Friction Temperature of POM—PE Sliding Contacts

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ABSTRACT The design of traction mechanisms of continuous conveying units (e. g. plastic chains) is so far based on a purely mechanical dimensioning. However, mechanical limits are only applicable in a limited way to avoid system failure. With higher speeds or pressure, especially the thermal stress increases, which results in system failure based on softening or melting of the materials at a certain temperature. By means of systematic studies, correlations between friction temperature, coefficient of friction, wear and process parameters are examined. On this basis, a model for calculating the friction temperature is developed.

KEYWORDS friction temperature, thermal collapse, thermoplastics, sliding friction

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KURZFASSUNG *Reibflächentemperaturen von POM-PE Gleitkontakten:* Die Konstruktion von Zugmitteln für kontinuierliche Fördereinheiten (z. B. Kunststoffketten) beruht bisher auf einer rein mechanischen Dimensionierung. Allerdings sind mechanische Grenzwerte zur Vermeidung von Systemausfall nur in bedingt anwendbar. Bei größeren Geschwindigkeiten oder Druck erhöht sich insbesondere die thermische Beanspruchung, was bei einer bestimmten Temperatur zum Systemausfall durch Erweichung oder Schmelzen der Werkstoffe führt. In systematischen Untersuchungen wurde die Korrelationen zwischen Reibungstemperatur, Reibungskoeffizient, Verschleiß und den Prozessparametern untersucht. Auf dieser Basis wurde ein Modell zur Berechnung der Reibungstemperatur entwickelt.

SCHLAGWÖRTER Reibtemperatur, thermisches Versagen, thermoplastischer Kunststoff, Gleitreibung

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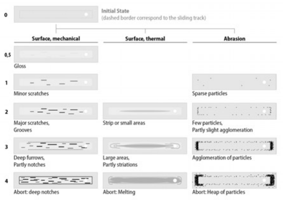
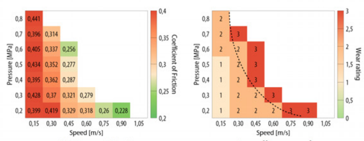
Wear Rating



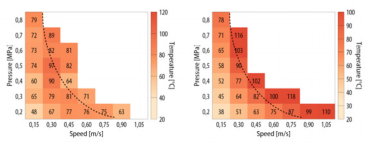
Experimental Results



Coefficient of friction

Overall wear rating

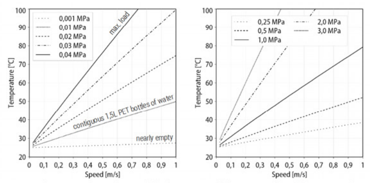
Friction Temperature



Measured friction temperature

Calculated friction temperature

Outlook Theoretical temperature maxima in a conveyer system with Multiflex chains



Normal contact (e. g. in straights)

Radial contact (in sliding curves)

TECHNISCHE UNIVERSITÄT CHEMNITZ

PROFESSUR FÖRDERTECHNIK

RÖCHLING STIFTUNG
Konsequent in Verantwortung

Motivation

The design of traction mechanisms of continuous conveying units (e. g. plastic chains) is so far based on a purely mechanical dimensioning. However, mechanical limits are only applicable in a limited way to avoid system failure. With higher speeds or pressure, especially thermal stress increases, which results in system failure based on softening or melting of the materials at a certain temperature. By means of systematic studies, correlations between friction temperature, coefficient of friction, wear and process parameters are examined. On this basis, a model for calculating the friction temperature is developed.

Experimental Studies

The experimental studies comprise a two-dimensional variation of the parameters sliding speed and contact pressure. These parameters were chosen according to values occurring in conveyor systems with plastic chains and slide rails. To avoid influences by additives or fillers, a pure POM copolymer and a pure UHMW-PE were selected as sliding pairing.

The test program was subdivided into Step-Tests and 24h-Tests. Step-Tests are intended to allow a quick estimation of the application limit of the material pairings and the possibility of validating whether the faster Step-Tests are sufficient for a predication of the load limit. During a run of a Step-Test, the sliding velocity was hourly increased, while the pressure was fixed.

While the coefficient of friction and the temperature can be measured by the test bench, it is not possible to measure wear of POM against UHMW-PE. Therefor, the subjective wear rating used by our research team was revised and enhanced.

