- Dlouhodobé zatížení



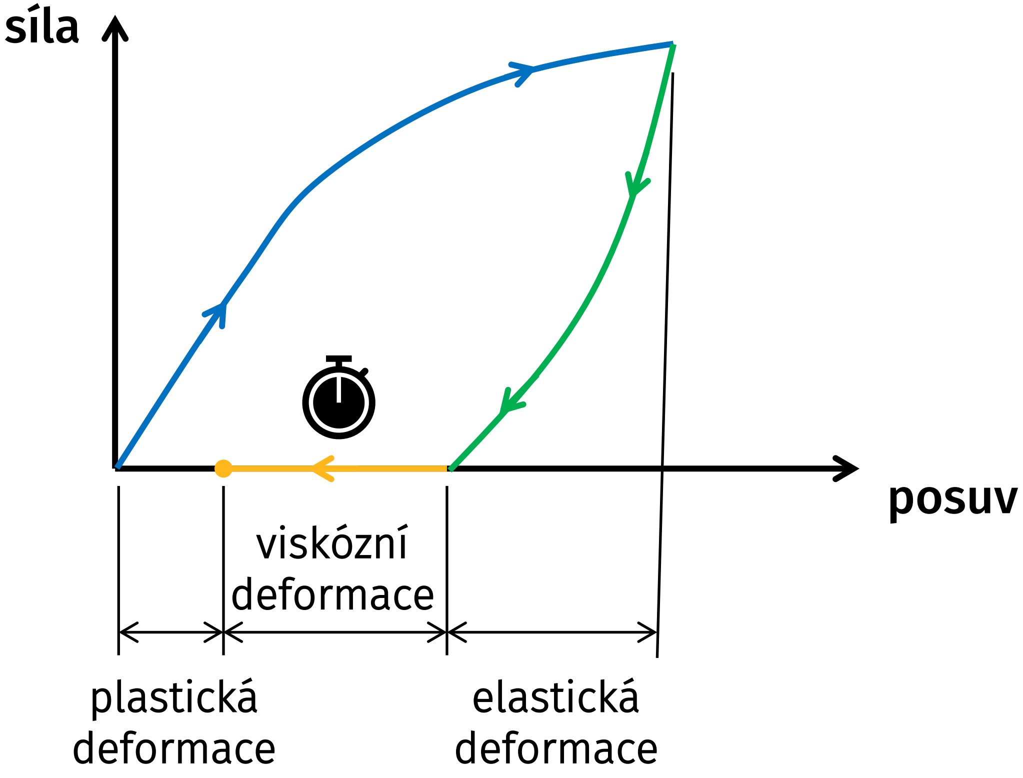
Plasty

- Elasticita → VISKOelasticita



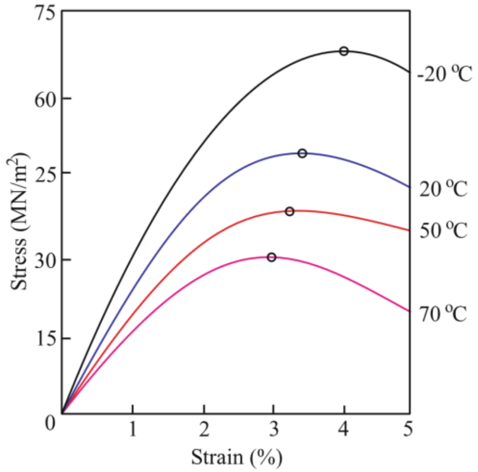


- Plasticita

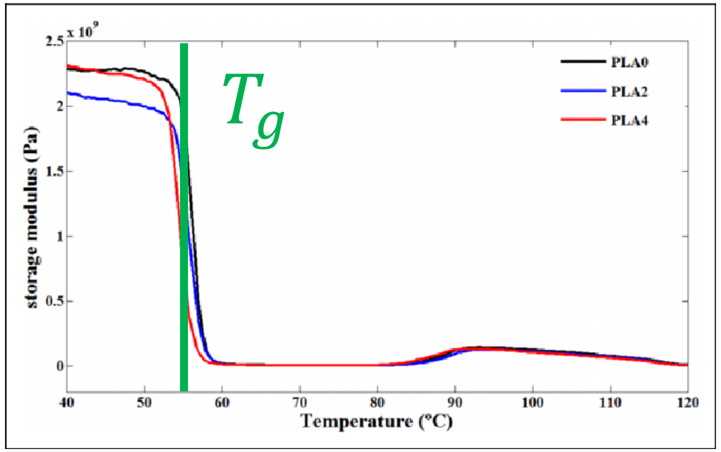


Plasty

■ **Závislost na teplotě**

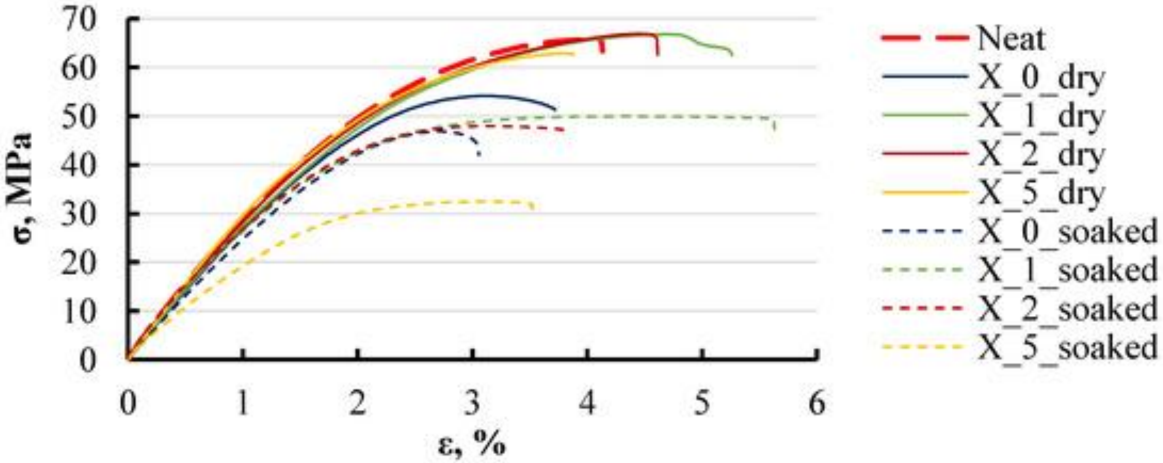


BRINSON, Hal F. and BRINSON, L. Catherine, 2015. Polymer Engineering Science and Viscoelasticity: An Introduction. Online. ISBN 9781489974846. Available at: https://doi.org/10.1007/978-1-4899-7485-3.



Yousefzade, Omid & Jeddi, Javad & Vazirinasab, Elham & Garmabi, Hamid. (2018). Poly(lactic acid) phase transitions in the presence of nano calcium carbonate: Opposing effect of nanofiller on static and dynamic measurements. Journal of Thermoplastic Composite Materials. 32. 089270571875938. 10.1177/0892705718759386.

