Suggestions for...

Study of surface interaction between plug and sheet in plug assisted thermoforming

CMT / Accuform / IKP / FabriKal cooperative project

(The following suggestions were prepared by Accuform, Czech Republic, November 2004)

Introduction

As discussed between CMT and Accuform during K-show in Germany this year, we would like to continue in cooperation to study the surface interaction between plug and sheet. Below are tasks CMT and Accuform suggested. Please feel free to comment, if you have any additional suggestions, please let us know. If any of the tasks is successfully solved, publication on various conferences is planned.

Project tasks

**Task 1. Evaluation of surface interaction coefficients (SIC) for various CMT plug materials**

This evaluation is based on a previous study done by CMT et al. The results of the study were presented at SPE Thermoforming conference 2004.

As the necessary data already exist, the additional evaluation work can be done by Accuform in cooperation with CMT.

In the evaluation, five (5) CMT materials are used for plugs. PP sheet, used in the tests, was characterized by IKP. The aim is to evaluate surface interaction parameters (until now referred as friction coefficients in T-SIM) for CMT materials.

As confirmed by CMT, CMT plugs perform differently with different polymeric sheets. Due to this, an idea to separate the friction coefficient (between sheet and plug) into two values was suggested. One value would be connected with plug, one with sheet. These values could be called “SIC”. The actual “friction coefficient” \( \mu \) used in simulation could be calculated as follows:

\[
\mu = \text{SIC}_{\text{CMT material}} \times \text{SIC}_{\text{Sheet material}}
\]

This assumption has to be verified. If there are any troubles to separate SIC for plug and for sheet, we can easily keep SIC for sheet equal to 1 and use SIC for the plug directly as the friction coefficient. Other possibility is that the SIC for sheet could be “hidden” in the K-BKZ model parameters (as different materials behave differently).

*Input for this task:*

- Presentation from SPE Thermoforming 2004
- MS Excel sheet with measured thicknesses on cups
- CAD mold + cup data (2D drawings should be good enough as the geometry is not complicated)
- PP data from IKP test (obtained from CMT or IKP)
Output from this task:
- Refitted PP material file, perhaps including a new parameter SIC\(_{PP}\) (surface interaction parameter for PP)
- Data related to CMT plug materials (heat transfer between CMT material and PP sheet, SIC for CMT plug materials). The data should be available for direct usage in T-SIM in order to allow users to simulate CMT plug directly.

Task 2. Evaluation of F/d curves dependency on various factors
This task focuses on the testing method used by IKP. The aim is to analyze the actual simulation model used to predict measured F/d curves. Accuform will run T-SIM to calculate F/d curves under various conditions and prepare a set of results for subsequent analysis.

Input for this task:
- The only input for this task is the (well known) geometry of F/d tests preformed at IKP.

Output from this task:
- Dependency of F/d curves on:
  1. Sheet material (general materials from viscous through viscoelastic to elastic, including materials with different damping parameters influencing strain hardening behavior)
  2. Plug material with various SIC from 0.0 to 1000.0
  3. Plug material – plugs made of CMT materials (SIC from Task 1)
These three (3) tests will provide us with an overview of friction (SIC) influence and material properties influence on the simulated F/d curves.

Remark: Some results from this study could be confidential as they may contain Accuform's know-how about the reverse engineering method used for F/d curves fitting. Details will be available after an internal discussion in Accuform.

Task 3. Evaluation of plug material performance
As discussed with CMT, materials with a high SIC / friction coefficient (and low heat transfer) could perform better in thermoforming process. The idea is that using such materials would result in a wider range of the final thickness distribution variability as a function of the plug design. This means that with high-friction materials, the tool designer would have more freedom when creating plugs as the plug design influences the final thickness distribution in a wide range.

Accuform will run T-SIM analysis in order to verify the assumption described above.

Input for this task:
- All required data (3D molds and plugs) will be created by Accuform. Common cups (rounded and rectangular shape) will be used in the study. Large set of plugs with various shapes will be evaluated.

Output from this task:
- Results should confirm or disprove the idea to develop higher-friction materials in order to get better thermoforming performance.

Remark: This task focuses on the final thickness distribution variability only. The final product quality from the point of view of cup transparency, haze etc. is not (and using T-SIM cannot be) evaluated.
**Task 4. Plug wear study**
CMT in cooperation with FabriKal is working on a plug wear study now. The results could be later on analyzed and used for better description of change of plug properties in time (number of forming cycles).

*Input for this task:*
- CMT/FabriKal data (cups thicknesses if available)

*Output from this task:*
- Description of change in plug properties (SIC / friction coefficient) as a function of number of cycles. The function could be used in T-SIM for simulation.

**Task 5. SIC parameters for other materials than PP**
It would be good to have some additional thickness data for cups made with CMT plugs, where the sheet material is other than PP. Analysis would be done by Accuform.

*Input for this task:*
- Measured thicknesses on cups
- Cups geometry, plug geometry (dependent on actual cups measured)

*Output from this task:*
- Refitted material files, perhaps including a new parameter SIC$_{\text{Mat}}$ (surface interaction parameter for sheet material)

**Task 6. Temperature influence study**
Accuform will study influence of temperature on the predicted F/d curves and on the final thickness distribution using PP data obtained in Task 1. This should give us an overview how temperature influences the PP forming process (from the simulation point of view).

*Input for this task:*
- PP material file
- Cups geometry, plug geometry (perhaps those from Task 1)

*Output from this task:*
- Thickness profiles at various temperatures
- F/d curves at various temperatures

**Task 7. Evaluation of thickness distribution curves dependency on various factors**
The aim of this task is to analyze the actual simulation model used to predict thickness profiles. Accuform will run T-SIM to calculate thickness profiles under various conditions and prepare a set of results for subsequent analysis.

*Input for this task:*
- Cups geometry, plug geometry (perhaps those from Task 1).

*Output from this task:*
- Dependency of the thickness distribution on:
1. Sheet material (general materials from viscous through viscoelastic to elastic, including materials with different damping parameters influencing strain hardening behavior)

2. Plug material with various SIC from 0.0 to 1000.0

3. Plug material – plugs made of CMT materials

These three (3) tests will provide us with an overview of friction (SIC) influence and material properties influence on the simulated thickness profiles.

Task 8. New friction measurement device

CMT suggested to develop a new friction measurement device to measure contact behavior at conditions similar to real plug assisted thermoforming. Discussion between CMT and Accuform resulted in several ideas how this could be done. Sketches of two possibilities are below.

In cooperation with IKP, the new device design and prototype manufacturing could be done.

Input for this task:
- Ideas of a new friction measurement device
- Various existing sources focusing on friction measurement (books, Internet pages etc.)
  (See also Appendixes A and B.)

Output from this task:
- Friction measurement device design + prototype

Suggested device designs: