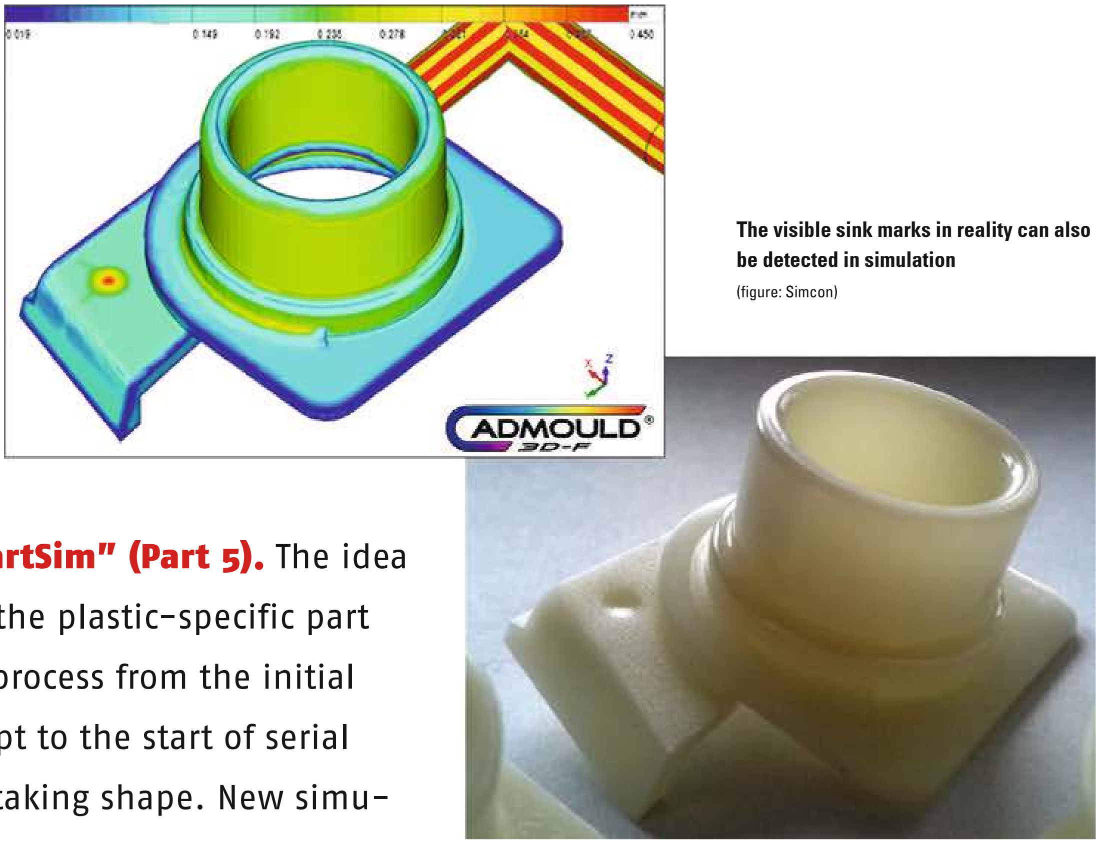

The visible sink marks in reality can also be detected in simulation

(figure: Simcon)

"Advanced PartSim" (Part 5). The idea of optimizing the plastic-specific part development process from the initial product concept to the start of serial production is taking shape. New simulation analysis methods allow the determination and evaluation of burn streaks and sink marks.

Virtual Prediction of Part Failure

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To support plastics processing companies during the part development process, research partners from Austria, Slovenia and Germany have, in an EU-funded Cornet project ("Collective Research Networking"), developed four methods to be used in the different stages of the product development process. This approach is similar to the Stage-Gate model [1], which divides the product development process into different stages and gates.

In the previous parts of the project (**Box** "Advanced PartSim"), methods for a structured feasibility check, life-time prediction, and robust process design were presented. The most recent part focused on a method for the automatic prediction of part failure using simulation software during the product development process. The automated, software-based identification of part failure using physical parameters leads to a reduction in development time, as time-consuming iterations during mold trials can often be eliminated. Furthermore, optimized molds can also reduce the rejection rate.

After discussion with several industrial partners following the project, sink marks and burn streaks were selected as the main problems with such part failures as they are a common phenomenon in industrial practice. This topic was developed systematically to deploy simulation tools for predicting part failure.

Sink marks are undesirable indentations on a part surface that can be explained by material accumulation. During processing, increased shrinkage can be detected in this area which cannot be compensated by the holding pressure. Firstly, the visibility of sink marks is due to differing surface geometries in the deformed and non-deformed areas, and secondly, the perception of sink marks on the part depends on local surface quality as regards roughness, structure and optical characteristics such as gloss, color and incidence of light.

Provoking Burn Streaks and Sink Marks

The aim of the trials performed by the international project group was to illustrate and predict the geometric influences and the influence of different process pa-

Translated from Kunststoffe 11/2013, pp. 32–34
Article as PDF-File at www.kunststoffe-international. com; Document Number: PE111531

rameters in the simulation tool. For the identification of possible physical parameters that could be calculated in the simulation software, real parts were produced with an existing mold. During these trials, part failures were provoked using different process parameters. All parts were analyzed regarding sink marks and burn streaks, and the faults were quantified. At the same time, corresponding injection molding simulations were carried out – on the one hand, with the process parameter set with part failure, and on the other, with the process parameter set with which no part failure was found **(Fig. 1)**.

In the next step, the correlation between the results of the injection molding simulations and the real part failures was analyzed. Therefore, different physical parameters calculated by the simulation software – e.g. the local shear rate – were considered in order to obtain information on possible part failure in the trials.

For the injection molding trials, two different geometries were selected and the respective parts were produced. The specimen was produced in two geometric versions **(Fig. 2)** from PC (grade: Lexan 121R; manufacturer: Sabic). A more practical specimen made of PP (grade: Moplen 2348 M; manufacturer: LyondellBasell) will be used for validation of the results **(Title figure)**. Both parts show visible and measurable sink marks in different areas with accumulation of material **(Fig. 3, Title figure)**. The sink marks on the specimen were analyzed by micrometer and gauge and evaluated in terms of their optical and tactile properties. During this examination, it turned out that not only the depth of the sink mark but also the gradient of the change of depth is important for the subjective perception.

"Advanced PartSim"

The target of the EU project "Advanced PartSim" is to optimize the product development at an early stage through the use of virtual, knowledge-based systems. The overall project was presented at the start of the series (part 1, issue 7, p. 50) Existing simulation tools will be expanded and combined to create a new product development system using

- a feasibility check (part 2, issue 8, p. 74),
- life-time prediction (part 3, issue 9, p. 158),
- robust process design (part 4, issue 10, p. 198) and
- part failure prediction (part 5)

to help companies in the plastic processing industry take decisions on critical issues.

Basic knowledge can be gained by developing the different methods to create different tools for plastic processing companies for future critical problems.

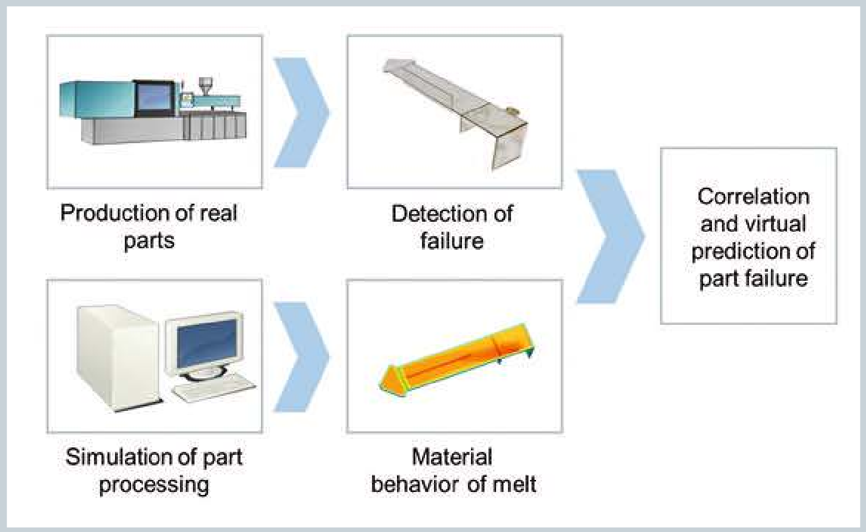

Fig. 1. After production of real parts, simulations were started using the same process parameters to detect part failures (figure: Ecoplus)