- **Vliv vlhkosti**



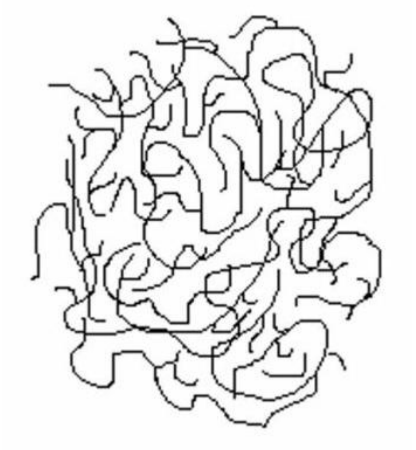
STANKEVICH, Stanislav; ZELENIAKIENE, Daiva; SEVCENKO, Jevgenijs; BULDERBERGA, Olga; ZETKOVA, Katerina et al., 2024. Moisture Absorption and Mechanical Degradation of Polymer Systems Incorporated with Layered Double Hydroxide Particles. Online. *Polymers*. 2024-11-30, vol. 16, no. 23, p. 3388. ISSN 2073-4360.

KOVY → $E = f(\text{teplota})$

PLASTY → $E = f(\text{teplota, čas, rychlost def., vlhkost, ...})$

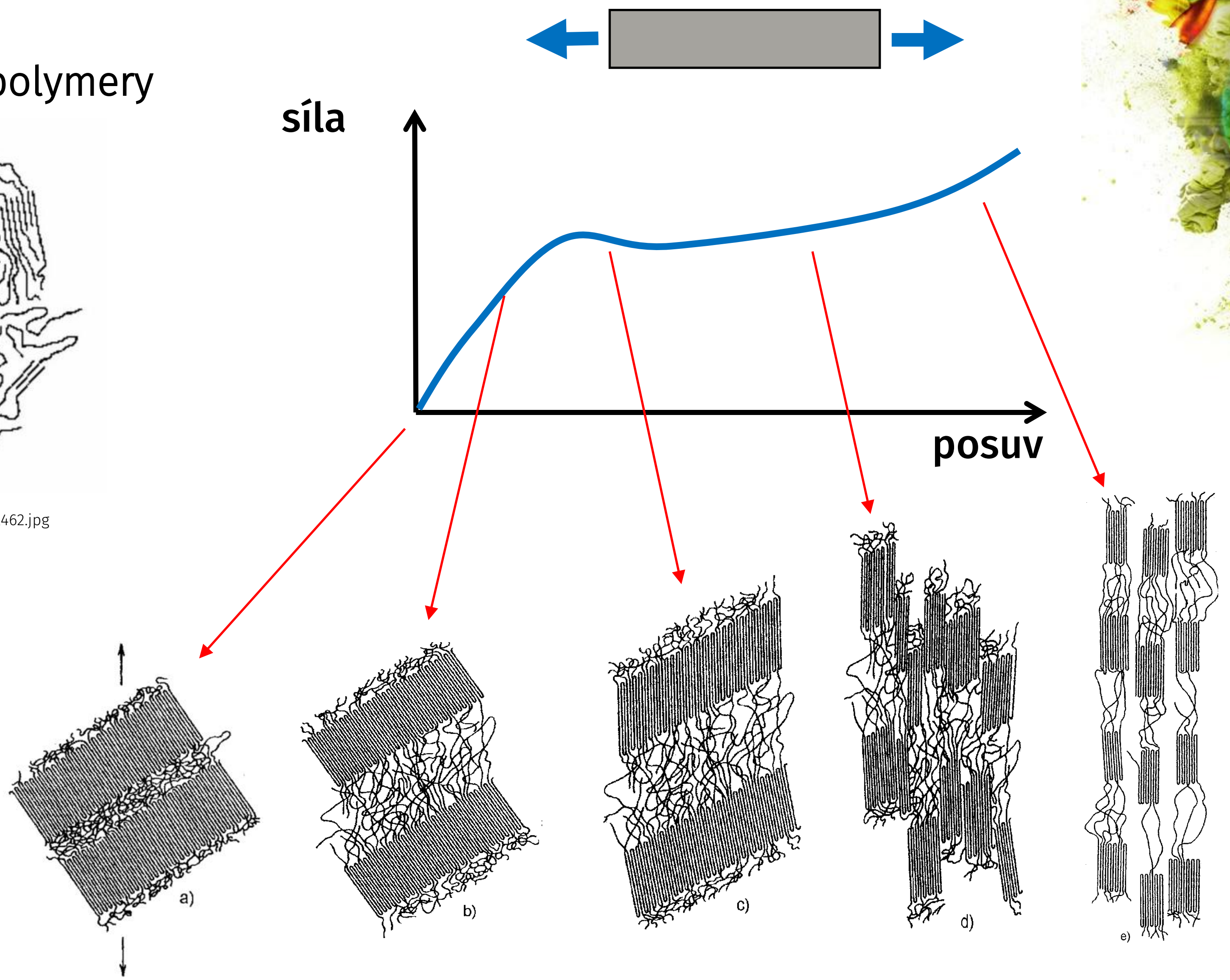
Proč?

Amorfní polymery



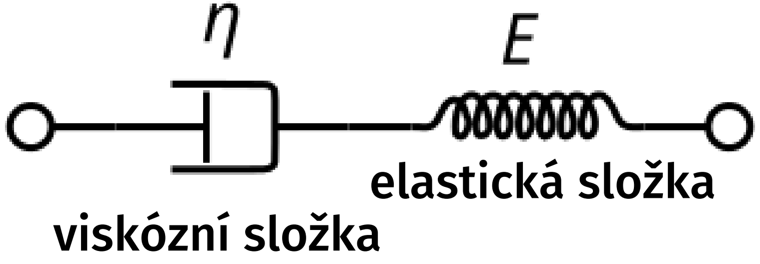
Semikrystalické polymery

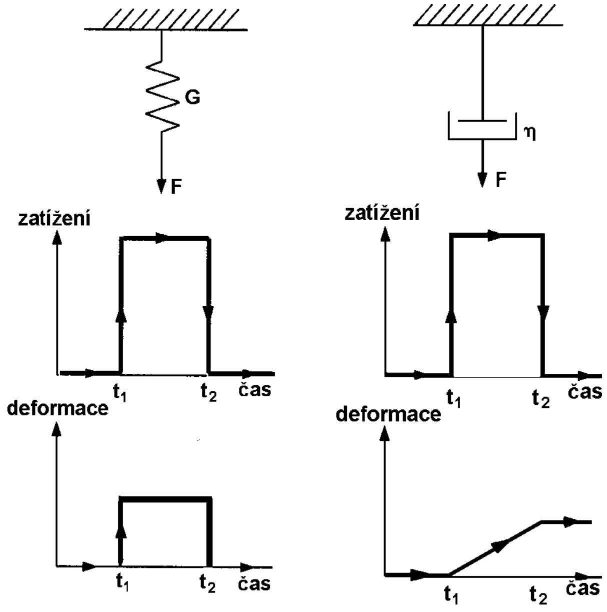
https://madisongroup.com/wp-content/uploads/2023/01/Amorphous_semicrystalline_polymer_chains-800x462.jpg



