Mechanics of sliding friction

Polymer Technology

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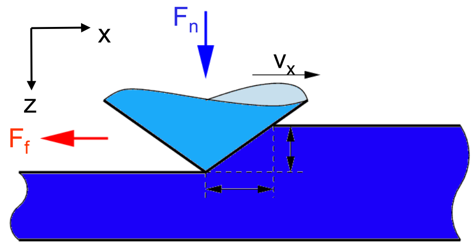
Introduction

Polymers are frequently used in in applications where frictional properties are important like in hip joints, bearings and gearboxes. Until now it is basically unknown why some polymers have better tribological properties than others. This leaves us with the following question: "Which intrinsic properties of polymers contribute to friction and how, by knowing these properties, can we tailor polymers to minimize friction?"

Principles

The friction force is attributed to a deformation and an adhesion related component



$F_f = F_{def} + F_{adh}$

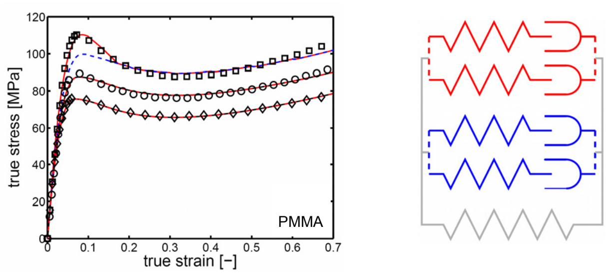
- conformation
- thermodynamic state
- deformation kinetics

- configuration
- physics
- chemistry

The tip geometry, normal load (F_n) and sliding velocity (v_x) are control parameters; the friction force (F_f) and penetration into the surface are measured.

Constitutive model

To simulate the deformation related component a multi-mode model is employed



$$\boldsymbol{\sigma} = \boldsymbol{\sigma}_r + \boldsymbol{\sigma}_s^h + \boldsymbol{\sigma}_{s,\alpha}^d + \boldsymbol{\sigma}_{s,\beta}^d$$

$$= G_r \tilde{\mathbf{B}}^d + \kappa(J-1)\mathbf{I} + \sum_i^n G_{\alpha_i} \tilde{\mathbf{B}}^d_{e,\alpha_i} + \sum_j^m G_{\beta_j} \tilde{\mathbf{B}}^d_{e,\beta_j}$$

Figure 1: constitutive relations capturing the intrinsic stress-strain response of glassy polymers

Experimental

Response of polycarbonate with a 50μm tip and a constant normal force of 300mN at 4 different sliding velocities

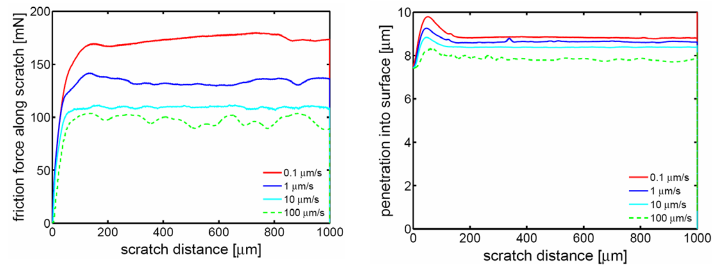


Figure 2: Friction force vs. scratch distance (left); penetration into surface vs. scratch distance (right)

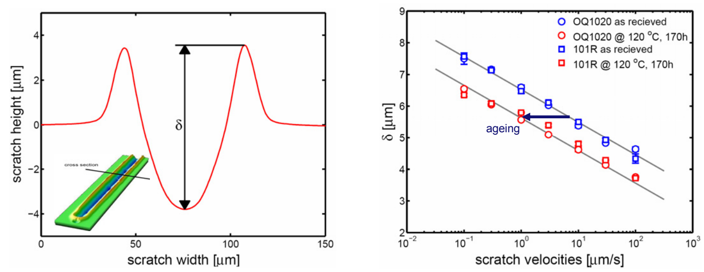


Figure 3: Cross section of 3D residual deformation profile (left); dependence of the residual deformation on thermodynamic state and sliding velocity (right)

Interpreting friction measurements

Comparing numerical simulations with experimental results gives quantitative predictions, but more importantly friction between metal and polymer only indirectly, via increasing the plastic deformation zone, contributes to the friction force measured.

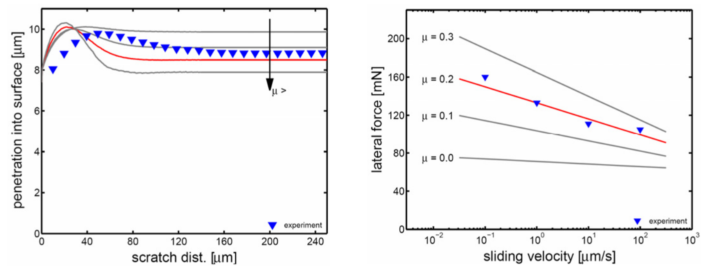


Figure 4: Simulations (solid lines) compared to experiments (▼). Penetration into the surface for different μ at a sliding velocity of 0.1 μm/s (left); dependence of the friction force on sliding velocities for different μ (right).

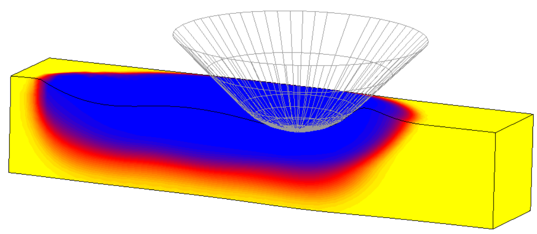


Figure 5: numerical simulations of sliding friction experiments