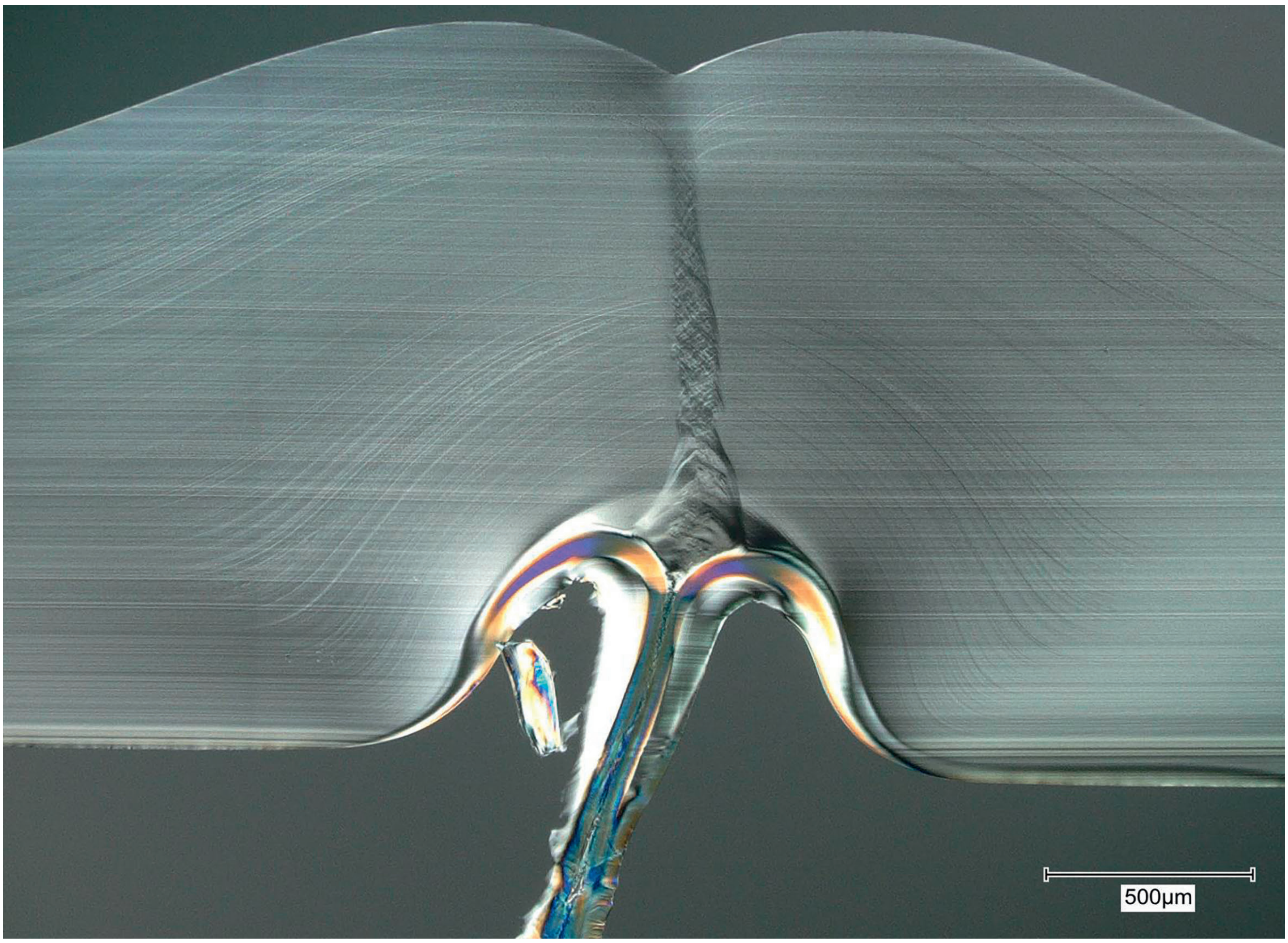
Heating of the Mash Seam

Variothermal Temperature Control in Extrusion Blow Molding Improves Quality of the Weld Line

Extrusion blow molding enables cost-effective production of hollow plastic articles with complex geometries and differing volumes. One disadvantage, however, is that blow-molded components often fail at the weld line. Variothermal temperature control can be utilized to significantly improve the quality of the weld line.



Weld line as a problem: the view of extrusion blow molded hollow articles under a polarization microscope shows that without temperature control, a cold plug shrinking inwards leads to a notch that reduces the quality of the weld line © IKV

The majority of blow-molded components are used as packaging in the consumer goods and food industries or as technical components, e.g. in the automotive or chemical industries [1]. The process already meets the high requirements with regard to low material consumption. Improving the extrusion blow molding process is therefore not only about increasing process efficiency, but also about improving component quality [1, 2]. In addition to relatively low material consumption, the process also has low scrap rates [3]. In addition, there is potential for optimization, especially with regard to the critical areas of blow-molded components, especially the weld line, which is mainly dependent on the melt temperature. In order to improve this aspect of the component, the Institute for Plastics Processing (IKV) in Industry and Trade at RWTH Aachen University, Germany, is investigating the use of variothermal temperature control, as this offers the advantage of increasing the temperature locally in the mold.

Targeted Introduction of Heat

During blow molding, the temperature of the material has a significant influence on the component quality, especially on the weld line. If the parison has already cooled down significantly, it can no longer be joined and stretched without problem. In numerous plastics processing methods (e.g. injection molding), variothermal mold temperature control has become established as the solution to this problem. This concept makes it possible to apply heat locally and for a limited period of time to the blow mold cavity.

Numerous scientific studies have been carried out on the effects of variothermal mold temperature control on component quality and process stability in plastics processing and have shown that it delivers reproducible and constant component quality [4–9]. In extrusion blow molding, variothermal mold temperature control has so far only been used to improve surface quality [10]. Recent investigations at IKV have shown, however, that variothermal temperature control also offers great potential for improving weld lines in polyethylene (PE) [11, 12].

In this context, the aim of this research project was to improve the quality of blow-molded components by targeted introduction of energy in critical areas of the mold without significantly increasing the cycle time. The results of the project on the influence of variothermal temperature control on the weld line quality are presented below. The focus of the investigations was on the simulative calculation of the temperature distribution and the microscopic analysis of the weld line.

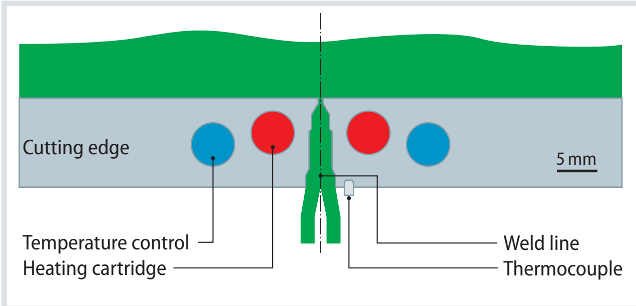


Fig. 1. Variothermal temperature controlled cutting edge with integrated heating cartridge and cooling channel Source: IKV, graphic: © Hanser

Materials and Methods

Extrusion blow molding tests were carried out to analyze the influence of variothermal temperature control on weld line quality. For the tests, rotationally symmetrical bottles with a diameter of 80 mm were produced on a single-station blow molding machine (type: BM-206, manufacturer: Bekum Maschinenfabrik GmbH, Berlin, Germany) with an LDPE (type: Purell PE 3020D, manufacturer: LyondellBasell, Rotterdam, Netherlands) having a density of 0.927 g/cm^3 and a melt flow rate (MFR) of 0.3 g/10 min (190 °C, 2.16 kg).

The module-based blow mold for producing bottles has interchangeable cutting edges. These were modified so that a heating cartridge can be installed for variothermal temperature control. The heating cartridge is positioned so that it is as close as possible to the cutting edge at a distance of 4 mm, thus enabling rapid heating. The heating cartridge has an output of 500 W and is controlled by a thermocouple (type K), which is attached to the cutting edge. Behind the cartridge heater there is a water cooling channel with a diameter of 8 mm to dissipate the heat introduced by the heating cartridge (**Fig. 1**).

Figure 2 shows the sequence of the heating and cooling phase. The cutting edge is heated during the extrusion of the preform. After the preform is taken over by the mold, the cooling time begins, during which the cutting edge is cooled by a water temperature control system. The heating phase starts again as soon as the part has been demolded.