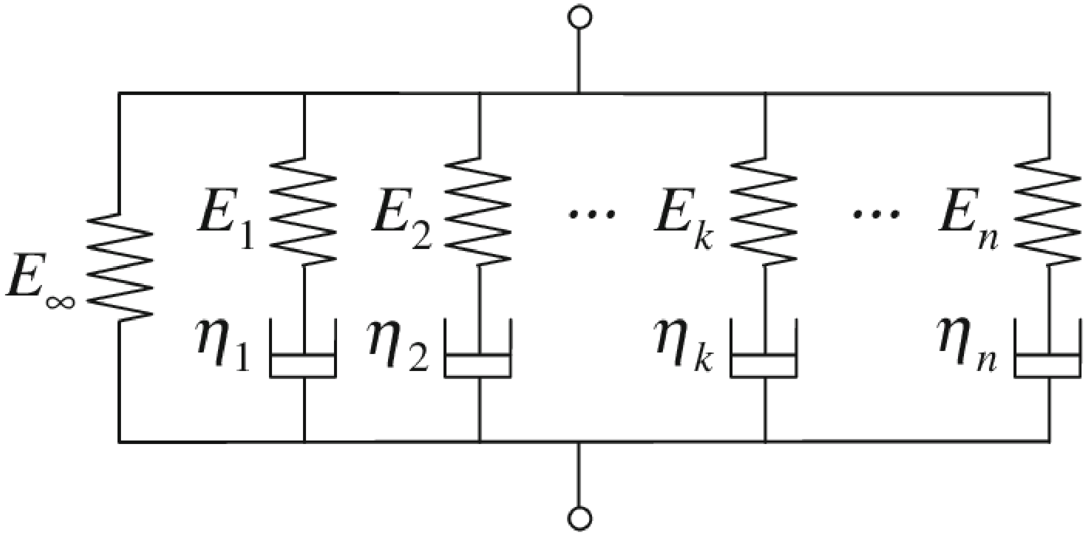
Modelování plastů

- Maxwellův model





- Zobecněný Maxwellův model



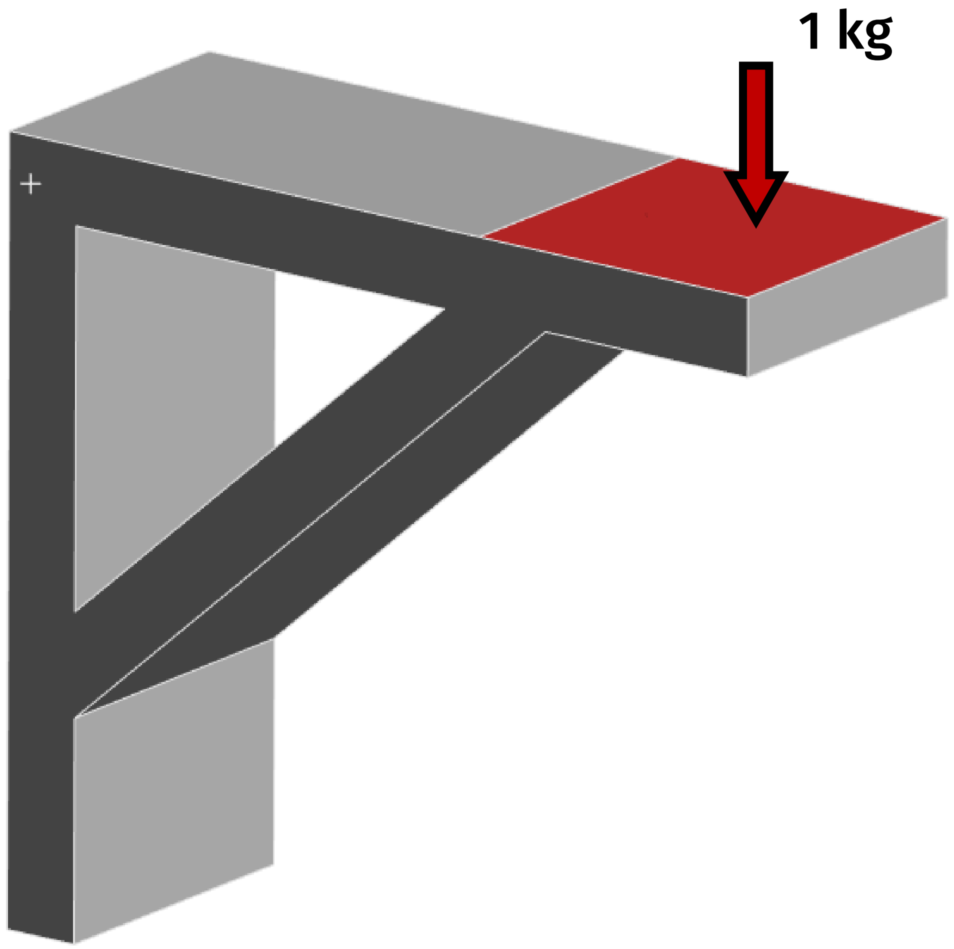
Matematické vyjádření **= Prony series**

$$E(t) = E_\infty + \sum_{i=1}^{N} E_i \exp\left(-\frac{t}{\tau_i}\right)$$

Gaspard de Prony

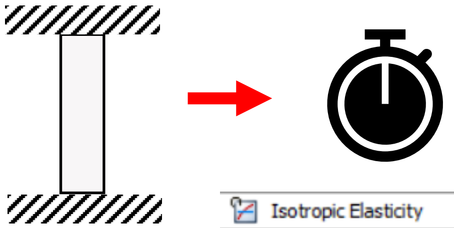
Ukázka – Prony series

- Deformace plastové konzoly



Ukázka – Prony series

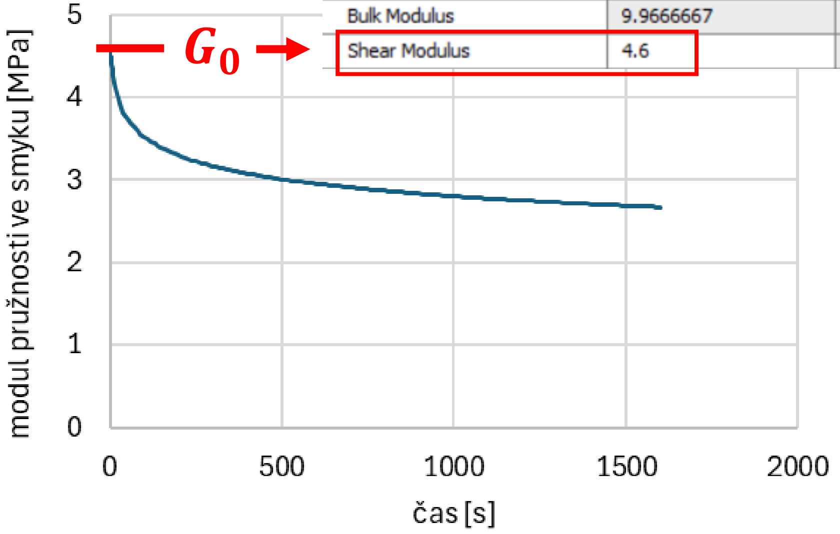
- Prony Series viskoelastický model
- Materiálová data → relaxační zkouška

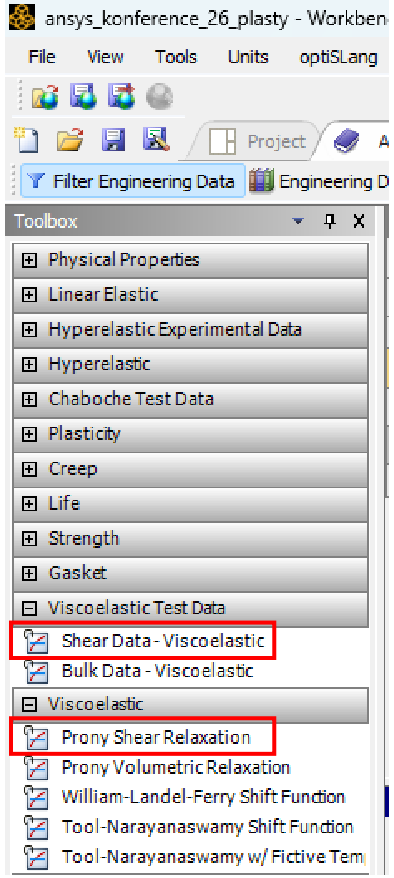


~0.1 s

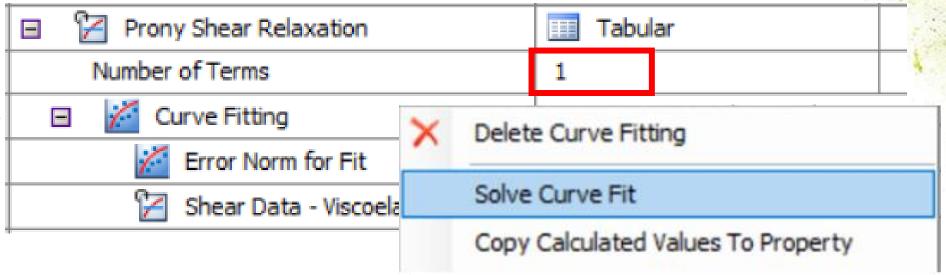
Isotropic Elasticity		
Derive from	Shear Modulus an...	
Young's Modulus	11.96	MPa
Poisson's Ratio	0.3	
Bulk Modulus	9.9666667	MPa
Shear Modulus	4.6	MPa

