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Status and developments in tribology of polymer composites

A.K. Schlarb[1,2,3,*]

[1] Chair of Composite Engineering, University of Kaiserslautern, Kaiserslautern, Germany.
[2] INM-Leibniz Institute for New Materials, Saarbrucken, Germany.
[3] Research Center OPTIMAS, University of Kaiserslautern, Kaiserslautern, Germany.

*Corresponding e-mail: alois.schlarb@mv.uni-kl.de

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ABSTRACT – Plain bearing applications based on plastics offer engineering benefits, such as freedom from maintenance, tolerance for lack of lubrication, and noise reduction. Under higher pressures per unit area and at higher surface speeds, however, the potential use of plastics is limited. However, it is possible to improve the performance capabilities of polymer-based tribomaterials noticeably through reinforcement with different additives. Nevertheless, the matrix material still behaves sensitive to temperature. The paper describes the development of polymer based tribomaterials and proposes an approach for the simulation of the temperature distribution and wear behavior in a polymer/steel tribological system.

1. INTRODUCTION

Polymeric materials are increasingly used in tribological applications due to their high strength-to-weight ratio, ease of manufacturing, and self-lubricating properties. In particular, in the automotive industry, the pressure for resources saving and CO_2 reduction leads to smaller and smaller assemblies with the same or even higher performance. The specific requirements for tribological components therefore increase enormously in recent times. While a few years ago in some applications unreinforced plastics could be used, the higher stresses in the form of high revs and high contact pressures today require tribomaterials with superior specific strength.

As has been shown e.g. by Erhard [1] the performance of a tribological system depends basically on two fundamental mechanisms, adhesion at low contact pressure and smooth surfaces and deformation at high pressure and rough surfaces.

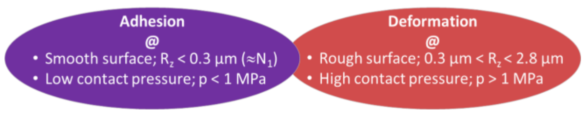

Figure 1 Basic mechanism in tribology of polymers.

The incorporation of different additives in plastics is the key to the tailor these properties resulting in a balanced performance in terms of friction and wear behavior, strength and operating tolerance under different conditions. Friedrich et al showed that the addition of fibers (carbon CF, glass GF) and internal lubricants such as Graphite Gr or polytetrafluoro-ethylene P(TFE) can tremendously influence the tribological behavior. In a polyetheretherketone PEEK matrix a combination of CF, Gr, and PTFE performed best at ambient and elevated temperature.

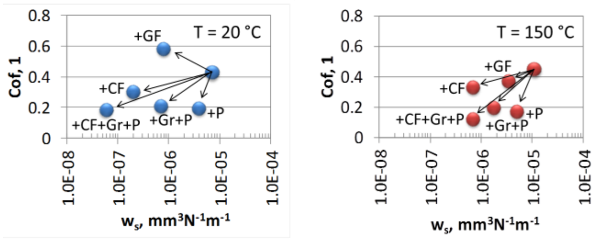

Figure 2 The effect of fillers on cof and wear w_s.

In the last decade it was found [3] that the tribological behavior furthermore can be improved by adding submicron particles into the polymer. Last but not least it was shown by Zhang et al [4] that the interaction of fillers from micro-size to nano-size triggers new mechanisms resulting in significantly improved tribological behavior.

However, as can be seen in Fig 2 the tribological performances of polymer-based composites also depend on temperature. This is due to the fact that the behavior of thermoplastic materials in general is related to temperature significantly. For the basic understanding of effects leading to different wear mechanisms and finally tribological behavior a better knowledge of the thermal balance and temperature distribution in a tribological system is required.

This paper deals with the modelling and simulation of the thermal balance and at least local temperatures and wear behavior in a composite/steel tribological system.

2. METHODOLOGY: EXPERIMENTS, MATERIALS, PROCESSING, MODELLING AND SIMULATION

Tribological tests were performed using a block-on-ring BoR apparatus. The counterbody was a 100Cr6 body with a mean surface roughness, R_a, equals to 0.3 µm. During the test, friction force was measured and the friction coefficient cof was calculated based on the friction force and load. Temperatures at different positions of the body were measured with both, thermocouples. However, the temperature in the contact surface can't be measured. Therefore a model of the tribological system was defined and the temperature along the body finally calculated by using FEM-simulations. The input materials data for the simulations were calculated on mixing rules from the data of the individual components. The simulation was performed by using the Software ANSYS. A specimen's mass loss, Δm, was measured after the test, and the wear rate w_s was calculated using the equation 1 (see appendix). Two body materials, pure PEEK (A) and a PEEK-based composite (B) were compounded via an optimized extrusion compounding process. The materials were injection molded into plates and the bodies with 4x4x10 mm^3 finally cut out of the plates.

3. RESULTS AND DISCUSSION

3.1 *Tribological Testing*

Figure 3 shows the cof and a schematic reduction of the behavior as a function of time for the two different materials; table 1 the corresponding wear rates.

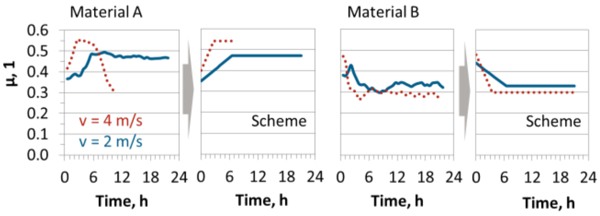

Figure 3 Cof; measured and schematic for simulation.