The experimental design (**see Table 1**) varies the cutting edge temperature, but also the type of temperature control (v: variothermal, c: conventional). Apart from the variable parameters mentioned, the remaining machine parameters such as cycle time and extruder speed have been kept constant.

For the investigation of the weld line quality, samples were taken perpendicular to the weld line of the bottle base (**Fig. 3**). The resulting 15 µm thick microtome sections (thin sections) were examined microscopically with a polarization microscope (type: VHX-500, manufacturer: Keyence Corporation, Osaka, Japan) to compare the sample geometry and to evaluate the degree of crystallization of the material [13]. Three bottles for microscopic analysis were produced for each experimental point.

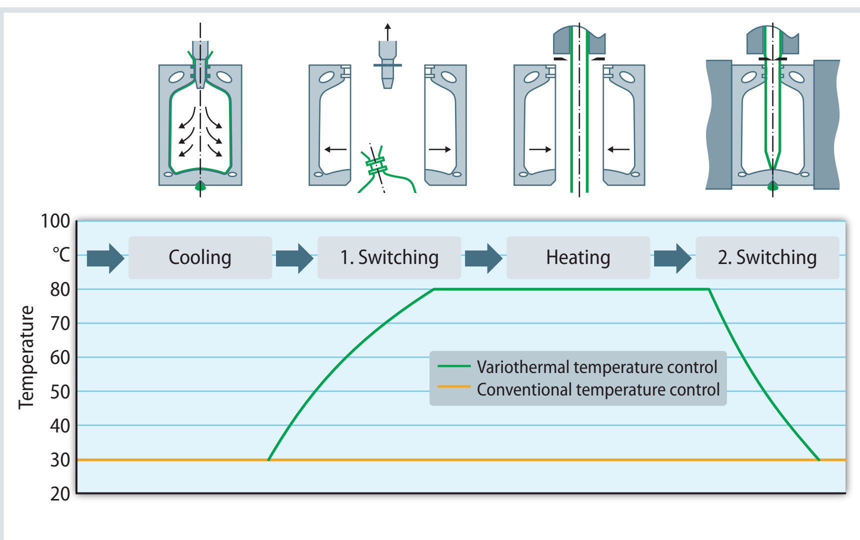


Fig. 2. Schematic representation of blow molding cycle and temperature of the cutting edge
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Simulation of the Weld Line

The influence of the changing cutting edge temperature on the temperature distribution of the weld line was determined by thermal simulation. These »

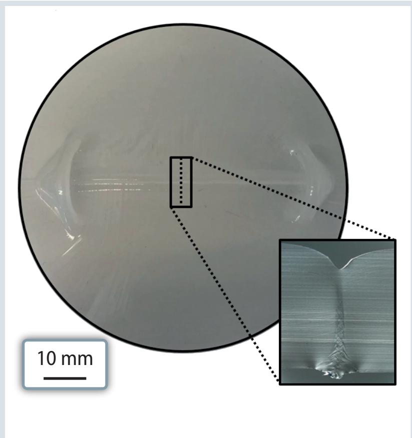

Fig. 3. Position and size of the microtome sections at the base of the bottle Source: IKV, graphic: © Hanser

simulations are necessary because the temperature distribution of the preform during the formation of the weld line (which cannot be measured directly) is responsible for the achievable part quality. The open source software OpenFoam (manufacturer: OpenFoam Foundation, London, England) was used for the simulation. The boundary conditions and material properties of the simulation are shown in **Figure 4**, the results of the simulations for cutting edge temperatures of 20 °C and 80 °C and for the times 0 s and 2 s in **Figure 5**.

In the first time step of the simulation, it can be seen that the plastic has a homogeneous temperature of 200 °C in both cases. The material that is in contact with the cutting edge has a significantly lower temperature. At a cutting edge temperature of 20 °C (left) the contact temperature is 48.7 °C. In contrast, the contact temperature for the hotter cutting edge (right) is significantly higher at 97.9 °C. After a cooling time of 2 s, the plastic temperature in both cases approaches the initial cutting edge temperature. The temperature gradient that was observed in the first time step of the simulation can no longer be seen.