G_0



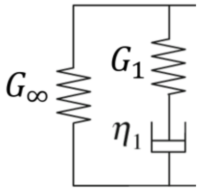


zpracování dat v Ansysu

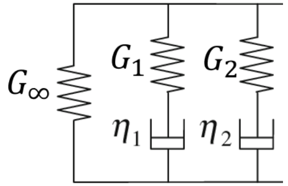


Index i	Relative Moduli(i)	Relaxation Time(i) (s)
1	0.36308151	209.75648

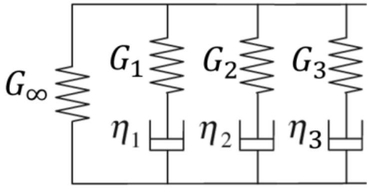
$$g_i = \frac{G_i}{G_0} \qquad \tau_i = \frac{\eta_i}{G_i}$$



Index i	Relative Moduli(i)	Relaxation Time(i) (s)
1	0.21459563	37.459581
2	0.20619121	568.26243

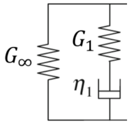


Index i	Relative Moduli(i)	Relaxation Time(i) (s)
1	0.15706013	126.55662
2	1.2068346E-05	186.83122
3	0.21292188	265.19043



Ukázka – Prony series

$n = 1$



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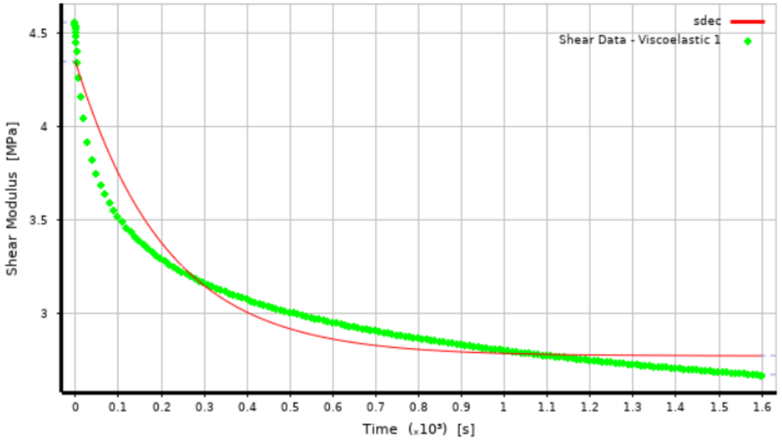
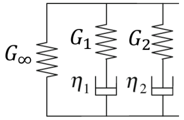
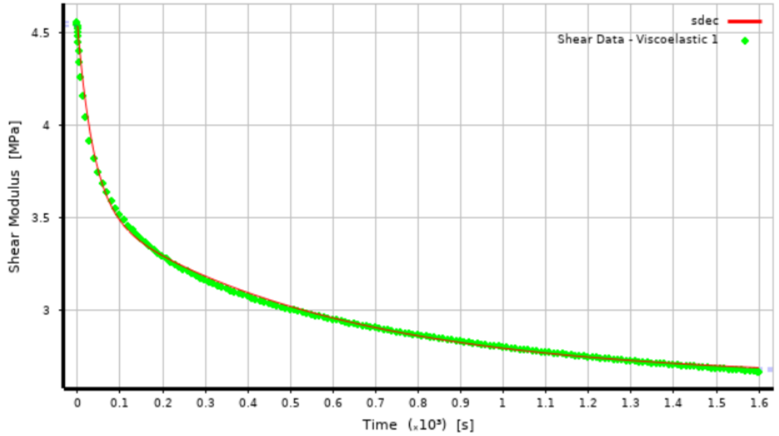


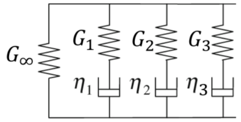
$n = 2$



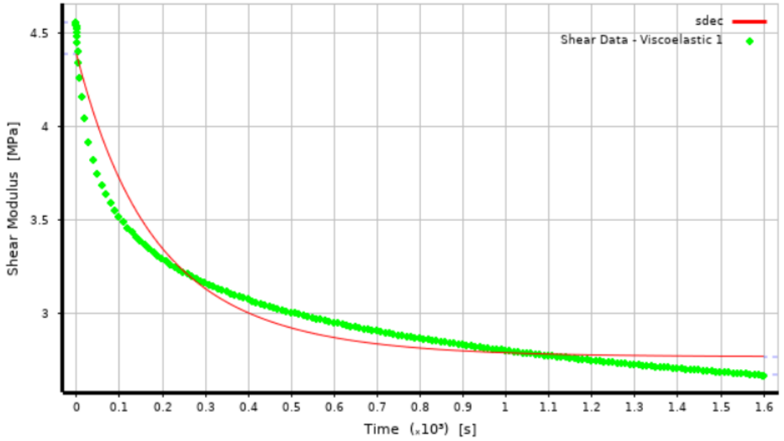
Index i	Relative Moduli(i)	Relaxation Time(i) (s)
1	0.21459563	37.459581
2	0.20619121	568.26243



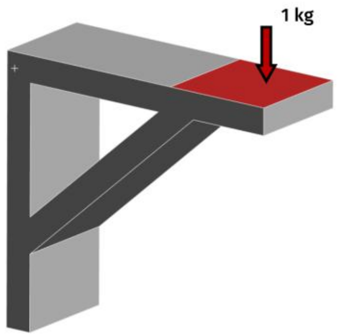
$n = 3$



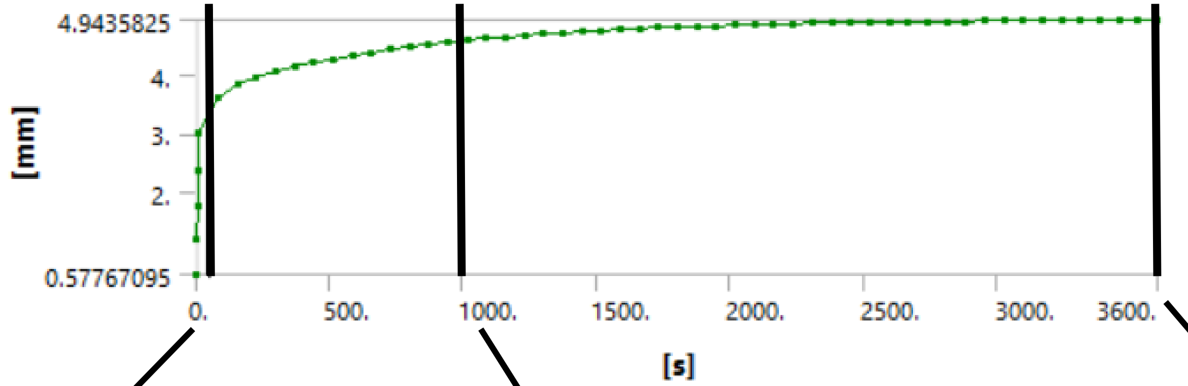
Index i	Relative Moduli(i)	Relaxation Time(i) (s)
1	0.15706013	126.55662
2	1.2068346E-05	186.83122
3	0.21292188	265.19043

