

Polymer-Polymeric Friction at Temperatures and Rates Simulating the Thermoforming Process

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Abstract

Plug assist thermoforming is one of the most important process variants for the thermoforming industry. The purpose of the plug assist is to pre-stretch the heated polymer sheet prior to the application of pressure and/or vacuum during the final part function. Parametric studies performed on simulation models the thermoforming process material distribution in the thermoformed part.

This report presents the results of investigating the friction behaviour of a polymer to plug assist material at thermoforming conditions. A new measurement technique to determine friction coefficients will be shown and explained in detail. This technique allows the characterization of the friction coefficient as a function of temperature and rate and shows the sensitivity respectively. The results are then applied to modelling parameters for simulation of the thermoforming process.

Introduction

Plug assist thermoforming is one of the most beneficial forming process for the thermoform industry. In plug assist thermoforming, there are different material pairings and transitions, like plug-sheet or sheet-mould, with different properties. One of the key-factors that influence the efficiency of plug assist thermoforming is the friction between the plug and the polymer.

Friction is a so called "system-parameter" and therefore not easy to describe in a theoretical way. To estimate the friction influence and to quantify the coefficient of friction, measurement devices representing the real process are necessary. In the following, a new developed measurement device able to quantify the coefficient of friction is described.

As friction is influenced by many variables like: temperature, the normal force, the structure of the polymer and the plug, the speed of sliding or revolution etc. the IKP technique allows to gain those numbers. Sheet materials like HDPE and PS versus steel and Hytac B1X syntactic foam plugs respectively were tested. The tests were performed in a wide range of temperature to see the dependency of the friction on the temperature. The results obtained experimentally were implemented in a special simulation program to optimise the parameters that influence the thermoforming process.

Experimental Procedure

Materials

In this study, two different grades of plug and polymer sheet were examined. For the amorphous polymers segment a high-impact Polystyrene (HI-PS) was chosen. The

glass transition temperature was $T_g \sim 95^\circ\text{C}$. Sample thickness was 1mm and diameter $d \sim 25\text{mm}$. The surface roughness was as delivered from the material supplier. As semi-crystalline material, a commercial grade of high-density Polyethylene (HDPE) was tested. The melting temperature was $T_m \sim 136^\circ\text{C}$, sample thickness 1mm and diameter $d \sim 25\text{mm}$. Both polymers were tested versus a polished steel and a syntactic foam (Hytac B1X) with a diameter of 20mm respectively.

Measurement Device

The dynamic and static coefficients of friction were obtained using a torsional rheometer RMSII from Rheometrics. The plug and the polymer discs were mounted between the parallel plate fixtures of the RMS II with the 200 gm-cm transducer. The disc specimens were glued on the fixtures. The instrument was operated in a steady shear where a lower parallel plate fixture was first rotated continuously at 0.1 Hz. The parallelism of the samples during the measurement was very important and therefore, a spring was put between the polymer disc and the fixture to reduce the observed strong oscillation on the signal. The transducer was erode for both torque and normal force and then, the run started (figure 1).

Temperature influence

Measurements were made over a wide range of temperatures. The two main aims were first to ensure a constant measurement result at different temperatures and second a close measurement at “thermoforming conditions”. Thermoforming conditions for HI-PS is at temperatures between 130°C - 170°C and for HD-PE at 130°C . Therefore measurements were basically performed at 23° , 50° , 90°C and than in 5-10K steps coming closer to the area of main interest of each polymer. The time required for heating the specimen was set to 15 minutes and observed thoroughly.

Theory

The measurement device was set up in a parallel-parallel mode. Signal of torque and normal force of the upper fixture were measured directly at the machine by means of an oszillograph. For calculation the torque of the upper fixture applied by rotation of the lower turning fixture and the normal force applied by pressing upper and lower fixture are available. The coefficient of friction was now calculated using the relationship between torque and normal force as follows [1]:

$$\mu = \frac{3}{2R} \cdot \left(\frac{\Gamma}{F_N} \right) \quad [1]$$

where: μ = coefficient of friction; R = sample radius of the smallest contact area; Γ = torque and F_N = normal force. The factor 1.5 is the reciproke of the mean radius and was insert for correction of the velocity gradient over the round plates.

Results and Discussion

As a result of a single point measurement at a chosen temperature and velocity, the calculated coefficient of friction over measurement time is shown in figure 2. As it can be seen μ increases until a sharp maximum which displays the transition of static and dynamic coefficient. Following on, the lower plate is still rotating but the upper is now turned in a certain angle. μ decreases and stays almost constant at a certain value – called the dynamic coefficient of friction. It is enabled to get μ_{static} as the peak and μ_{dynamic} as the mean of the curve after peak.