Experimental Results

- Step-Tests can be used to estimate the coefficient of friction. Due to the short load steps, the wear shifts to higher load combinations. The temperature reaches high values in lower load combinations. To predicate wear and temperature, Step-Tests are not adequate.
- The coefficient of friction decreases with increasing sliding velocity or contact pressure. At low speeds the coefficient of friction stays nearly constant.
- With increasing velocity and pressure, the wear grows. The wear was the abort criterion for a test run.
- Like the wear, the friction temperature rises with ascending velocity or pressure. If temperatures in a load combination reach 80 to 90 °C, the temperature drops in higher load combinations. Temperature maxima occur in wear ratings of 2.
- At low wear ratings of 1, an extended running-in behavior can be noted. The running-in reduces in higher wear ratings. At ratings of 3 no running-in appear.
- Friction temperature and wear are connected. There is no relation to the coefficent of friction, except the running-in behavior.

Friction Temperature Model

A semi-analytical model was developed with which the maximum frictional temperature in stationary state can be calculated at a periodically repetitive movement pattern. This model was approved by results of the experimental studies.

Due to the model assumptions, the determination of the maximum temperature in conveying systems can be done. In a first approach, the Multiflex chain system was theoretically examined. Calculated results show a good conformity with the observed behavior. The validation with measurements on a realistic conveyor has not been done yet and is the next step.

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1. Experimental Method

1.1. Test Program

The experimental studies comprise a two-dimensional variation of the parameter sliding speed and contact pressure. These parameters were chosen according to the values occurring in conveyor systems with plastic chains and slide rails. The speed covers values from 0.1 to 1 m/s and the pressure values from 0.2 to 0.8 MPa [Bosc12, Sump15]. The preferred material for chains is polyoxymethylene (POM) and for sliding rails it is ultra-high-molecular-weight polyethylene (UHMW PE). To avoid influences by additives or fillers, a pure POM copolymer and a pure UHMW-PE were selected.

The test program was subdivided into Step-Tests and 24h-Tests. The Step-Tests are intended to allow a quick estimation of the application limit of the material pairings and the possibility of validating whether the faster Step-Tests are sufficient for a predication of the load limit.

In a run of a Step-Tests, a specific pressure was set and the speed was increased from 0.15 m/s to 1.05 m/s with hourly increments of 0.15 m/s, while the first speed step ran an additional hour for running in. As soon as the pairing showed a strong wear, the run was abandoned. With every run the pressure was increased from 0.2 MPa to 0.8 MPa in increments of 0.1 MPa. On basis of the possible parameter combinations the trails for the 24h-Tests were made. For each parameter combination at least four experiments were carried out. The coefficient of friction and the friction temperature of all testing trails from one combination were determined by a linear regression over all respective values of the last 30 minutes of the experiment.

1.2. Measurement Principle

The experiments were carried out on an oscillating tribological test bench for plate-shaped samples [Sump11]. In this test bench, the upper sample is moved on the lower sample by a stroke length of 100 mm. The lower sample is fixated on a spring-mounted measuring table and experiences a displacement due to the resulting frictional force. The coefficient of friction results from the normal force, which is applied to the upper sample, and the displacement. With a pyrometer, the temperature in the friction contact side of the upper sample is measured contactless. During the entire test run the coefficient of friction and the temperature are recorded continuously. In figure 1 the test principle is shown schematically. The dimensions of the upper sample were 15 x 10 x 3 mm and that of the lower sample 180 x 25 x 5 mm.