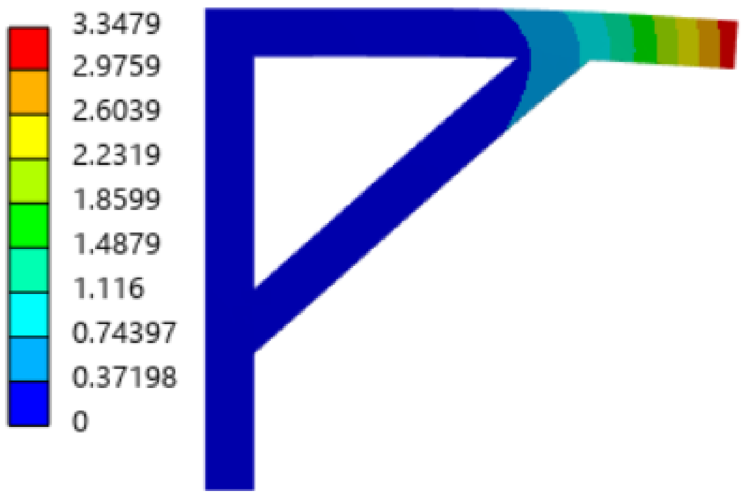


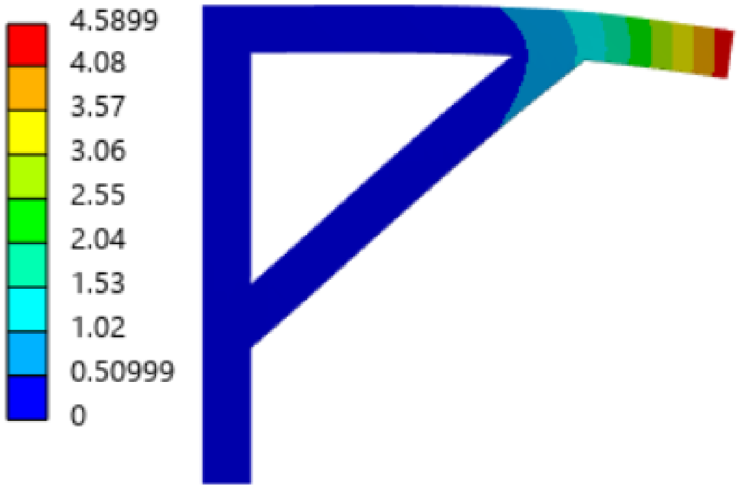
Ukázka – Prony series

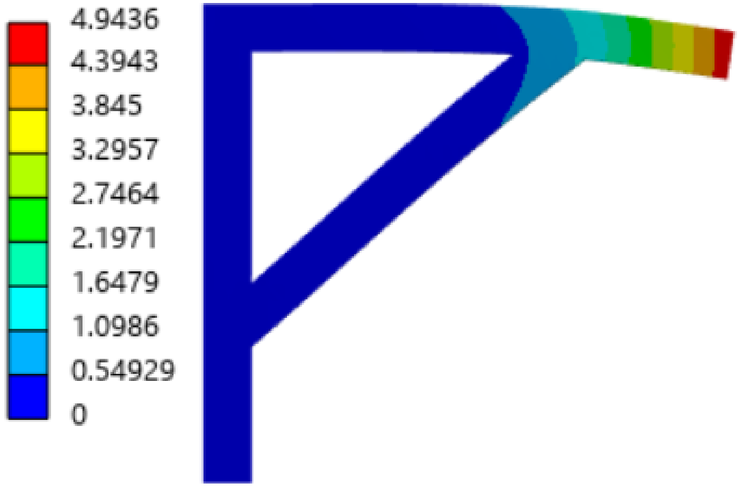


deformace v čase





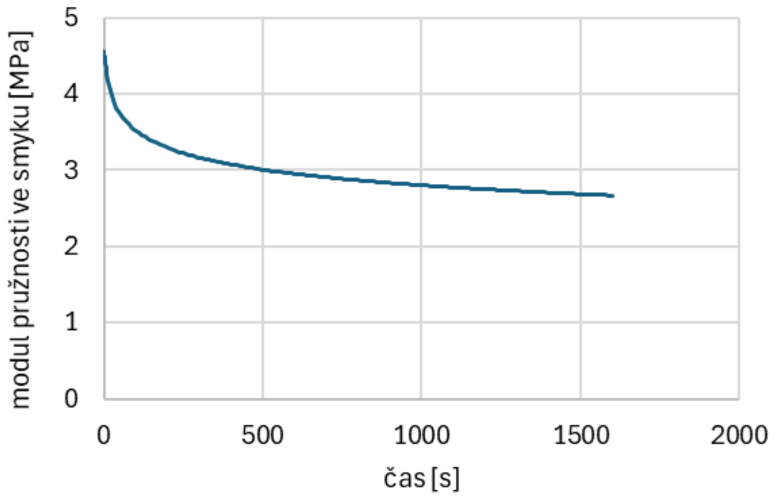




Stačí to?

