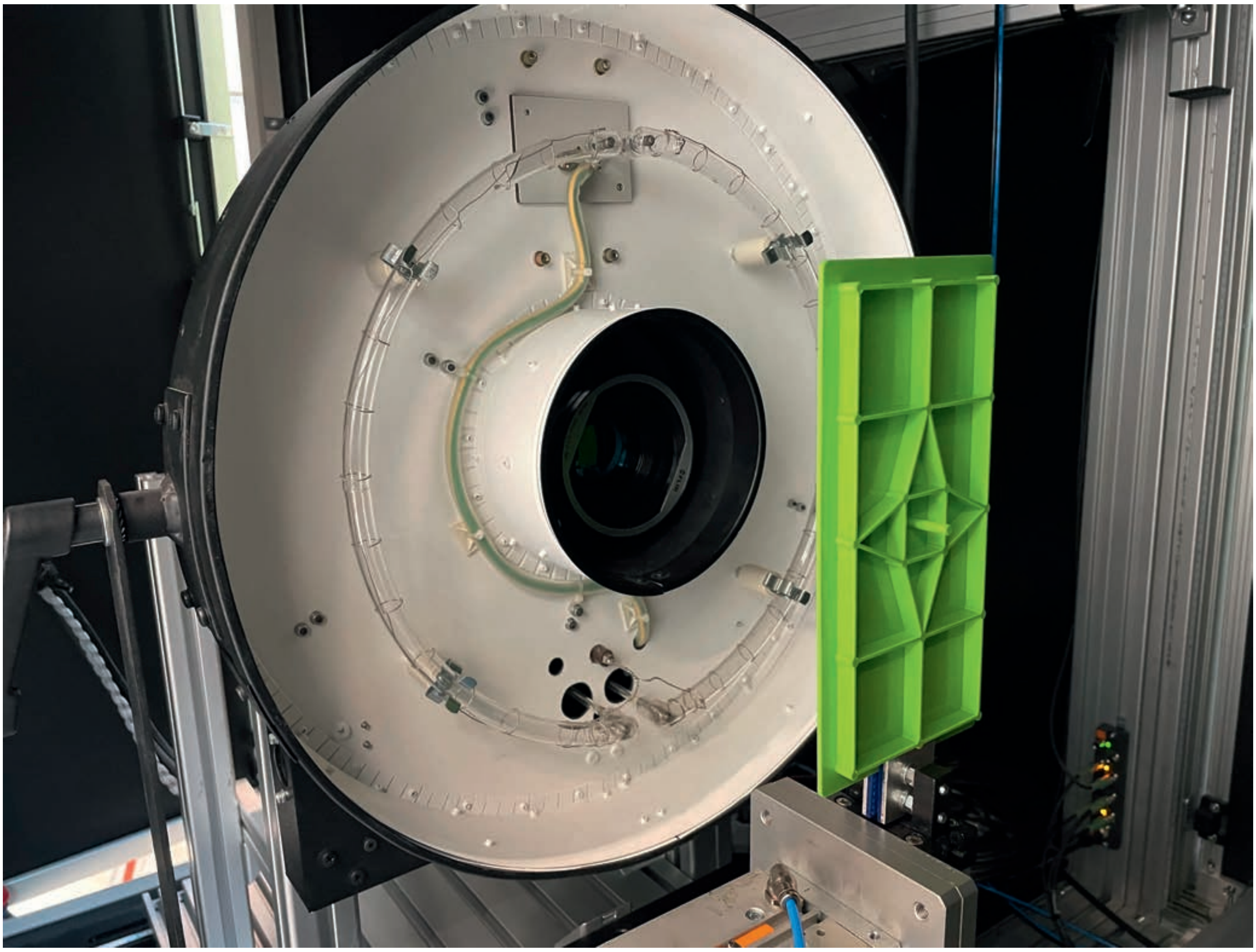
Active Thermography for Inline Quality Control

Putting Voids in their Place with Quality Control

Voids impair the strength of injection-molded parts, but they cannot be detected by conventional quality inspection methods. Injection molding machine manufacturer Engel, together with the Josef Ressel Center at the Wels campus of the University of Applied Sciences Upper Austria, has shown how active thermography can also be deployed to provide inline quality control during injection molding. The size of voids can be specifically influenced and held in check during ongoing production.



