PROCESS SIMULATION MODELING PARAMETERS FOR PLUG ASSIST THERMOFORMING OF HIGH DENSITY POLYETHYLENE

Abstract

High density polyethylene (HDPE) is one of the most difficult polymers to thermoform. Improvements in the processing of HDPE will afford the thermoformer additional opportunities to use this low cost polymer in new applications.

Process simulation of the plug assist thermoforming of HDPE has not been effective in providing improved thermoforming conditions for this polymer. These simulations are dependent on modeling parameters for the polymer's elongation characteristics and the polymer to plug assist interactions during forming. These parameters have been limited in the past to values that are not measured under thermoforming conditions.

The paper reports the development of process simulation modeling parameters for HDPE and the plug assist interactions under thermoforming conditions. The test methods for developing the modeling parameters are described and the improved parameters are reported. Finally, the value of this technology is illustrated by its application to the development of a thermoformed, deep drawn, HDPE food service container.

Introduction

Dave to discuss the background of f-k using HDPE for applications, modeling done, parameters used, limitations and the determination that measuring parameters at thermoforming conditions will improve model predictions.

Experimental

The objective of this work was to develop modeling parameters for the HDPE polymer at thermoforming conditions. Two areas of interest were investigated: the force deformation characteristics of the polymer and the frictional force between polymer and tool and polymer and plug assist.

The Institute for Polymer Testing and Polymer Science, University of Stuttgart has developed a test apparatus (1,2) that mimics the plug assist thermoforming process. This apparatus is capable of gathering force, deflection and time data at different temperatures and velocities during the complex deformation state of a polymer sheet. From this data, it is possible to obtain material parameters for the polymer model as well as coefficient of friction values.

For the polymer, the K-BKZ model is used. This model has been found to accurately follow the force deformation characteristics of polymers in the thermoforming process. The K-BKZ model is then used within a process simulation software package, T-SIM, to predict thermoformed part dimensions.

For the coefficient of friction, values were developed for the range of process temperatures over which the HDPE can be formed. These values are then used in the T-SIM, process simulation software.

Material

The HDPE investigated in this study is Fortiflex® G60-25-144. It is a homopolymer that has applications in sheet extrusion and blow molding. The Fortiflex softening point is 127°C - 132°C and its melting point is 134°C – 136°C. The sheet thickness for all tests was 1.0 mm.

Test Apparatus

All the testing was performed with a servo-hydraulic high-speed testing machine and configuration as depicted in Figure 1 (3).

Test Method

The test set-up is brought to test temperature and allowed to equilibrate. A sample of HDPE sheet is clamped in the fixture and allowed to reach the test temperature. The test is run and the data collected. The data is then plotted into a force/deformation (F/D) curve. All the tests were run under isothermal conditions, i.e. the test chamber, polymer sheet and plug assist were all at the same temperature. Testing was performed at three temperatures, 118°C, 125°C and 132°C, and three speeds, 20 mm/s, 200 mm/s and 500 mm/s for each of the plug material and sheet conditions. The total number of tests run for each plug material condition was 9 and resulted in 9 force/deformation (F/D) curves. A typical F/D curve is shown in Figure 2.

The first series of tests used a steel plug coated with silicone oil. It was assumed that the silicone oil would represent a zero coefficient of friction condition between plug and polymer. The results at zero coefficient of friction would then result in the F/D characteristics of the HDPE.

The second series of tests used a steel plug without the silicone oil coating. These test results together with the zero coefficient of friction test results would allow for the determination of a coefficient of friction between the HDPE and steel by fitting the data through the T-SIM software. This coefficient of friction will be used for the HDPE to tool value.

The third series of tests used a typical plug assist material for the plug, HYTAC-B1X an engineering thermoplastic matrix syntactic foam. From these tests and the zero coefficient of friction tests, a coefficient of friction value for HDPE to HYTAC-B1X was determined.

Finally, the results of the zero coefficient of friction tests for obtaining the K-BKZ parameters for the HDPE were compared to the K-BKZ parameters obtained using the measured coefficient of friction values.

Discussion of Results

HDPE Material Properties, Zero Coefficient of Friction Measurements

The F/D curves of the HDPE to oil coated steel were used to determine the HDPE K-BKZ parameters. A typical F/D curve is shown in Figure 3. The curves show that above 40mm of deformation, there is an artifact in the test data, which may not be a result of the polymer elongation characteristics. It is theorized that above 40mm of deformation either the silicone oil is no longer at the interface between the steel plug and the HDPE and some friction is present or there is significant strain hardening in the polymer. Only the 500mm/s rate data was used in determining the K-BKZ parameters from this series of tests.