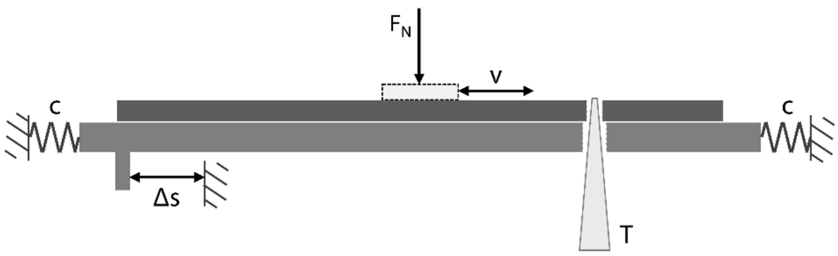

Figure 1: Schematic measurement principle

1.3. Rating of Wear

A quantitative evaluation of wear in the tested thermoplastic friction pairings is not possible [Sump11, GüLu15]. Measurements of weight and thickness of conditioned samples before and after the experiments showed no measurable differences or the differences were very scattering and so small that they were within the fault tolerance of the measuring devices. Therefore, a subjective wear rating was developed [Sump11]. Since this evaluation is only designed for abrasion, it has been revised and enhanced. The surface of the lower and upper sample as well as the abrasion of the sliding pairing are rated using a specified wear value on basis of visual traits. On the surface a distinction between mechanical and thermal appearance is made. The wear values range from 0 ("no wear") to 4 ("wear-related abort") and is shown schematically in figure 2. The wear rating of a pairing is determined by the maximum wear value of the five visual criteria. Wear ratings up to 1 can be used for continuous running, whereas wear ratings of 2 represents a threshold in which the material pairing can still be used for short-term operations. With a wear rating equal or greater than 3 the two materials are not suitable for a sliding application.

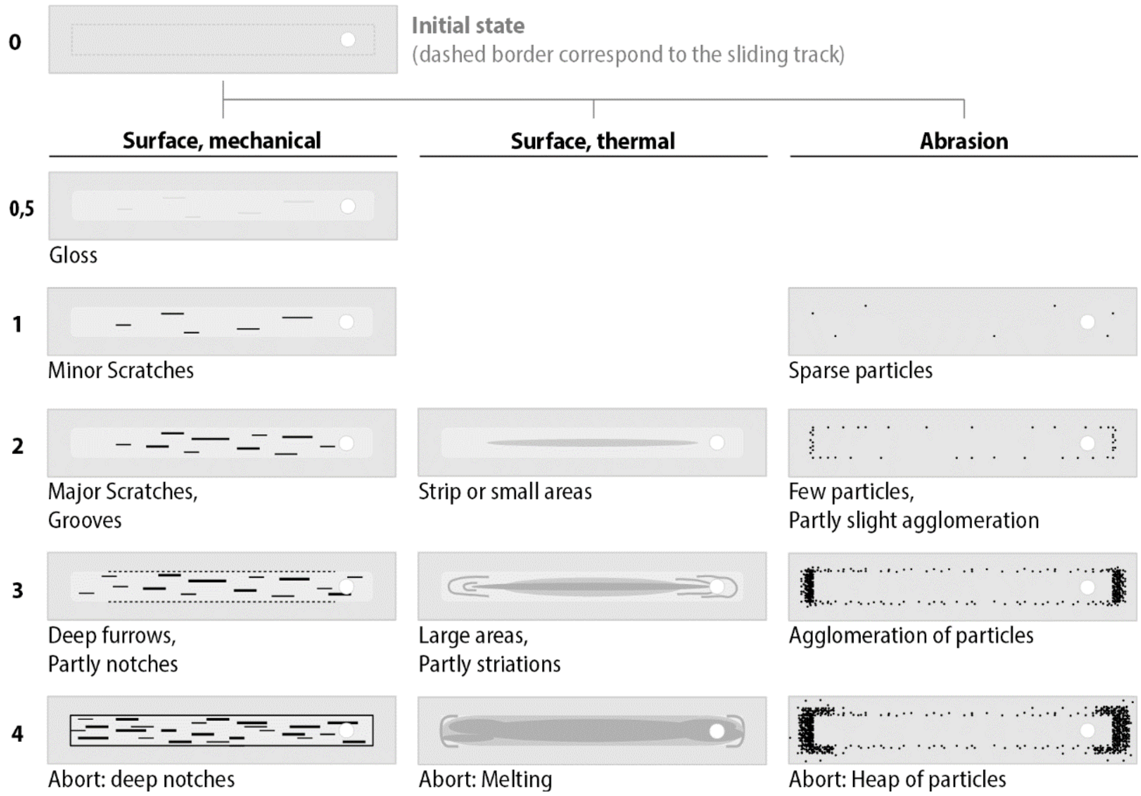

Figure 2: Wear rating pattern

2. Experimental Results

2.1. Step-Tests

In the Step-Tests, high coefficient of friction are obtained by 0.36—0.39 at low speed. These decrease with increasing speed as well as increasing pressure. At the same time, the frictional temperature rises, reaches a maximum at certain loads and drops again as the speed increases. The temperature drop is always associated with a high thermal wear of the UHMW PE sample, so the test run had to be stopped. With higher contact pressures, the temperature maximum increases. At the maximum temperature, the coefficients of friction are approx. 0.25—0.3. The results are shown as pv-matrices in figure 3.