The flat sample parts of different wall thicknesses and reinforcing elements on the back are inspected fully automatically in the measuring cell.

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The ability to control part quality in an ongoing process is the dream of every injection molder. The aim here is to eliminate all influences that act on the process and thus affect part quality. Universities and research institutes have been working on this topic for many years now. So far, applications in industrial injection molding production have been sporadic, but demand for inline quality control solutions at the moment is growing substantially. The reasons for this are, on one hand, rising quality requirements generally and, on the other, efforts directed at more sustainable manufacturing. Inline process control makes for constant processes, saves on energy and raw materials and lowers the reject rate.

Reliable and accurate measurement of the relevant quality parameters are essential for feedback control. Since voids are usually located inside the part, they elude visual surface inspection, especially when colored thermoplastics are being processed. Suitable methods for detecting and measuring these defects are therefore needed, e.g. active thermography.

In active thermography, energy is introduced into the part with the aid of a flash lamp or a halogen lamp. The resulting local temperature differences lead to compensatory heat flows. Through the application of suitable evaluation methods, the change in temperature over time, as recorded by an infrared camera, can be used to draw conclusions about internal defects. The original image captured by the camera serves as a basis for determining the size of the voids using industrial image processing methods.

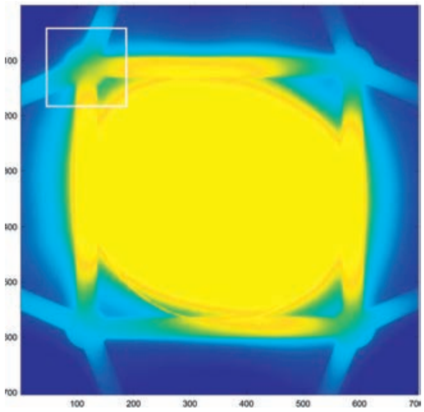

Fig. 1. The camera image shows the area of the four central nodes of the webs on the back of the part. This is where voids are most likely to occur. In Figure 2, only the section of the upper left node is shown in more detail for illustration purposes. © Engel/Josef Ressel Center

More Safety, Especially for Thick-Wall Parts

Active thermography is non-destructive and possesses other advantages over other quality control methods. Measurement is unaffected by external influences such as changes in ambient temperature, the melt and mold temperature, and the time of measurement after demolding. In addition, reflection from other heat sources can be eliminated very easily.

Voids are formed when material shrinks. The thicker the wall, the more likely they are to form. Accordingly, parts whose geometry features thick-wall webs and ribs for providing greater stiffness are particularly at risk. For safety-critical parts, this poses a significant challenge. Aside from part geometry, wall thickness, the design of the injection mold and the layout of the gating system, it is the process settings on the injection molding machine that exert the greatest influence. Unlike the mold design, however, the process parameters can be quickly and easily readjusted to the specific requirements or be corrected if the boundary conditions change.

More than 1000 Parts Tested and Evaluated

At Engel's technical center in Schwertberg, Austria, flat polypropylene samples were molded in different wall thicknesses and with reinforcing elements on the back side. The engineers created a quality control cell by integrating the thermographic measuring cell into the injection molding cell. This allowed the parts to be transferred fully automatically from the mold cavities to the measuring cell. The measuring cell encloses the camera and flash lamp as well as a pneumatic gripper for positioning the part (**Title figure**). The linchpin is the CC300 control system of the injection molding machine which controls the entire automation and in turn feeds the results of the quality measurement back into the process settings.

Measurement starts automatically as soon as the linear robot (type: Engel viper) installed on the injection molding machine has positioned the part in front of the camera. The system records the change in temperature over time and triggers data evaluation. If voids are detected in the first step, their size is calculated from the temperature data by means of statistical and image processing methods. This result subsequently serves as a control variable for the purposes of quality control. As the camera and robot are fully integrated into the injection molding cell, process consistency as well as complete data integration can be guaranteed – this would not be possible with a conventional stand-alone solution.