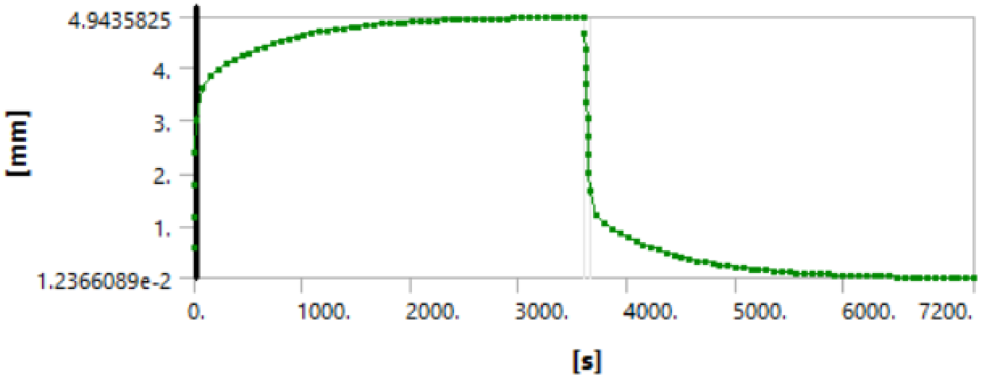
LINEÁRNÍ VISKO**ELASTICITA**

rychlost relaxace nezávislá
na velikosti zatížení



❌ **VELKÉ DEFORMACE**

po odtížení je deformace nulová



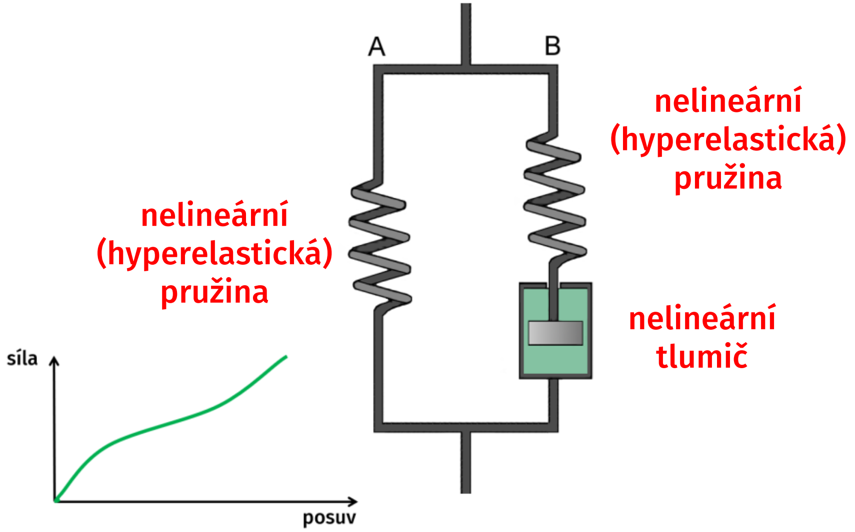
❌ **TRVALÉ DEFORMACE**

❌ **CYKLICKÁ PLASTICITA**

Kam dál?

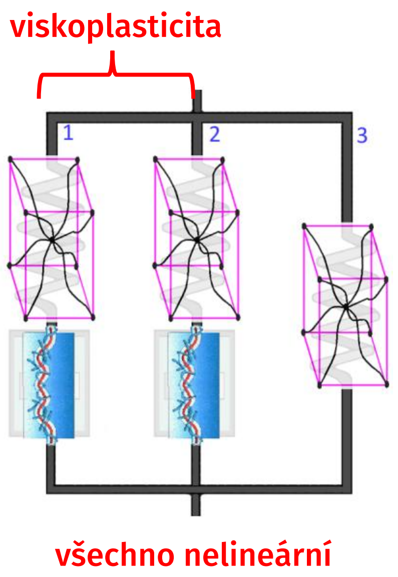
dostupné v Ansys Mechanical Enterprise

Bergström-Boyce



- ✔ VELKÉ DEFORMACE
- ✘ TRVALÉ DEFORMACE
- ✘ CYKLICKÁ PLASTICITA

Three-Network Model



- ✔ VELKÉ DEFORMACE
- ✔ TRVALÉ DEFORMACE
- ✔ CYKLICKÁ PLASTICITA

Jörgen Bergström

PolymerFEM
Advanced Material Models

SVS FEM

33 Ansys KONFERENCE

PolymerFEM Advanced Material Models → Ansys part of SYNOPSYS

PolyUMod

A Library of Advanced User Materials

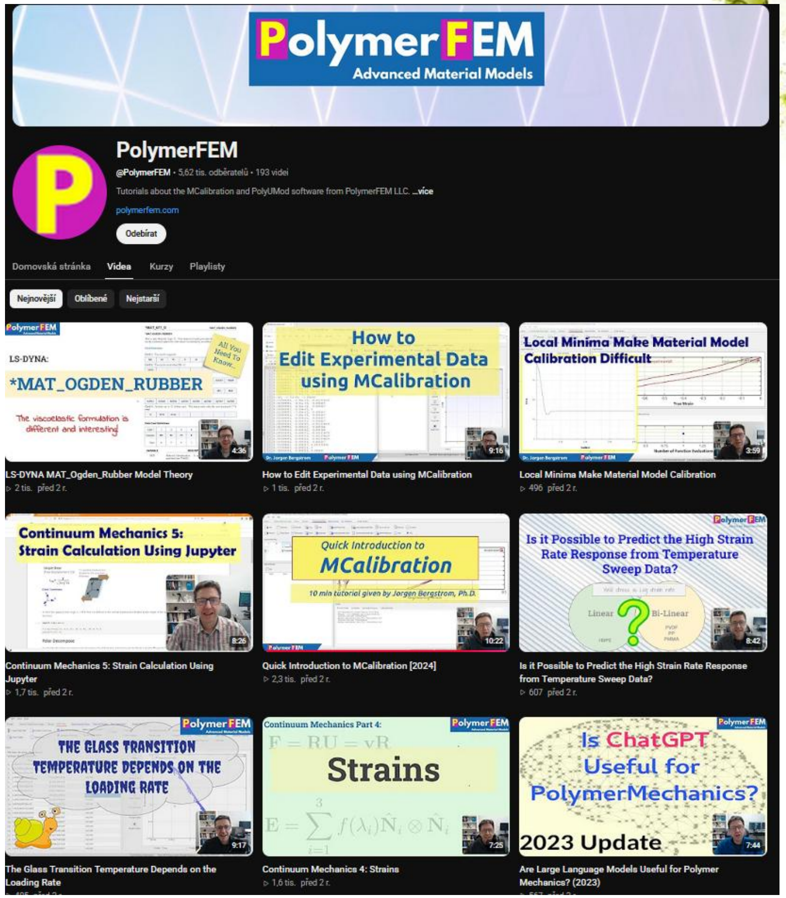
PolyUMod-Linear-Elastic	All
PolyUMod-Neo-Hookean	All
PolyUMod-Eight-Chain	All
PolyUMod-Bergstrom-Boyce	All
PolyUMod-Bergstrom-Boyce-Mullins	All
PolyUMod-Anisotropic-Bergstrom-Boyce-Mullins	All
PolyUMod-Hybrid	All
PolyUMod-Arruda-Boyce	All
PolyUMod-Dual-Network-Fluoropolymer	All
PolyUMod-Three-Network	All
PolyUMod-Anisotropic-Eight-Chain-Bergstrom	All
PolyUMod-Micro-Foam	All
PolyUMod-Parallel-Network	All
PolyUMod-Three-Network-Foam	All
PolyUMod-Dynamic-Bergstrom-Boyce	All
PolyUMod-Silberstein-Boyce-1	All
PolyUMod-Silberstein-Boyce-2	All
PolyUMod-Flow-Evolution-Networks	All
PolyUMod-A2N	All
PolyUMod-TNV	All
PolyUMod-SuperE31	M, AB
PolyUMod-SuperEP31	M, AB
PolyUMod-SuperE32	M, AB
PolyUMod-SuperEP32	M, AB
PolyUMod-SuperEP33	M, AB
PolyUMod-SuperEP34	M, AB
PolyUMod-SuperEP35	M, AB
PolyUMod-Template	All

dostupné v Ansys Mechanical

pouze v PolyUMod

2: (Yeoh) + (Power Flow)
3: (Yeoh) + (Anisotropic Power Flow)
4: (Yeoh + Mullins)
5: (Yeoh + Mullins) + (Power Flow)
6: (Yeoh + Mullins) + (Anisotropic Power Flow)
7: (HGOB)
8: (HGOB) + (Power Flow)
9: (HGOB) + (Anisotropic Power Flow)
10: (HGOB + Mullins)
11: (HGOB + Mullins) + (Power Flow)
12: (HGOB + Mullins) + (Anisotropic Power Flow)
13: (Hyperfoam)
14: (Hyperfoam) + (Power Flow)
15: (Hyperfoam) + (Anisotropic Power Flow)
16: (Hyperfoam + Mullins)
17: (Hyperfoam + Mullins) + (Power Flow)
18: (Hyperfoam + Mullins) + (Anisotropic Power Flow)
19: (Yeoh) + (PSC Flow)
20: (Yeoh + Mullins) + (PSC Flow)
21: (HGOB) + (PSC Flow)
22: (HGOB + Mullins) + (PSC Flow)
23: (Hyperfoam) + (PSC Flow)
24: (Hyperfoam + Mullins) + (PSC Flow)
25: (Yeoh + Linear Temp Dependence)
26: (Yeoh + Linear Temp Dependence + Mullins)
27: (Yeoh + Linear Temp Dep) + (PSC Flow + Linear Temp Dependence)
28: (Yeoh + Linear Temp and Moisture Dependence)
29: (Yeoh + Linear Temp Dep) + (PSC...inear Temp and Moisture Dependence)
30: (HGOB + Linear Temp Dependence)
31: (HGOB + Linear Temp Dependence + Mullins)
32: (HGOB + Linear Temp Dep) + (Ani... PSC Flow + Linear Temp Dependence)
33: (HGOB + Linear Temp and Moisture Dependence)
34: (HGOB + Linear Temp and Moistur...low + Linear Temp and Moisture Dep)
35: (Yeoh + Tanh Temp Dependence)
36: (Yeoh + Tanh Temp Dependence) + (PSC Flow + Tanh Temp Dependence)