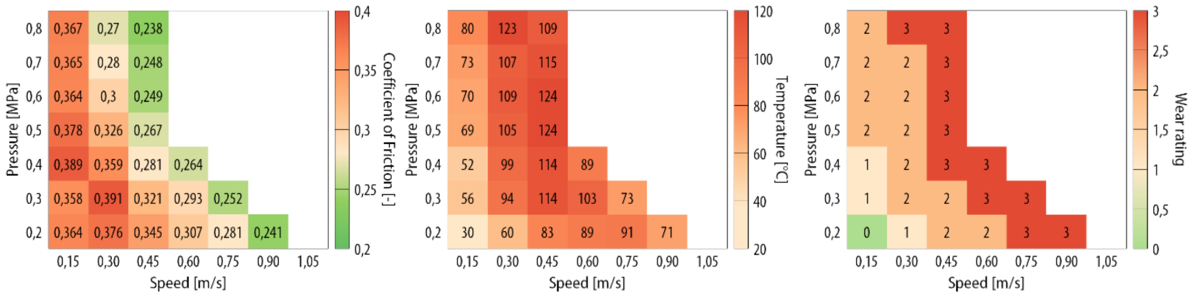

Figure 3: Coefficient of friction (left), friction temperature (middle) und wear (right) of the step tests

2.2. 24h-Tests

The 24h Tests show an analogous behavior to the Step-Tests regarding coefficient of friction, temperatures and wear (see figure 4). However, the temperature maxima and the wear limit shift to lower load combinations, which result in a smaller number of tested load combinations. Also, lower temperature maxima of 80 to 100 °C are formed. It is noticeable that the coefficient of friction remains approximately the same compared to the Step-Tests. Good wear ratings of 1 are achieved only at the lowest speed (0.15 m/s) and pressures of less than 0.6 MPa. In the threshold of acceptable wear, it is possible to drive up to 0.6 m/s in the lowest pressure tier, while the speed drops continuously to 0.15 m/s with increasing pressure load. If the range of wear rating till 2 is considered, a connection of temperature and wear emerges, in which temperature rises with increasing wear rating. Temperature maxima appear in wear threshold (ratings of 2).

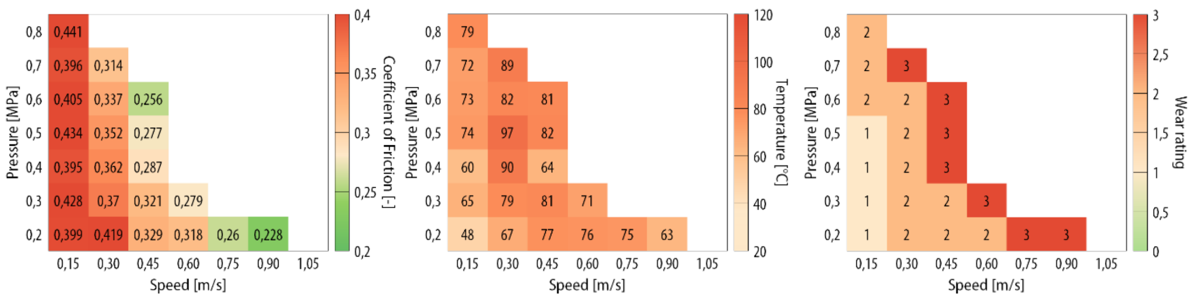

Figure 4: Coefficient of friction (left), friction temperature (middle) und wear (right) of the 24h tests