Coefficient of Friction Measurements: HDPE to Steel

Simulation trials were run with different coefficient of friction measurements and the new K-BKZ parameters from the zero coefficient of friction measurements. These were compared to the measured F/D curves for the HDPE to steel tests at 500mm/s. Up to the 40mm deformation, a coefficient of friction of 1.0 gives good results over the three temperatures: 118°C, 125°C and 132°C. Figure 4 shows the comparison between the simulated F/D curve versus the measured curve.

Coefficient of Friction Measurements: HDPE to HYTAC-B1X Plug Assist Material

The coefficient of friction between plug assist material and polymer was measured for two surface roughness conditions: as-machined and polished. Simulation trials were run in a similar manner as the HDPE to steel trials for each of the surface conditions. The tests at 500mm/s up to 40 mm of deformation were used. The machined HYTAC-B1X to HDPE coefficient of friction was found to be temperature dependent with values of 0.4 at 118°C, 0.3 at 125°C and 0.8 at 132°C. For the polished plugs, the coefficient of friction was 0.8 at 118°C, 0.8 at 125°C and 1.5 at 132°C. Figure 5 shows the comparison between the simulated F/D curve versus the measured curve.

HDPE Material Properties, HDPE to Steel with Coefficient of Friction Equal to 1.0

The curve fitting with the measured coefficient of friction eliminated the artifact found in the steel coated with oil tests. Figure 6 shows the comparison between the simulated F/D curve versus the measured curve. The K-BKZ parameters for the HDPE from these results are different than those used previously for T-SIM simulation.

Conclusions

1. The use of a silicone oil coated steel plug to obtain polymer K-BKZ model parameters under thermoforming conditions in the IKP thermoforming characterization test was only useful up to deformations of 40mm or less. There appears to be a frictional effect between the steel plug and the polymer at higher deformations.

2. The use of coefficient of friction values at thermoforming conditions developed from the IKP test in the development of polymer K-KBZ parameters has resulted in different parameters than previously used. Further work is needed to determine if these newly developed parameters result in improved predictions from the T-SIM model.

3. The measured F/D curves for the HDPE polymer under the 9 different conditions exhibit differences in their ability to be fitted with the T-FIT algorithm. The data at 500mm/s was used to develop the new K-BKZ parameters to limit the fitting problems over the whole range of data. Further work with a more easily modeled polymer such as polystyrene is needed to optimize the methods used in the IKP test for the determination of improved modeling parameters.

References

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3. B. Hegemann, P. Eyerer, N. Tessier, T. Bush, SPE ANTEC 2002 Proceedings, In Process.

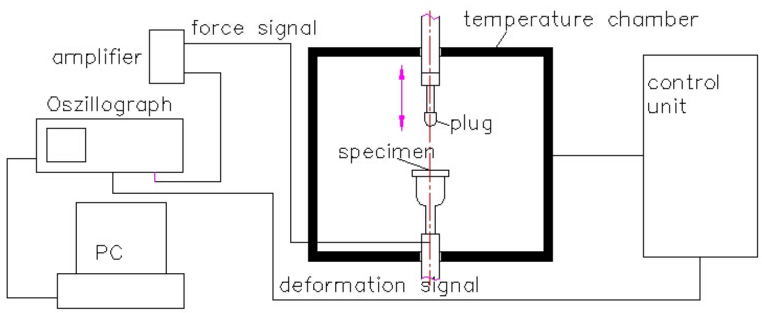

Figure 1. IKP Test Apparatus

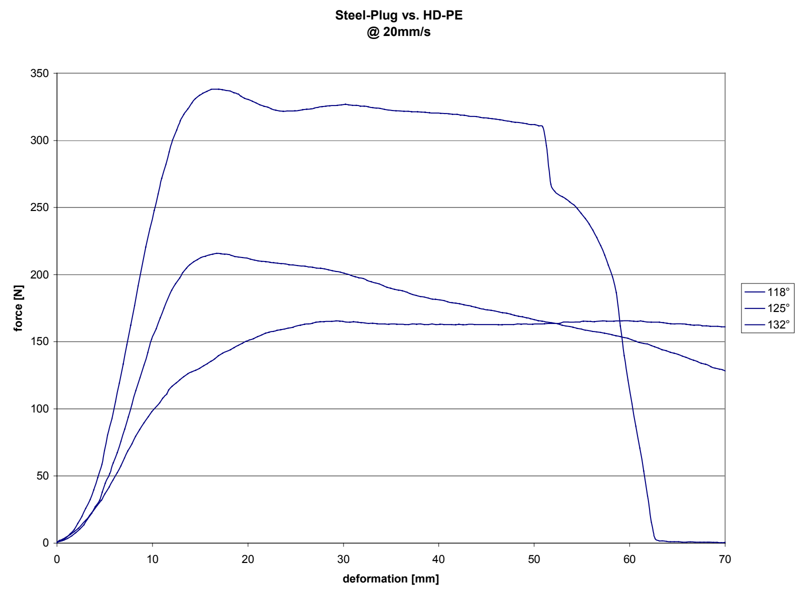

Figure 2. HDPE Force Deformation Curves: Steel Plug, Plug Speed 20mm/s

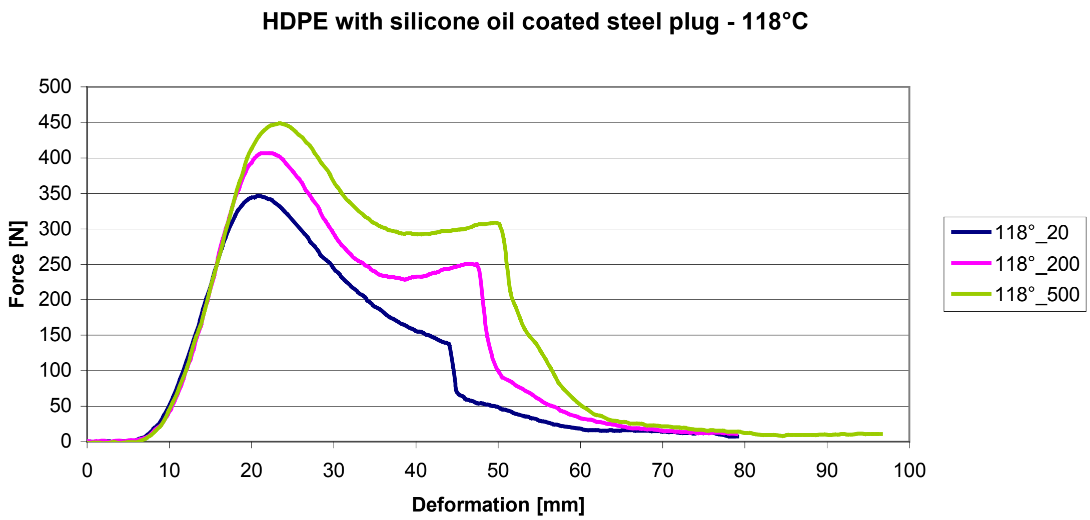

Figure 3. HDPE Force Deformation Curves Silicone Coated Steel Plug 118°C

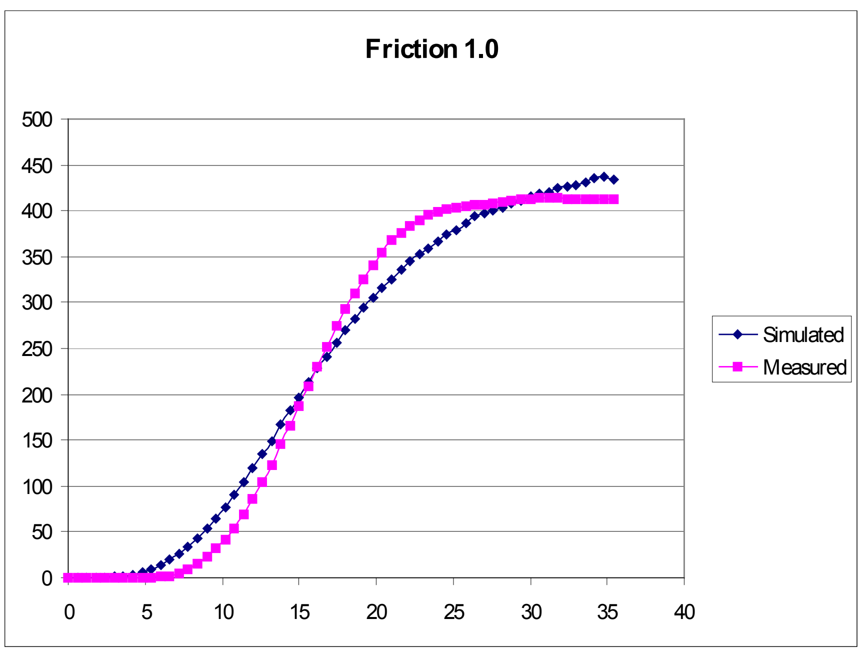