YouTube:



SVS FEM

Bergström-Boyce

Constant	Meaning	Property	Units
C1	μ_A	Initial shear modulus of network A	Stress
C2	N_A	Square of the limiting chain stretch of network A: $\lambda_A^{lock}=\sqrt{N_A}$	Dimensionless
C3	μ_B	Initial shear modulus of network B	Stress
C4	N_B	Square of the limiting chain stretch of network B: $\lambda_B^{lock}=\sqrt{N_B}$	Dimensionless
C5	$\frac{\dot{\gamma}_0}{\tau_{base}^m}$	Material constant related to flow resistance	$Time^{-1}(Stress)^{-m}$
C6	c	Strain exponential	Dimensionless
C7	m	Stress exponential	Dimensionless
C8	ε	Optional material constant adjusting the strain factor in viscous flow rule, default value: $\varepsilon = 1 \times 10^{-5}$	Dimensionless

8 parametrů

Three-Network Model

Input Parameters: Network A

Constant	Meaning	Property	Unit	Range
C1	μ_A	Shear modulus	Stress	$\mu_A \geq 0$
C2	$\hat{\tau}_A$	Flow resistance	Stress	$\hat{\tau}_A > 0$, $\hat{\tau}_A < \hat{\tau}_B$
C3	m_A	Stress exponential	-	$m_A \geq 0$

Input Parameters: Network B

Constant	Meaning	Property	Unit	Range
C1	μ_{Bi}	Initial shear modulus	Stress	$\mu_{Bi} \geq 0$, $\mu_{Bi} \geq \mu_{Bf}$
C2	μ_{Bf}	Final shear modulus	Stress	$\mu_{Bf} \geq 0$
C3	β	Shear modulus evolution rate	-	$\beta \geq 0$
C4	$\hat{\tau}_B$	Flow resistance	Stress	$\hat{\tau}_B > 0$
C5	m_B	Stress exponential	-	$m_B \geq 0$

Input Parameters: Network C

Constant	Meaning	Property	Unit	Range
C1	μ_C	Shear modulus	Stress	$\mu_C \geq 0$
C2	q	Relative contribution of I_2	-	-

Input Parameters: Flow Properties

Constant	Meaning	Property	Unit	Range
C1	a	Pressure dependence	-	-
C2	n	Temperature exponential	-	$n \geq 0$

Input Parameters: Temperature Factor and Nominal Temperature

Constant	Meaning	Property	Unit	Range
C1	$\hat{\theta}$	Temperature factor	Temperature	-
C2	θ_0	Nominal temperature	Temperature	-

Input Parameters: Locking Stretch

Constant	Meaning	Property	Unit	Range
C1	λ_L	Locking stretch	-	$\lambda_L \geq 1$

Input Parameters: Bulk Modulus

Constant	Meaning	Property	Unit	Range
C1	κ	Bulk modulus	Stress	$\kappa > 0$

$$\sigma_A=\frac{\mu_A}{J_A^e \overline{\lambda_A^{e*}}}\left[1+\frac{\theta-\theta_0}{\hat{\theta}}\right]\frac{\mathcal{L}^{-1}\left(\overline{\lambda_A^{e*}}/\lambda_L\right)}{\mathcal{L}^{-1}(1/\lambda_L)}\operatorname{dev}\left[\mathbf{b}_A^{e*}\right]+\kappa(J_A^e-1)\mathbf{1}$$

$$\sigma_B=\frac{\mu_B}{J_B^e \overline{\lambda_B^{e*}}}\left[1+\frac{\theta-\theta_0}{\hat{\theta}}\right]\frac{\mathcal{L}^{-1}\left(\overline{\lambda_B^{e*}}/\lambda_L\right)}{\mathcal{L}^{-1}(1/\lambda_L)}\operatorname{dev}\left[\mathbf{b}_B^{e*}\right]+\kappa(J_B^e-1)\mathbf{1}$$

$$\sigma_C=\frac{1}{1+q}\left\{\frac{\mu_C}{J\overline{\lambda^*}}\left[1+\frac{\theta-\theta_0}{\hat{\theta}}\right]\frac{\mathcal{L}^{-1}\left(\frac{\overline{\lambda^*}}{\lambda_L}\right)}{\mathcal{L}^{-1}\left(\frac{1}{\lambda_L}\right)}\operatorname{dev}[\mathbf{b}^*]+\kappa(J-1)\mathbf{1}+q\frac{\mu_c}{J}\left[I_1^*\mathbf{b}^*-\frac{2I_2^*}{3}\mathbf{I}-(\mathbf{b}^*)^2\right]\right\}$$

$$\dot{\mathbf{F}}_A^v=\dot{\gamma}_A\mathbf{F}_A^{e-1}\frac{\operatorname{dev}[\sigma_A]}{\tau_A}\mathbf{F}$$

$$\dot{\gamma}_B=\dot{\gamma}_0\cdot\left(\bar{\tau}_B-\tau_c\right)^{m_B}\cdot\left(\frac{\theta}{\theta_0}\right)^n$$

$$\dot{\mathbf{F}}_B^v=\dot{\gamma}_B\mathbf{F}_B^{e-1}\frac{\operatorname{dev}[\sigma_B]}{\tau_B}\mathbf{F}$$