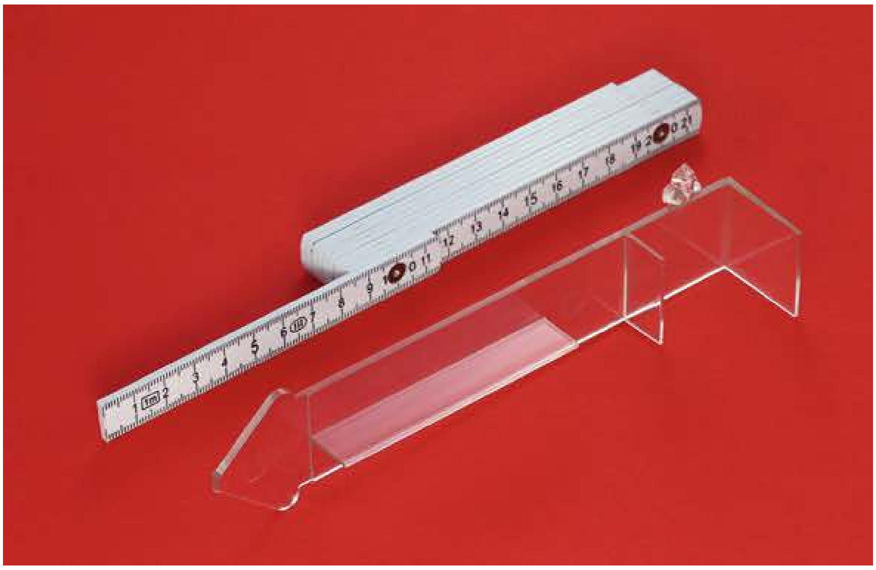

Fig. 2. The test part was produced with different thickness and two different injection points (figure: Simcon)

Invisible or Non-occurring Failures

Evaluation in practice shows that simulation can predict the local shrinkage and its change in different areas. The results can be used as a measure of the visibility of sink marks. Comparing the relative depth of the sink mark of 0.23 mm from the simulation with the measured real shrinkage of 0.25 mm on the real part **(Title figure)** shows that there is a high correlation between the simulation and the measurement of the real part. It illustrates that a prediction of sink marks using simulation tools can be used to modify the part geometry or the production process.

The prediction of burn streaks in simulation was also investigated in detail. Such defects occur through overheating of the plastic material due to a high shear rate during injection of the material. To find a dependence of the occurrence of burn streaks on different process conditions, test parts **(Fig. 2)** were produced in two different thicknesses (1.5 mm, 2.5 mm), each with four different injection rates (66, 100, 110 and 125 cm^3/s). →

The process parameters were chosen so that burn streaks either do not occur at all or are provoked directly.

Injection molding tests were reconstructed in a simulation with the real process parameters. Due to the fact that material damage is dependent on absolute temperature and the duration of impact, a model was chosen that includes both temperature and time of impact. Thus, a modification of the scorch index – already known in rubber processing – to describe the incubation behavior is developed. Using the simulation software Cadmould 3D-F (Simcon kunststofftechnische Software GmbH, Würselen, Germany), an index for the burn streak distribution can be calculated and analyzed using the following formula:

$$VBsc = \int \frac{1}{t_0} \exp\left(\frac{-T_0}{T}\right) dt$$

t_0, T_0 = const

Using the index, it is possible to differentiate between the appearance or non-appearance of burn streaks based on temperature (T) and time (t), **(Fig. 4)**. In areas with high damage, very good correlation between the simulation results and the burn streaks on the test parts can be seen. However, critical values for each plastic material or plastic material group have to be found. Another way to attain a general implementation is to adapt the mathematical approach for the material so that the resulting index is defined between 0 % and 100 %. In rubber processing, a scorch index higher than 80 % should be avoided. The same strategy can be adapted for the detection of burn streaks as well.