For HD-PE versus steel the results over the whole temperature range are shown in figure 3. The static coefficient there is always higher than the dynamic one and both are only close the melting temperature almost identical. From a temperature of 105°C the coefficient increases significantly which is explained by the lower shear stiffness and the changing molecular structure of the material. Measurement of semi-crystalline polymers can only be done close to the melting point. One has to consider that in real process the surface temperature might be higher than the melting point.

For HI-PS versus Hytac B1X the results over the whole temperature range are shown in figure 4. The static and dynamic coefficient increase simultaneous until the glass transition point, whereas after T_g the static coefficient increases much more than the dynamic but is only measurable until a maximum temperature of 130°C. Measuring at higher temperatures presents just the dynamic coefficient. Here most probably a pure shear of the material and a total stick between the polymer and the plug is present. Indication for pure shear is also the decreasing coefficient with further increasing temperature which could be linked to the lower viscosity of polystyrene at higher temperatures.

Conclusion

At IKP a new technique for measuring the coefficient of friction is established. It is enabled to measure over a wide range of temperatures and rates. Friction coefficients for semi-crystalline polymers can be done close to the melting point except the temperature limitation of mounting the samples on the fixture. In case of amorphous polymers measuring is possible in the viscous state but has to be improved in terms of shear. Investigation and comparison to shear measurement results has to be done and the question of total stick and shear answered.

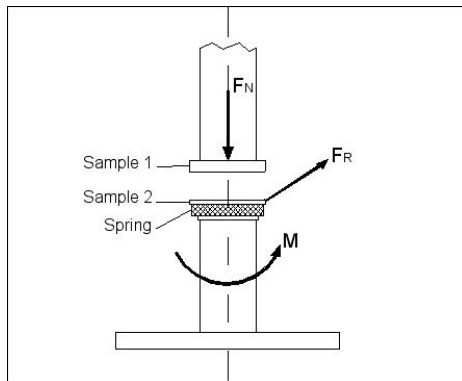


figure 1: sketch of measurement device

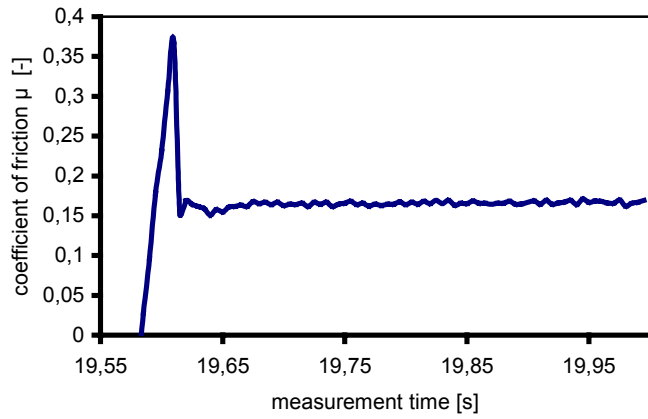
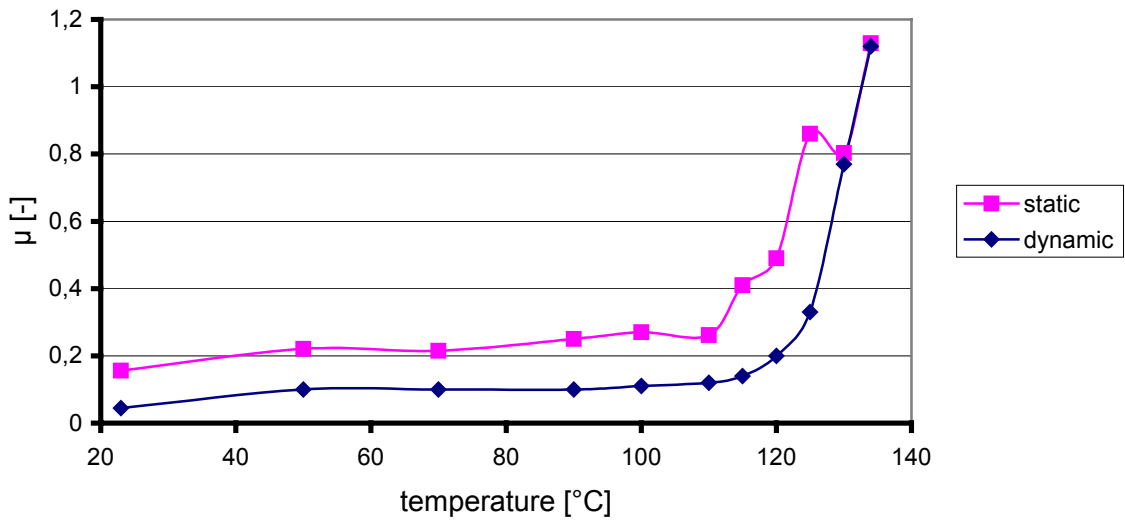


figure 2: coefficient of friction in principle

steel vs. HD-PE, 0.1Hz



Hytac B1X vs. PS, 0.1Hz