Evaluation software for computing void size was developed. Starting with the image captured by the camera (**Fig. 1**), it determines the position of the part, defines regions of interest, processes the data in several steps, detects any voids and computes their size (**Fig. 2**). The first image on the left was taken 3.5 s after flash excitation. At most, there is only a suspicion of a void here. The second image shows the same cross-section with the offset image removed. In the third image, the low-frequency image sections have been removed. In the fourth image, a »

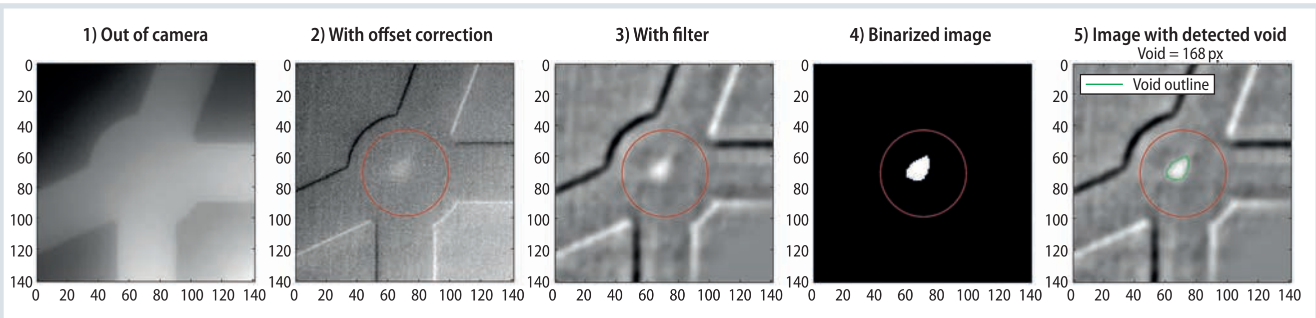

Fig. 2. Industrial image-processing methods aid in detection and sizing. The first image was taken 3.5 s after flash excitation. After several processing steps, the last image shows the detected void using overlays with an outer line.

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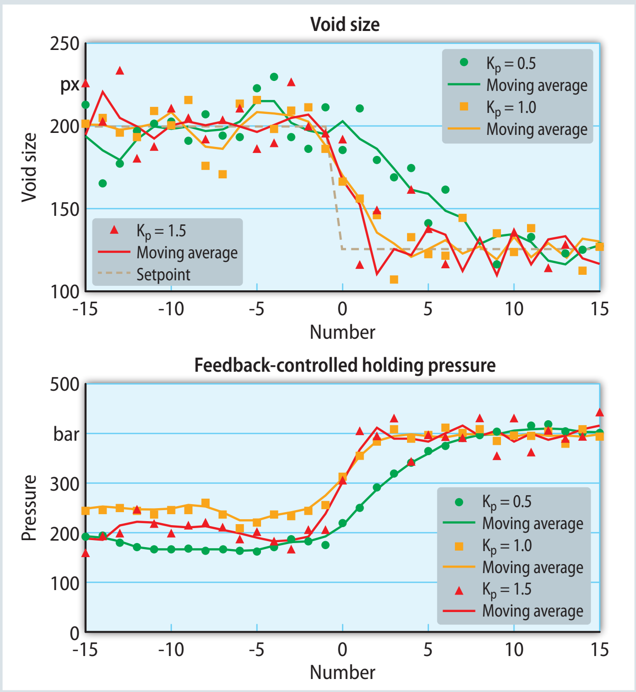

Fig. 3. Void size and holding pressure correlate with one another. Suitable controller dynamics were determined on the basis of step response for three different controller gains (K_p).
Source: Engel/Josef Ressel Center; graphic: © Hanser

threshold level has been determined from the statistical distribution of the gray values and used to binarize the void region. Any artifacts found in the evaluation are recognized as such and ignored. The final image shows the detected void with the help of overlaying with an outer line. The software thus ensures that consistent image quality and, hence, reliable evaluation are achieved.

After initial tests in the laboratory environment, the development partners started an extensive parameter study under industrial conditions. The aim was to find correlations between individual process parameters and void size and to further develop the algorithm used to determine void size. The parameters

- melt temperature,
- cooling water temperature,
- holding pressure, and
- holding pressure time

were varied systematically. For each set of parameters, numerous parts were produced and examined thermographically. In total, the quality of more than 1000 parts was tested and evaluated.

Visualization Software Clarifies Correlations

The process parameters that exert the greatest influence in practice and therefore are particularly amenable to feedback control depend in turn on the part geometry, the individual boundary conditions and the permissible process windows. The correlations can be mapped with the aid of expert knowledge, simple process models and even neural networks.