Table 1 Wear rates of 2 materials at 2 conditions.

Test conditions		Material A	Material B
p, MPa	v, m/s	w_s, mm^3/Nm 10^6	w_s, mm^3/Nm 10^6
1	2	10.51	1.00
1	4	7.24	2.04

It clearly can be seen that at about 3 - 6 hours a steady state is obtained. The wear rate of material A is much higher compared to material B.

3.2 *Model and Simulation Results*

The model is based on a simplification of a Block on Ring BoR laboratory tribometer consisting of a body and a counterbody. An intermediate material is not considered. Due to the tribological stress heat $\dot{q}_g$ in the interface between the interacting bodies is generated continuously. The heat is discharged via the body ($\dot{q}_1$), the counterbody ($\dot{q}_2$) and ultimately the surrounding area ($\dot{q}_{13}$, $\dot{q}_{23}$). Fig 3 shows a scheme of the situation.

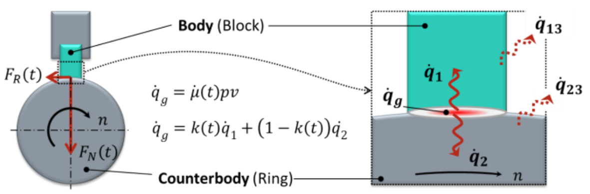

Figure 3 Basic model of the tribological system.

Based on this model the absolute temperature distribution in the body is determined in 2 steps:

a) Measurement of the friction coefficient $\mu = \mu(t)$ and temperature T at 1-5 locations in/on the body.
b) Simulation of the temperature $T = T(x, y, z)$ based on the generated heat flow $\dot{q}_g$ and adjustment of the heat distribution coefficient k until the simulated and measured values at discrete points coincides.

Basic equations for simulation listed in the appendix.

The procedure results in the distribution of temperature in 3-dimesnions. Figure 4 shows the simulated distribution in the body in the steady state and the progress of temperature along the length of the body on the center end edge path of 2 different materials. Dots represent measured data.

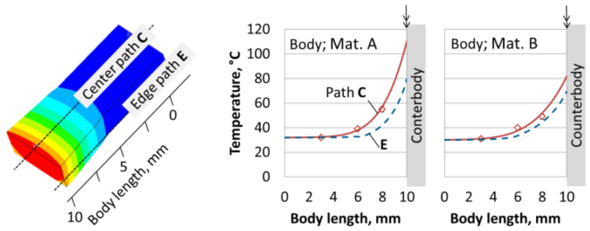

Figure 4 Temperature distributions in the body.

It clearly can be seen that the temperature in material B is significantly lower. Knowing that the glass transition temperature T_g of PEEK equals 143°C and that flash temperature might be much higher than the mean values this might explain a reason for the significantly higher wear rate of material A.

The evolution of wear can be predicted by transferring the local thermo-mechanical conditions, which have been determined by simulation, to a Representative Volume Element RVE and applying the maximum stress criterion as failure criterion.

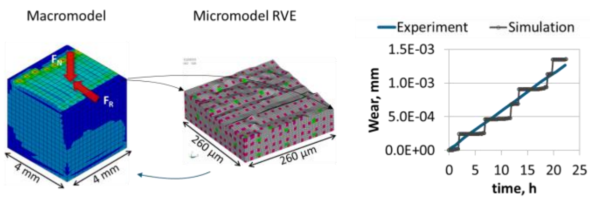

Figure 5 Macro-model, RVE, and wear evolution.

4. CONCLUSIONS

The results show that:

a) FEM-modelling allows access to the local temperatures in the whole body and thus the temperature in the contact surface.
b) This inside view enables a better understanding of a tribological system under different conditions.
c) The model already allows the wear simulations of a pure polymer e.g. PEEK.
d) Further research is necessary to implement reliable failure criteria for composite materials.

5. REFERENCES

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LIST OF ABBREVIATIONS

Constants

A: contact area
F: load (normal force)
h: heat transfer coefficient
k: distribution factor
L: silding distance
m: weight
p: contact pressure
$\dot{q}$: heat flow
t: time
T: Temperatur
U: Perimeter
v: sliding speed
λ: thermal conductivity

Indices

s: specific
1: body
2: counterbody
3: environment

MODEL BASICS/EQUATIONS

A. Calculation of the wear rate

$$w = \frac{\Delta m}{\rho F L} \qquad (\frac{mm^3}{Nm}) \qquad (1)$$

B. Estimation of the temperature distribution in the body

1. Frictional heat

$$\dot{q}_g = \dot{\mu}(t) p v \qquad (\frac{J}{s}) \qquad (2)$$

with

$$\dot{q}_g = k(t)\dot{q}_1 + \big(1 - k(t)\big)\dot{q}_2 \qquad (\frac{J}{s}) \qquad (3)$$

and

$$\dot{q}_{13} = h_{13}(T_1 - T_3) \qquad (\frac{J}{s}) \qquad (4)$$

follows

$$T_1 = \frac{\dot{q}_g}{k(t)h} - T_3 \qquad (K) \qquad (5)$$

2. Temperature distribution profile after Carslaw and Jaeger

$$\Delta T = T_1 \frac{\cosh(m(l-x))}{\cosh(ml)}$$

with

$$m = \sqrt{\frac{hU}{\lambda \mathrm{A}}}$$