In a pilot study, the high prediction quality of the robust process was shown with the example of a shell for a mirror drive (figure: MUL)

"Advanced PartSim" (Part 4). Researchers from Austria, Slovenia and Germany are working on the optimization of the plastic-designed development process from the initial product idea to the start of serial production. Through the use of Design of Experiments before the commencement of mold testing, a robust process parameter set is to be specified without wasteful iteration loops.

Virtual Mold Sampling for Robust Processes

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In a recently completed EU-funded Cornet project (Collective Research Networking), the research collaboration team achieved its target to define a robust injection molding process that is insensitive to disturbance variables. The project involved combining methods of injection molding simulation with statistical design of experiments back at the product, mold and process development stage. This enables high-quality parts to be produced even under changing production conditions.

Variations in production conditions can be taken into account in several ways in injection molding simulation. Batch fluctuations can be depicted, for example, by varying the material data (as input parameters for the simulation). Mold wear can be shown in the simulation as the increase in the size of the virtual cavity. This way, disturbance variables can be considered back at the product development stage to minimize their influence in series production.

Translated from Kunststoffe 10/2013, pp. 198–201
Article as PDF-File at www.kunststoffe-international.com; Document Number: PE111496

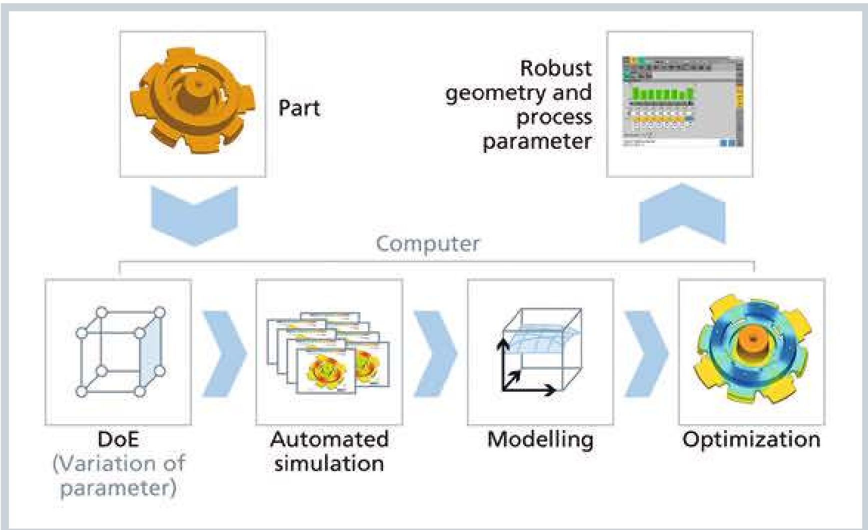

Fig. 1. The procedure of the robust process method is based on a stage-gate process (figure: Ecoplus)

Using the simulation method, the number of iteration loops can be reduced. Furthermore, the machine setter can start the mold testing with the process parameter set from the simulation, saving expensive machine time and material.

Step by Step to the Required Process Parameter Set

In the first step **(Fig. 1)**, potential influencing process parameters are derived from the geometry data of the part, and relevant disturbance variables in production are analyzed. Then the quality characteristics of the part are defined, such as dimensions contained in the target value and tolerance, as well as gaps, roundness, flatness or warpage. From the collected data, it is possible to draw up, with the help of an Excel-based checklist, a reasonable Design of Experiments (DoE) in which the test points are subsequently simulated, automatically taking the different process parameters into account.

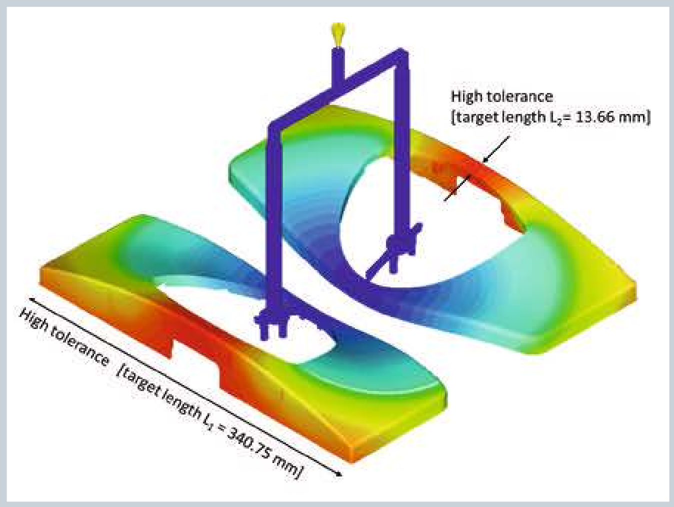

Fig. 2. The cover of a sanitary cistern has very low tolerances lengthwise and opposite the gate (figure: IKV)