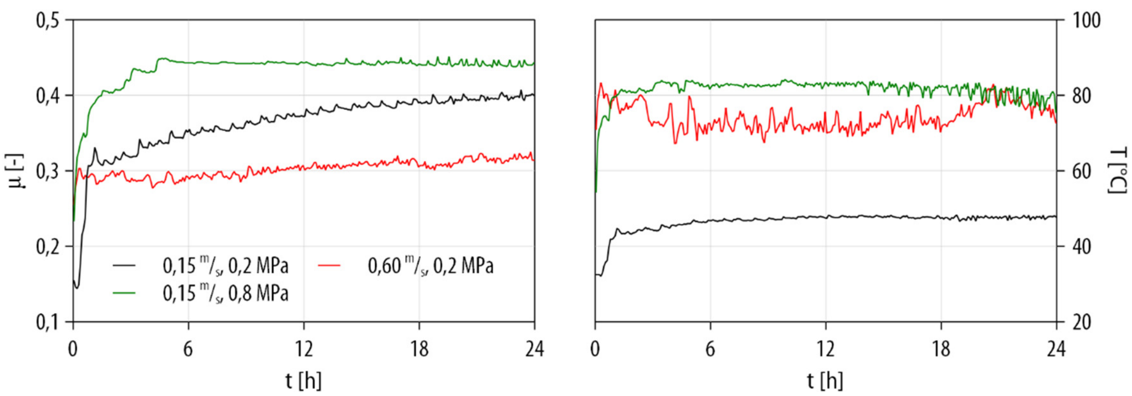

Figure 5: Running-in of the coefficient of friction (left side) and the temperature (right side) for selected loads of sliding speed and contact pressure

The running-in time, in which the coefficient of friction strongly increases, is reduced with increasing pressure as well as with increasing speed. If the softening temperature of the material is reached, a constant coefficient of friction is established. With an extended running-in behavior, the wear rating equal to 1 is present. Short running-in times are accompanied by the threshold of acceptable wear (rating of 2). Load combinations near or with the wear rating of 3 show no running-in and often an overshoot of the temperature during the first hours. The issue is depicted in figure 5.

3. Friction Temperature Model

The calculation of the friction temperature between two sliding bodies has been the subject of research for a long time [Jaeg42, KoHo01, LAMB09, OsBo09]. A lot of models have been developed which, however, do not provide realistic solutions for plastic-plastic friction and are consequently not applicable. Therefore, a semi-analytical model was developed with which the maximum frictional temperature in the stationary state can be calculated at a periodically repetitive movement pattern:

$$T_f = T_{amb} + C_f \, q_f$$

with the ambient temperature T_{amb}, the contact coefficient

$$C_f = \frac{\psi}{k_1 \, \psi \, + k_2 \, + \alpha_{amb} \, (1 - \psi)}$$

and the friction heat flux

$$q_f = \mu \, p \, v \, .$$

The friction heat flux q_f includes the coefficient of friction μ, the contact pressure p and der sliding velocity v. The contact coefficient C_f contains ψ as slice of contact time, k_1 as the heat transition coefficient of the moving body, k_2 as the heat transition coefficient of the stationary body and α_{amb} as the convection coefficient at the surface of the stationary body. The heat transition coefficients consist of the sample thickness, the heat conductivity and the heat transfer to the attached components. Attached components are at the example of the test bench, the measuring table and the upper sample socket. The heat transfer of the attachments can be determined by a numerical simulation. For complex geometries and interfacial contacts, the overall heat transition coefficient should be determined by a FEM calculation.

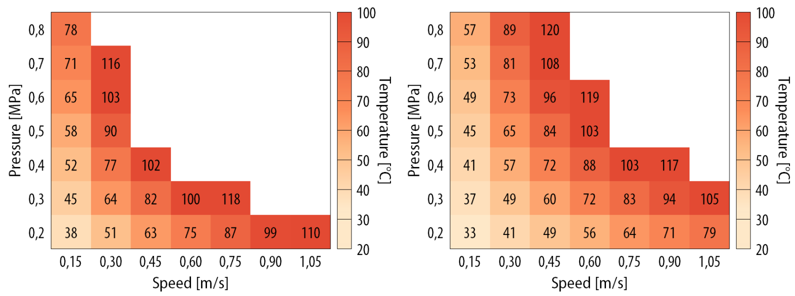

Figure 6: Calculated friction temperature for the load ranges of the test series (left side: normal; right side: with theoretical doubled thermal conductivity of the UHMW PE)

If the model is applied to the experimental setup, the friction temperatures shown in Figure 6 are obtained. The coefficient of friction at the lowest load level was taken as the basis and was set constant over the entire load spectrum. This makes it possible to visualize the temperature limit and thus the load limit. The calculated values show a good correlation compared to the 24h-Tests. Exemplarily, figure 6 also illustrates the shifting of this limit by doubling the thermal conductivity of the UHMW PE assuming similar friction conditions.

