Source: Frimo Group GmbH, Lotte, Germany

Quick Overview via 2-D Simulation

Thermoforming Analysis. A simplified 2-D thermoforming analysis tool for automotive interior components quickly shows the tendencies to be expected for stretching of film or sheet. With a few clicks of the mouse in the CAD system, critical regions can be identified at a very early phase of development and potential remedies verified.

PE104198

BERND SCHWARZE

High quality parts for automobile interiors usually feature a skin or film of semi-rigid polyurethane foam on the outer surface that is bonded to an injection molded backing (carrier). This approach offers designers a level of design freedom found with no other process. Almost any conceivably complex geometry can be realized without having witness lines from undercuts visible. The skin or film covers the minimal gaps at the parting lines in the foaming mold, so that no witness line appears.

The skin or film can be created in many ways: Sprayed, slush and cast skins are produced using so-called primary processing methods where a liquid or molten material is introduced into a one-piece mold. The mold consists of a nickel shell with the desired grain (texture) for the surface. At the same time, thermoformed film has been used less and less in the past ten years, because stretching of the film in some regions results in a shallower grain and severe distortion of the texture. Recently, however, this process has seen a resurgence in interest. Thanks to a new generation of TPO films (TPO2), such stretching can be reduced and the quality of the thermoformed film increased.

Simulation instead of Prototyping

As in all fields, engineers are under pressure to shorten development times, and this includes development of parts for au-

Translated from Kunststoffe 3/2008, pp. 101–103

© Carl Hanser Verlag, Munich

© 2008 Carl Hanser Verlag, Munich, Germany www.kunststoffe-international.com/archive Not for use in internet or intranet sites. Not for electronic distribution.

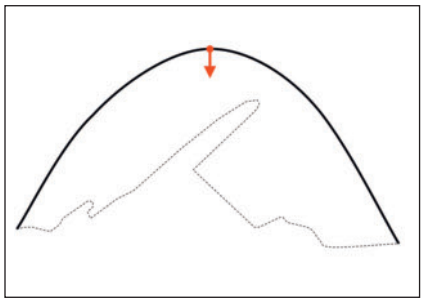

Fig. 1. State at the start of the simulation. Section through an instrument panel at the level of the instrument cluster (Y = constant)

tomobile interiors. Thanks to greatly improved simulation techniques, the number of physical prototypes can be reduced. Recently, for instance, simulation software that replicates three-dimensional thermoforming processes on the basis of film material's characteristics and all boundary conditions has become available. However, this software requires specially trained technicians to perform the calculations, which in turn need some time for preparation and subsequent execution. For instance, the entire three-dimensional geometry of the part, the viscoelastic characteristics of the film and additional process parameters must be known. This data is, however, often not available at the early phase of development where a decision as to the production method is supposed to be made.

A simple two-dimensional computational program can help to quickly obtain a first approximation for the degree of stretching during part development and test the positioning of the part geometry in the thermoform tool.

To keep the calculation as simple as possible, the model described here is based on the following assumptions:

- All geometric calculations are performed using one section (or several sections) through the thermoform tool.
- At locations where the film contacts the thermoform tool during thermoforming, it no longer moves on the thermoform tool.
- The film is solid, that is, incompressible.
- The film's movement is described by splines associated with three points (beginning, middle, end).
- For every change in spline length, the film thickness changes proportionally.
- If the spline touches the thermoform tool, it splits at the point of contact. At the point of contact, the spline is tangent to the surface of the thermoform tool.
- The middle point of the spline continues to move towards the surface of the thermoform tool until it touches the thermoform tool.

At the beginning of the calculation, the film must be "inflated" to such an extent that it does not contact the thermoform tool. Figure 1 shows the starting point for the simulation. The middle point moves downward in the direction indicated by the arrow until first contact is made. The spline divides into two halves and the procedure repeats with both halves (Fig. 2). This iteration continues until all splines are touching the thermoform tool's surface. For each spline, the program saves the thickness d of the respective section that results from the elongation

$$d = \frac{l_{prior}}{l_{after}} \cdot 100 \quad \text{[\% of initial thickness]} \qquad (1)$$

l_{prior} : Length of a segment prior to thermoforming

l_{after} : Length of a segment after thermoforming

Assuming that the density does not change, that is, that the film is solid, the cross-sectional area of the entire film must remain constant during the entire iteration process. As a check, this is verified at the end of the simulation:

$$\begin{aligned} \textit{cross sectional area} &= d_{prior} \cdot l_{prior} \\ &= \sum_i d_{i\,after} \cdot l_{i\,after} \\ &= const. \end{aligned} \qquad (2)$$