Figure 4. Comparison of Measured versus Simulated F/D Curves HDPE with Steel Plug, 500mm/s and 125°C

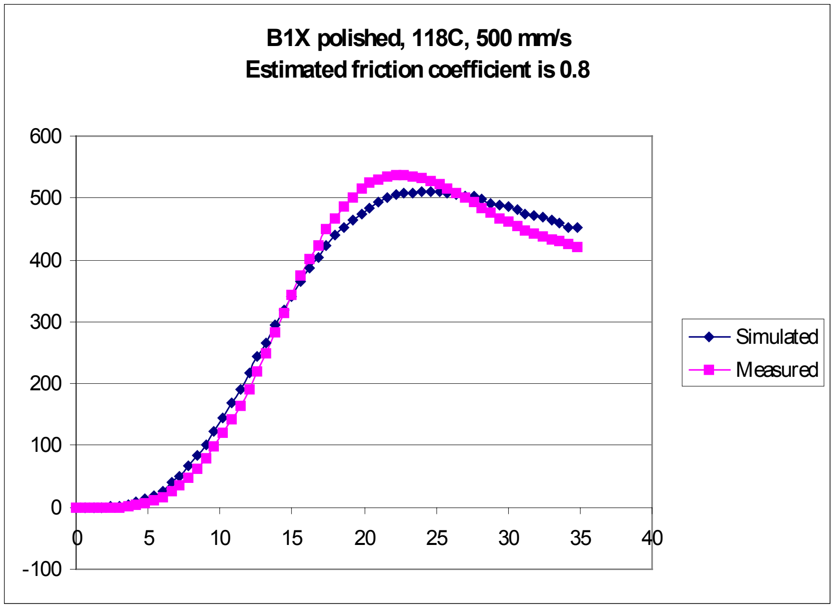

Figure 5. Comparison of Measured versus Simulated F/D Curves HDPE with HYTAC-B1X Plug, 500mm/s and 125°C

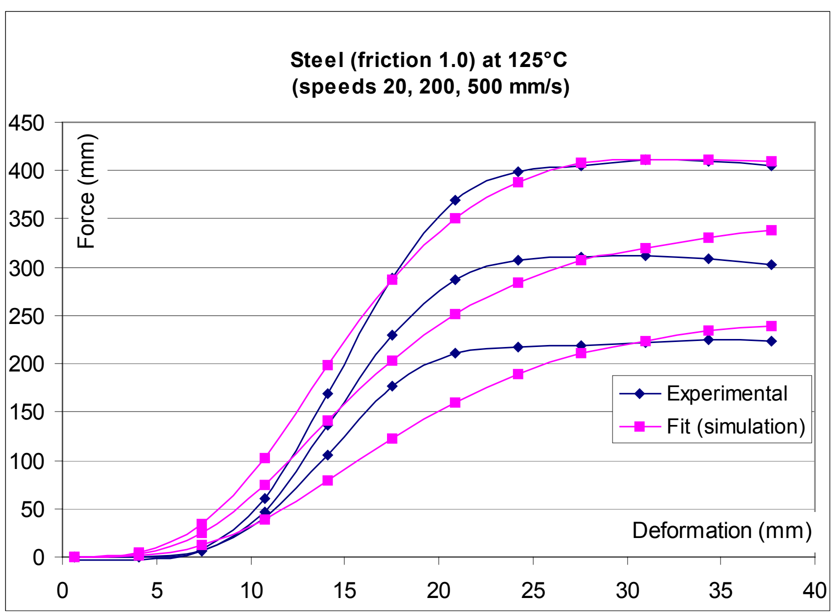

Figure 6. HDPE Force Deformation Curves Simulated versus Measured with Steel Plug. Friction = 1.0. 125°C