4. Brief Outlook

With the new friction temperature model, the determination of the maximum temperature in conveying systems can be examined. A first approach on Multiflex chains, present at the INSTITUTE OF MATERIALS HANDLING, CONVEYING AND PLASTICS ENGINEERING, has been done. Since every chain system features its own geometry and load parameters, the convoying system has been analyzed. Especially the geometry has an impact in resulting forces and contact pressures. For the selected chain system the range of pressure reaches from 0.0006 to 0.037 MPa in normal contacts (horizontal) and from 0.24 to 2.5 MPa in radial contacts (vertical in sliding curves). Due to the fact that both contacts differ in its contact areas, the induced heat viewed over the length of one chain pitch can take on the same amount. For both contacts the model parameters have been determined. The results are shown in figure 7. These results have not yet been validated with measurements on a realistic conveyor.

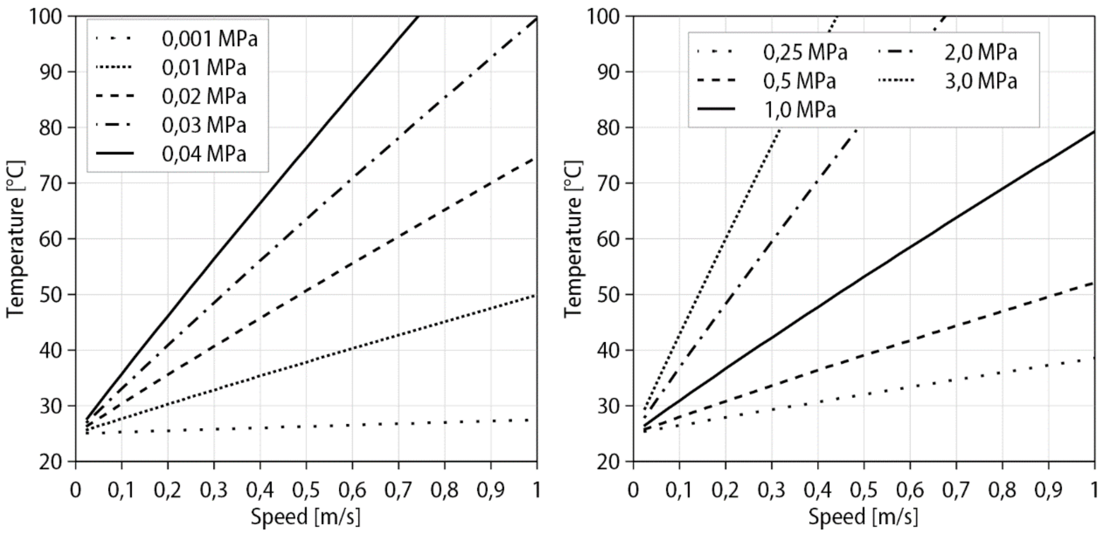

Figure 7: Theoretical maximum friction temperature occurring in normal contact (left) and radial contact (right)

5. Summary

The relationships between coefficient of friction, temperature and wear at variable sliding speeds and contact pressures were systematically examined by using a sliding pairing of POM and UHMW PE. Step-Tests, which were carried out initially and in which a pressure load is changed over one run hourly, can be used to roughly estimate the coefficient of friction and the wear. However, they do not provide long-term behavior, which has been tested with 24h Tests.

These studies showed a significant influence of friction temperature on friction behavior and wear. The often found statement, that the sliding speed has a greater influence than the contact pressure cannot be made. For this purpose, pressures in conveying systems vary widely. Also the general pv-value does not give any information about the real load limits due to its perpetual contact approach. Therefore, it is useful to define the load and application limit of a thermoplastic friction pairing based on temperature. With a suitable model, the friction temperature can be determined and applied to practical designs. For this purpose, a semi-analytical friction temperature model has been derived, which was validated with the results of the experimental studies and which was theoretically applied to a conveying system. Further studies on other thermoplastic sliding pairings and the model validation have to be carried out, in order to increase the application spectrum and the plausibility of this method.

Acknowledgement

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