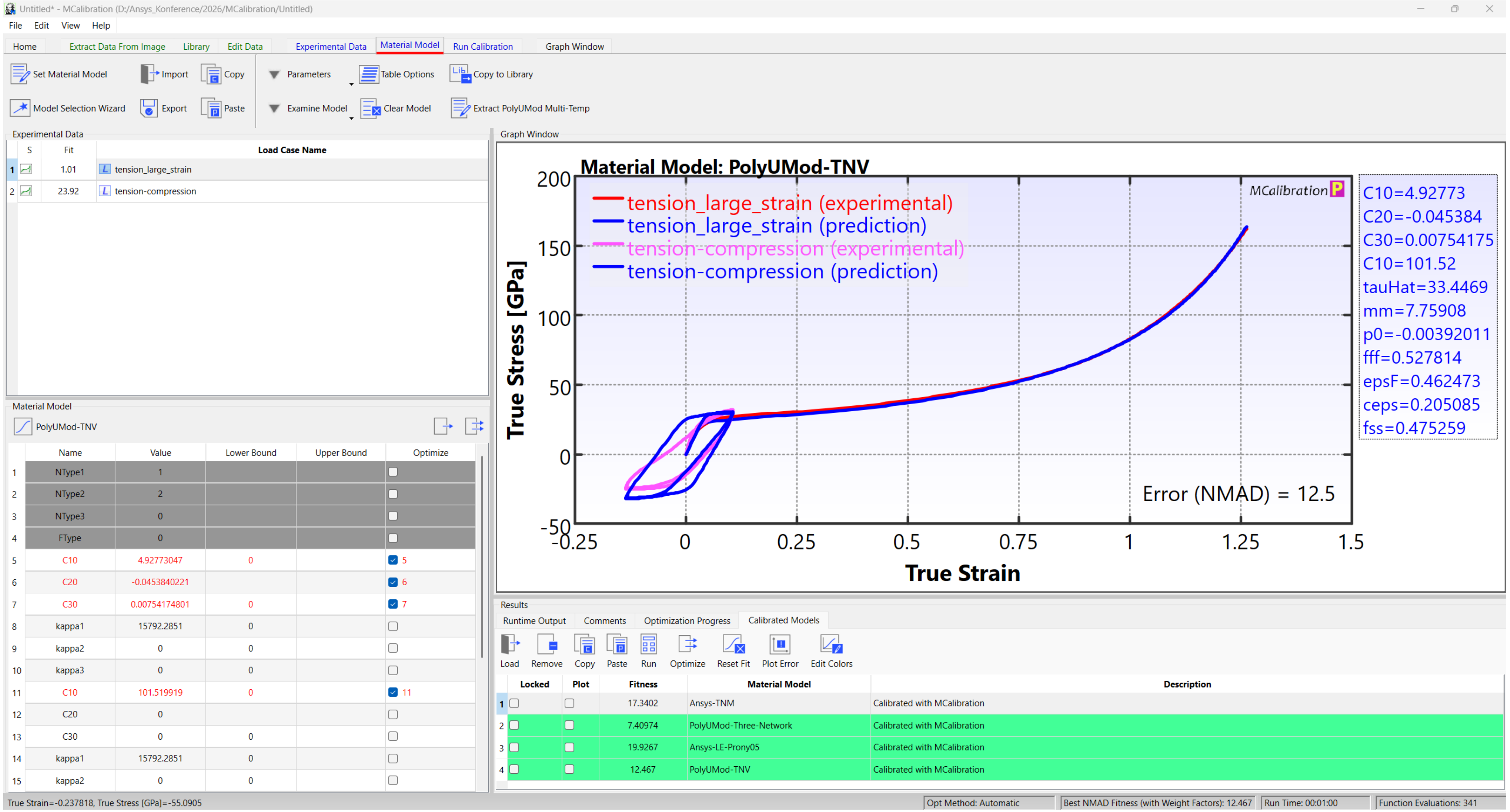
$$\bar{\tau}_B=\frac{\tau_B}{\max(\hat{\tau}_B+aR(p),0.001\hat{\tau}_B)}$$

MCalibration

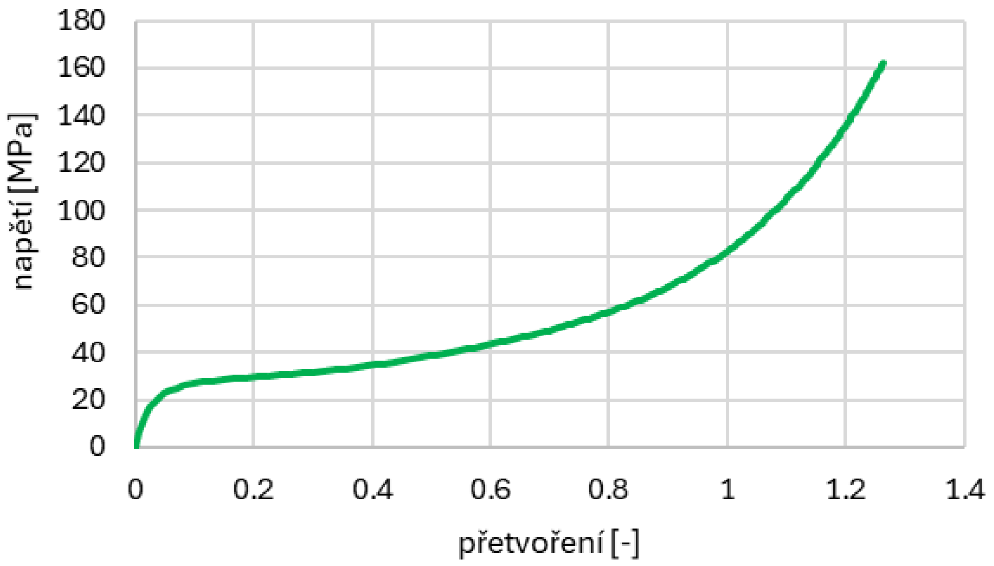
16 parametrů

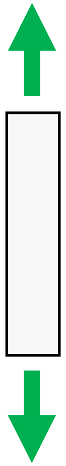
MCalibration

- Data z měření → materiálový model

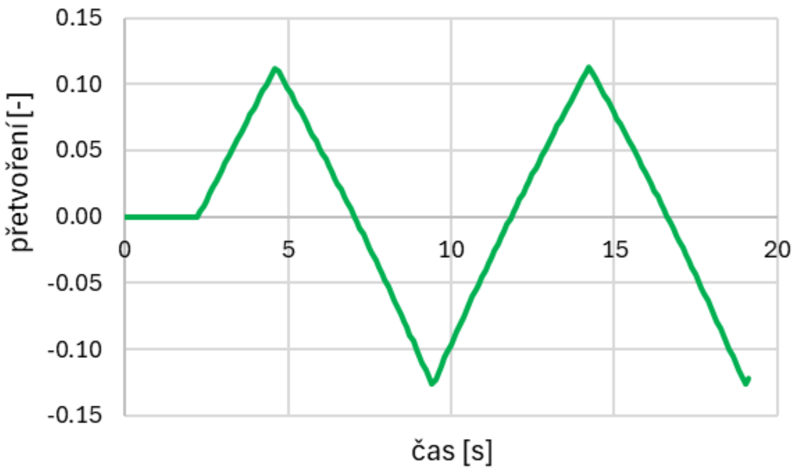


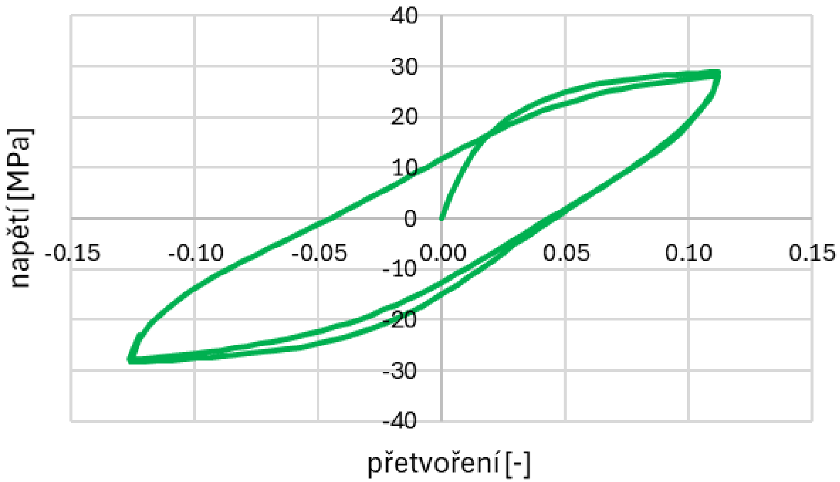
- **Tahová zkouška s velkou deformací**





- **Cyklické zatěžování**





Díky za pozornost a zůstaňme ve spojení

Tomáš Vítek