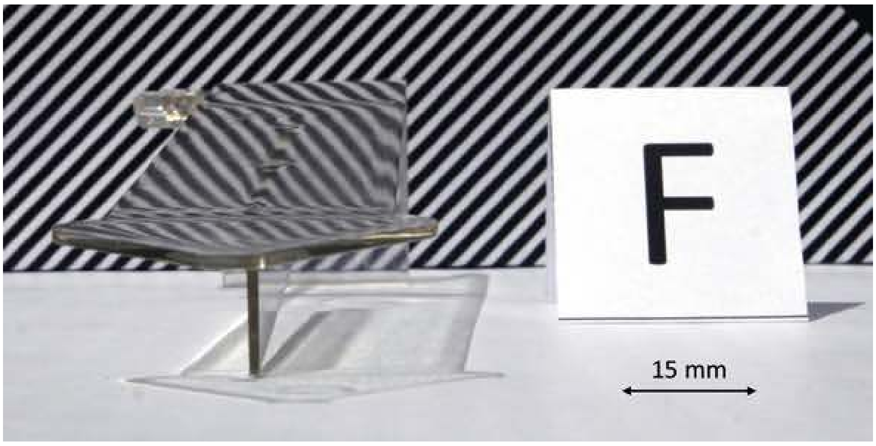

Fig. 3. Using a striped pattern, sink marks on the part surface can be detected (figure: Simcon)

Conclusion

During the tests, an approach was developed to predict sink marks and burn streaks at the part and process development stage. The adaption of the scorch index to detect burn streaks is a simple way to illustrate part failure, because all that is needed is to modify mathematical functions that are already implemented in the simulation software. Furthermore, sink marks can be easily detected as the user can use existing functions such as the local reduction in thickness **(Title picture)**. However, a new link between the local thickness reduction and the gradient of local shrinkage has to be developed and implemented to obtain a precise characterization of the sink marks.

The project shows the basic functionality of part failure prediction using simulation software. For a general description of burn streaks and sink marks, additional materials with their individual limit values need to be evaluated. In addition, a validation of the results for other geometrically different parts should be carried out. After analyzing these additional tests, the results of the project can be implemented in general part development. ■

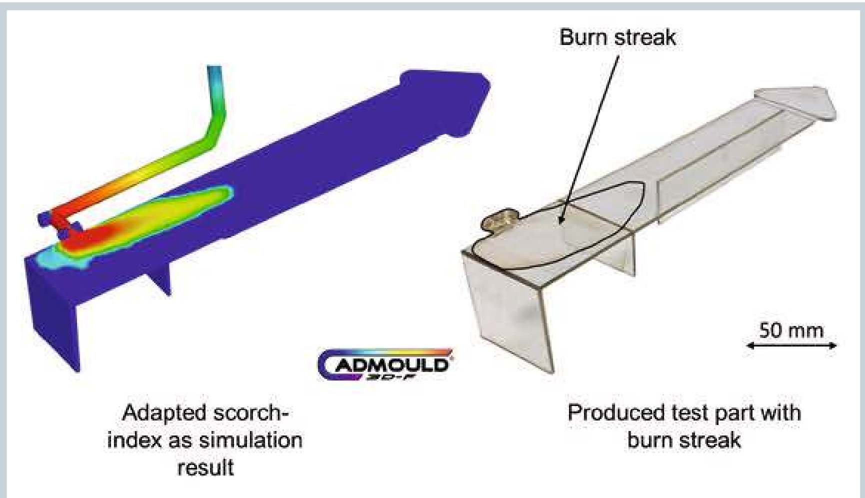

Fig. 4. Burn streaks were found both in reality and in simulation (figure: Simcon)

ACKNOWLEDGMENT

The research project 44 EN of the Forschungsvereinigung Kunststoffverarbeitung was sponsored as part of the "Promotion of Joint Industrial Research (IGF)" by the European Union, the Ministry of Higher Education, Science and Technology of the Republic of Slovenia, the FFG Austrian Research Promotion Agency and the German Federal Ministry of Economics and Technology (BMWi), following a resolution by the German Bundestag through the AiF.

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