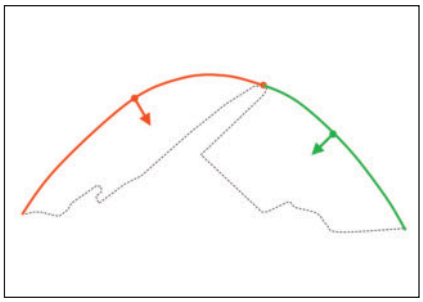

Fig. 2. Upon contacting the thermoform tool, the spline splits into two new segments that continue to be deformed until contact occurs again

In the scientific literature, the degree of stretching λ serves as a measure of the elongation of a material:

$$\lambda = \frac{l_{after}}{l_{prior}} \qquad (3)$$

As practiced in the automotive industry, the degree of stretching is used to assess the elongation. The degree of stretching is defined as

$$A = \left(\frac{l_{after}}{l_{prior}} - 1 \right) \cdot 100 \quad [\%] \qquad (4)$$

If, for instance, a segment has increased in length from 10 to 11 mm, this corresponds to a degree of stretching equal to 10 %; the thickness has then also decreased from 100 % to 90.9 %.

In this way, the degree of stretching can be calculated from the thickness using the following equation:

$$A = \left(\frac{1}{d\ /\ 100} - 1 \right) \cdot 100 \quad [\%] \qquad (5)$$

On a typical CAD workstation, a simulation takes about 10 to 15 min. It runs directly within the CAD system using an associated application program. Figure 3 shows the results of a simulation.

If the thickness of the film is plotted versus the index parameter u (see Fig. 3), the graph presented in Figure 4 results. For comparison, the as-measured results from a thermoforming trial with TPO2 film are also shown. The initial film thickness was 1.2 mm. Considering that this is strictly a geometric simulation which takes neither material characteristics nor process parameters into account, the agreement is good.

Only a Few Mouse Clicks for an Estimate

At the thin locations 1 and 2, the calculation is very close to the measured values. The results are thus well-suited for a fea- ▶

Fig. 3. Results of a simulation: the colors of the dots symbolize varying degrees of stretching together with the corresponding values of film thickness

© 2008 Carl Hanser Verlag, Munich, Germany www.kunststoffe-international.com/archive Not for use in internet or intranet sites. Not for electronic distribution.

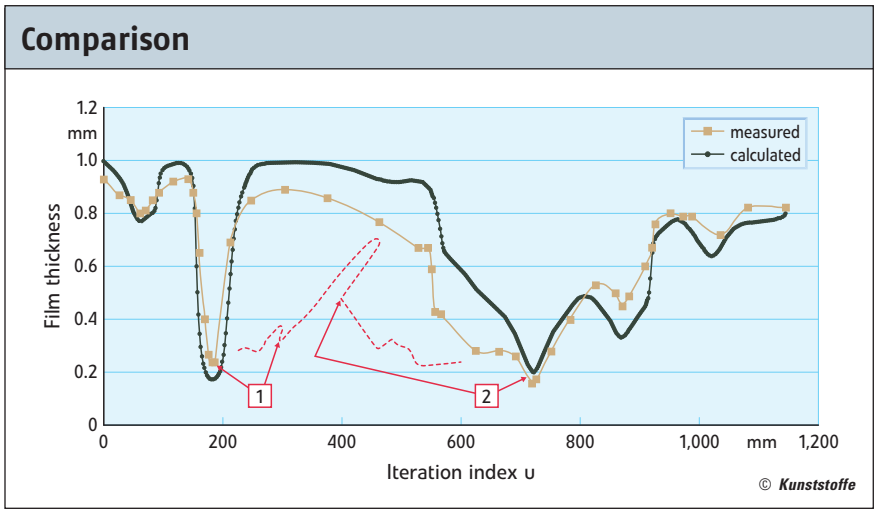

Fig. 4. Comparison of calculated and measured values of film thickness

sibility study or for the purpose of optimizing the thermoform tool orientation. The deviations result, on the one hand, from the fact that stretching in a transverse direction with respect to the section considered is not taken into account. In the case of instrument panels, elongation of this type is usually not very large. On the other hand, the program used for the calculations cannot take into account any kind of the plug assists that are often used for such parts. Plug assists are contoured parts that move into the inflated film and cause the film to shift from one region to another. The actual forming process on the thermoform tool takes place only after this has occurred.