From the simulation results, a mathematical process model is created by multivariate regression for each quality characteristic. In this process model, a statistical relationship is established between the process parameters and disturbance variables as input parameters and the resulting quality criteria as output parameters. In the next step, the process is optimized in terms of the robustness of the production process. To do this, an optimization algorithm is performed for the mathematical dependencies in the created model. The aim of the algorithm is to minimize the variance of all the quality characteristics while centering them within the tolerance ranges. The results of the research project show that the centering has a higher influence on the robustness of the process point than the variance. More weight should therefore be given to this in the optimization algorithm.

With the results of this operation, predicted values for all quality criteria and a corresponding process parameter set are available before production of the mold. The results can also be used for designing the part, the mold and the production process, as a virtual iteration loop can be performed. Based on the knowledge gained from the first optimization, modifications can be made to the part and mold to further improve the robustness. For example, additional ribs can be integrated to improve the warpage of the part.

Pilot Study 1: Automotive Shell for Mirror Drive

After validation of the method using a test part at the Institute of Plastics Processing (IKV), Aachen, Germany, [1] pilot studies were performed in a project with real industrial parts together with various industrial partners. Two of these pilot studies are described here.

	Optimum predicted by simulation	During serial production (average of 62 days)
Process parameter		
Initial temperature	131 °C	130 °C
Hot-runner temperature	300 °C	300 °C
Backpressure	–	80 bar
Injection rate	27 cm^3/s	30.4 cm^3/s
Holding pressure	800 bar	800 bar
Holding pressure time	6 s	6 s
Residual cooling time	5 s	7 s
Quality		
Cycle time	16.92 s	18.06 s
Nominal value measuring point 1: 83.75 mm ± 0.15 mm	83.754 mm	83.822 ± 0.035 mm
Nominal value measuring point 2: 83.75 mm ± 0.15 mm	83.746 mm	83.809 ± 0.037 mm

Table 1. The predicted optimum for the process matches very well indeed with the trial-and-error results of the injection molding production

In a pilot study with Magna Auteca AG, Weiz, Austria, the prediction quality of the method was shown. For this, a part already in series production – a shell for a mirror drive **(Title figure)** manufactured with a single-cavity mold and given quality criteria – was analyzed. The CAD data of the part and mold (including mold insert, cooling system and hot-runner system) were imported into the injection molding simulation software CadMould 3D-F 6.0 (supplier: Simcon kunststofftechnische Software GmbH, Würselen, Germany) together with material data of the glass fiber-filled PET compound (type: Arnite AV2 370XT; manufacturer: DSM Engineering Plastics).

The missing measurements – pvT behavior, viscosity and temperature-dependent thermal conductivity – were carried out by the Chair of Injection Molding of Polymers at the Montanuniversität Leoben, Austria [2]. Based on a D-optimized Design of Experiments with nine settings, a systematic variation of seven process parameters was performed within a process window that is suitable for the material and based on experience.

After the simulation, the results for the diameters calculated in the individual simulations (quality criteria) were linked to the selected process settings in mathematical process models to find an optimized process parameter set. The direct comparison for the target diameter – 83.75 mm with a tolerance of ±0.15 mm – shows that the predicted process optimum and the real optimum determined by Magna Auteca itself **(Table 1)** were identical. The predicted part dimensions differ by less than 0.1 % from the real values for random samples taken from 62 days of serial production.