Specially designed visualization software makes it possible to compare different sets of parameters, to display individual result images and finally to identify correlations. For a cooling water temperature (T_C) in the region of 40 °C and a melt temperature (T_M) of 230 °C, a clear correlation was found between void size and holding pressure.

After a series of tests, the developers at Engel and the Josef Ressel Center determined that holding pressure was the most relevant manipulated variable for exploring the possibilities of inline quality control using active thermography.

Holding Pressure as a Manipulated Variable

Reliable detection of void size (controlled variable) and its dependence on a process variable (manipulated variable) are fundamental to the implementation of inline quality control using active thermography. In inline quality control, the entire injection molding cell, including the quality measurement system, continuously adjusts the process values in order to keep the quality of the produced part constant.

In injection molding, which is a cyclical process, the quality measurement system automatically keeps recording new readings, evaluating them and transmitting the results to the feedback control system. This automatically calculates the manipulated variable – in this case the holding pressure – and transmits the value to the machine's controller.

The concept was tested on the production of flat PP sample parts with a view to safeguarding product quality at a consistently high level. For the first tests of the control system, the setpoint for the void size underwent a step-change. Suitable controller dynamics were determined on the basis of the transient response at different controller gains (**Fig. 3**). For these tests, the target size was reduced to 125 px (pixels) from 200 px, whereby 200 px corresponds to an area of about 0.5 mm^2.

First Step towards Commercialization

The quality control system was tested under different scenarios, such as that it responds dynamically to a change, but gives less weighting to random fluctuations. To this end, disturbances were introduced into the process by changing

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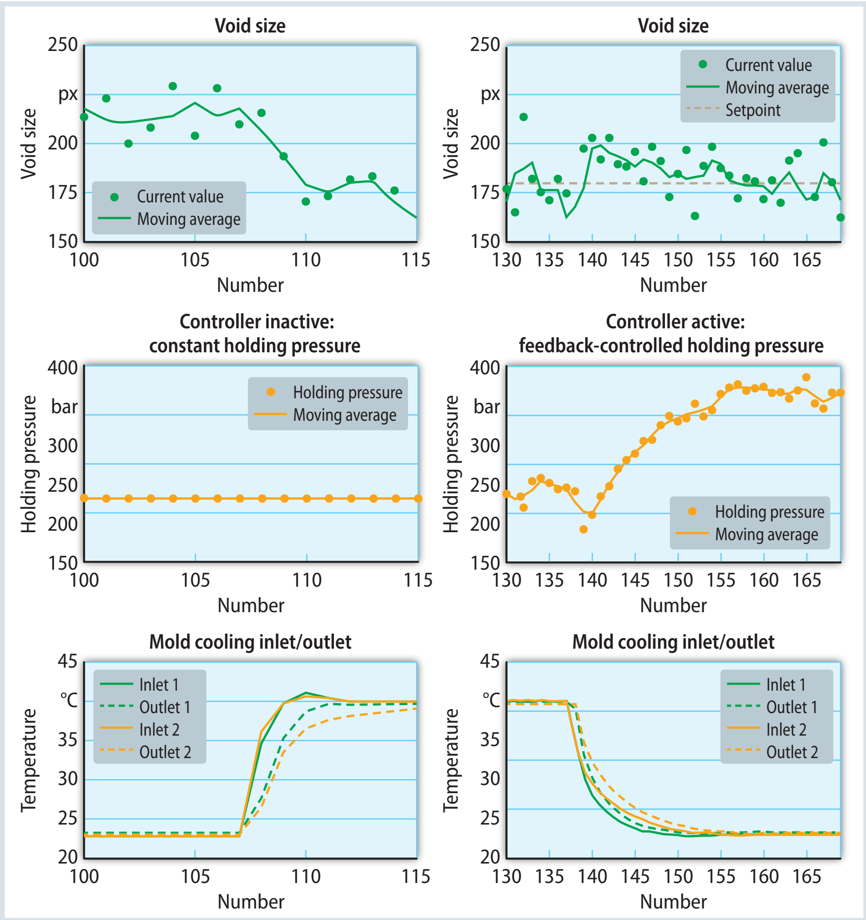