With very tall thermoform tools, the film must be inflated to a very high degree prior to starting the simulation (Fig. 5). This leads to a very high degree of stretching even in the regions that come into contact with the thermoform tool's surface very quickly. In practice, the results deviate, because the film is not inflated to such an extent before the thermoform tool is raised into the thermoforming position. This means that the thermoform tool approaches the film as it is raised, stretching the film as it moves further. As a consequence, regions where the film and thermoform tool come into contact early exhibit lower degrees of stretching, while the remaining regions experience increased stretching. The program also can simulate this process. Figure 5 shows the results obtained with a highly inflated film, and Figure 6 shows the results for the same section with a less highly inflated film. Significant differences occur in the region marked in red.

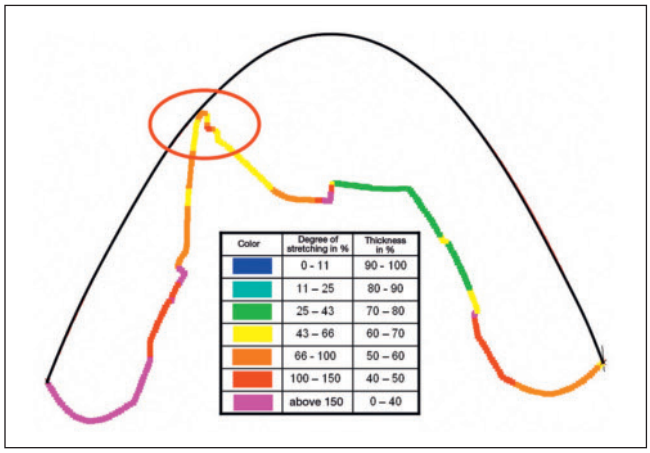

Fig. 5. Results with greater inflation for a tall thermoform tool

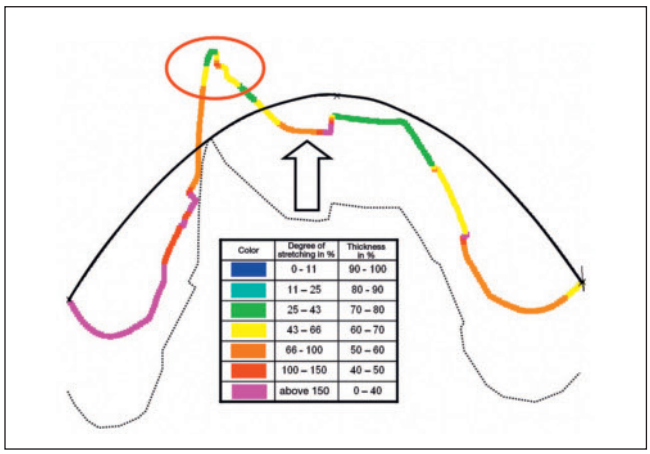

Fig. 6. Results with less inflation for a tall thermoform tool after taking into account the approach of the thermoform tool towards the film as the thermoform tool is raised

In actual practice, it is common through use of plug assists to further reduce stretching in regions that are visible in the vehicle by accepting a higher degree of stretching in the concealed regions. The new generation of TPO films can withstand extremely high degrees of stretching without tearing.

The simplified 2-D simulation presented here is not intended to be a substitute for 3-D simulation of thermoforming, but rather a complementary tool that can indicate at very early phases in development the tendencies for the anticipated stretching. With a few mouse clicks, the designer can, within 10 to 15 minutes, analyze in the CAD system where the critical regions are localized, and verify the effectiveness of possible corrective measures. In this way, physical trials can focus on specific aspects and be conducted much more quickly. ■

THE AUTHOR

PROF. DR.-ING. BERND SCHWARZE, born in 1967, is professor of CAD, design and machine components in the Department of Engineering and Information Technology at the University of Osnabrück, Germany.

© 2008 Carl Hanser Verlag, Munich, Germany www.kunststoffe-international.com/archive Not for use in internet or intranet sites. Not for electronic distribution.