Pilot Study 2: Cover of a Sanitary Cistern

In a second pilot study, Geberit Sanitarna tehnika d.o.o., Ruse, Slovenia, provided IKV with CAD data for a two-cavity mold and the relevant cooling channel design. It also supplied the requested quality criteria, namely the dimensions of the part to be examined. For the cover of the sanitary cistern **(Fig. 2)**, the tolerance of the dimensions in the lengthwise direction and in the narrow area opposite the gate is very small. The material is an ABS (type: Terluran GP-35; manufacturer: BASF) with a 5 % white masterbatch.

Based on this input data, the procedure for the robust process started with a De- →

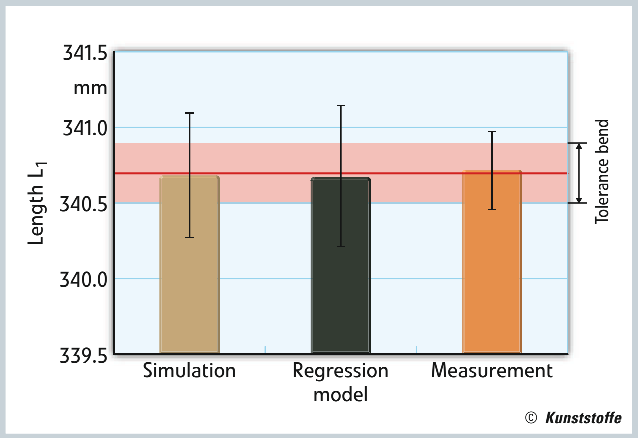

Fig. 3. The results of simulation, regression model and real part measurement of the lengthwise dimension, shown for one of the cavities, are very similar (figure: IKV)

sign of Experiments with a total of 243 simulations (3^5, three steps with 5 parameters), which was subsequently reduced by the Box-Behnken method to 46 parameter settings. The Box-Behnken reduction omitted the extreme points and did not take superior interactions between the parameters into account [3].

After simulation of all the points, and after deriving the mathematical process models and optimizing the robustness of the process, the predicted optimum process parameter set showed that, within the simulated process window, only the dimensions opposite the gate could not be reached. After discussion, it was established that this occurs due to provisions of mold material in this cavity area, because iteration loops were expected here. Thus, the simulation method showed the unnecessarily high provision of material at this point in the mold. The required iteration loop would have thus been unnecessary.

Parts were then made at Geberit's test center with the optimized process parameter set. The results of the lengthwise dimensions with a target value of 340.7 mm and a tolerance of ±0.2 mm in comparison with the simulation results show the very good prediction of the model **(Fig. 3)**. The high variance of the results for both the simulation and the regression model are caused by the batch fluctuations, which were included as disturbance factor. Because only one material batch was tested during production of the real parts, the measurement only maps the production fluctuation of the process.

The parts which were produced in the mold trials were analyzed in detail. Here, additional part failures occurred that could not be predicted by the simulation. The high injection rate led to surface streaks, while the low holding pressure was responsible for sink marks at one of the clamps. Nevertheless, minor modifications during the mold trials eliminated these two problems. Using the process parameter set derived from the simulation, the mold trials were faster and less material was used, so that, in general, the process causes less costs.

! "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. Existing simulation tools will be expanded and combined to a new product development system using

- a feasibility check (part 2),
- life-time prediction (part 3),
- robust process design (part 4) and
- part failure prediction (part 5)

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

After the start of the series of articles in the July issue, which introduced the complete project, the four methods have been presented in detail. In the next issue (November), the final method of part failure prediction will show how the use of injection molding simulation can help to prevent part failures.

Conclusion

Several pilot studies have confirmed the practical suitability of the predicted robust process. Areas of application include not only improving the product development process, but also optimizing existing production processes. The use of the robust process parameter set for existing molds can reveal further potential for improving the production process. Via the mathematical relationships, the machine setter recognizes the key process parameters and their effects, and, as an ideal solution, also finds process settings that are not exactly obvious.

For the successful use of the newly developed method, however, some requirements have to be met. Full and reliable material data have to be available for the simulation, and complete, congruent and correct CAD data regarding part geometry, cooling system and quality criteria are also essential. If the CAD data no longer conform to the mold, the simulation will predict a robust process but it may not be feasible in reality. Furthermore, measurement of the part dimensions has to be reproducible and very accurate. ■

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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