Fig. 4. Effect of change in mold temperature on void size, with and without inline quality control. To simulate temperature drift, the cooling water temperature (T_C) was raised from 23 to 40 °C and then lowered again. Source: Engel/Josef Ressel Center; graphic: © Hanser

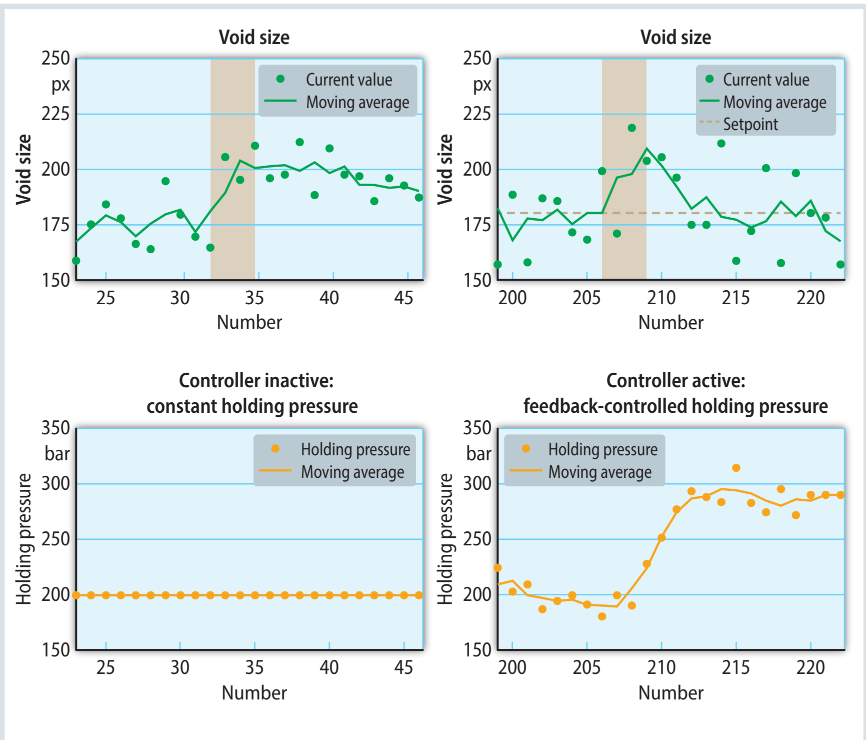

Fig. 5. Switching from recycled to virgin material during ongoing production (colored area). The controller responds to the rise in viscosity by increasing the holding pressure (right) and can thus maintain the set target size of 180 px. Source: Engel/Josef Ressel Center; graphic: © Hanser

other process variables and boundary conditions. Examples of influences that lead to an increase in void size are changes in the cooling water temperature or in the viscosity of the processed material.

A falling mold temperature leads to an increase in void size and vice versa. Temperature drift was simulated by raising the temperature for mold cooling (T_C) to 40 °C from 23 °C and then lowering it again (**Fig. 4**). Without feedback control, this gives rise to a changed void size (left). With active control (right), an increasing void size is counteracted by raising the holding pressure to compensate for the effects of the falling mold temperature.

Similarly, an increase in viscosity leads to an increase in void size. A viscosity change was induced by shredding previously manufactured parts and converting them into recycled material (**Fig. 5**). Recycled PP typically has a lower viscosity than virgin PP. During testing, a switch was made from recycled to virgin material. The switch from one material to the other led to a higher viscosity and thus to enlargement of the void. The controller responds to the rise in viscosity by raising the holding pressure and is thus able to maintain the set target size.

Conclusion

Integration of quality measurement into the injection molding cell is fundamental to inline quality control. Quality control makes it possible to ensure product quality on a sustained basis, even if the ambient conditions or the raw material change. For the necessary quality measurement of injection-molded parts, and especially the detection of voids, active thermography is a promising method that can be applied to a wide range of materials, from commodity thermoplastics to engineering and high-performance thermoplastics to fiber-reinforced polymers. Trials conducted in a joint research project by Engel and the Josef Ressel Center at the University of Applied Sciences Upper Austria in Wels have shown that the process offers plenty of potential for automated inline quality control in injection molding. The two development partners will continue to work on commercializing the concept of inline quality control and active thermography. ■