Formation of the Weld Line in the Blow Molding Trials

After building up the simulation framework, practical tests on the weld line quality were carried out. The samples produced at 20 °C cutting edge temperature and conventional temperature control serve as a reference to determine the effect of dynamic temperature control. **Figure 6** shows that the material in the reference sample forms a so-called cold plug on the underside of the mash seam, which is smaller at 50 °C. At 80 °C it is no longer formed, and the weld has a homogeneous geometry.

A plug also leads to weakness of the weld line as it is pulled inwards during cooling. This effect leads to a pronounced notch, which can reduce the strength of the weld line. All in all, it can be concluded that at higher cutting edge temperatures a more uniform wall thickness is obtained. This leads to more efficient use of the material.

The shape of the weld line on the inside of the bottle is similar at all cutting edge temperatures. The only difference is the bulging at low temperatures caused by the cooling and thus inward shrinking cold plug.

Simulation and Practical Trials in Comparison

In the simulation of the cutting edge, the plastic in contact with the blow mold cavity cools down to a temperature of 48.7 °C at a cutting edge temperature of 20 °C. This leads to a very low degree of crystallization and the formation of the cold plug, which was confirmed in practical blow molding tests.

The polarization micrographs show, through the phase shift of the polarized light, that amorphous material is present in the area of the cold plug (**Fig. 6**). As can be observed in the simulations, a temperature gradient is established due to the rapid cooling of the plastic over the wall thickness of the component, whereby the hotter material on the inside of the bottle has a higher shrinkage potential than the material on the outside of the bottle. The shrinkage occurs when the component is no longer under constraint after demolding. The cold plug is then pulled inwards and forms a pronounced notch at low cutting edge temperatures.

Both phenomena – plug formation and shrinkage – depend to a high degree on the temperature, so that an increase in the cutting edge temperature leads to an improvement in the weld line. In the simulation, a cutting edge temperature of 80 °C leads to a contact temperature of 97.1 °C. The higher contact temperature reduces the temperature gradient over the wall thickness of the bottle. In the blow molding trials, this results in a significantly better weld line. The material has a higher overall temperature and can therefore crystallize more uniformly.

This effect can be seen in the polarization micrographs. Due to the lower temperature difference over the wall thickness, the differences in shrinkage potential are reduced, so that the shrinkage effects occurring at 20 °C cutting edge temperature are almost negligible and a uniform, notch-free weld line is formed.

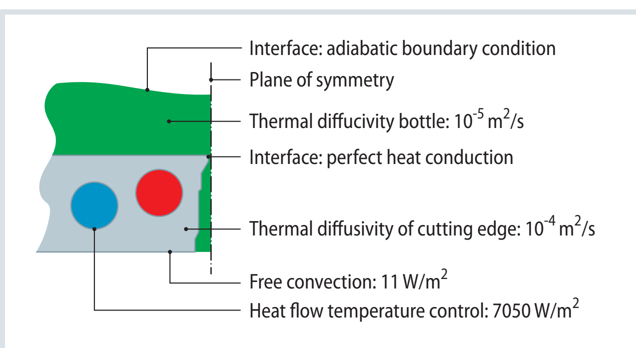

Fig. 4. Parameters and boundary conditions for the simulation of the cutting edge Source: IKV, graphic: © Hanser

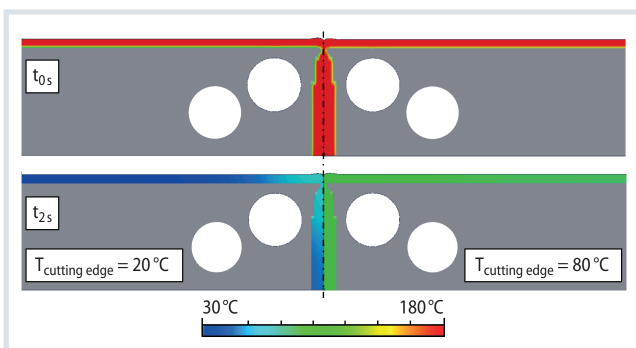

Fig. 5. Simulation of the cutting edge for different temperatures and times Source: IKV, graphic: © Hanser

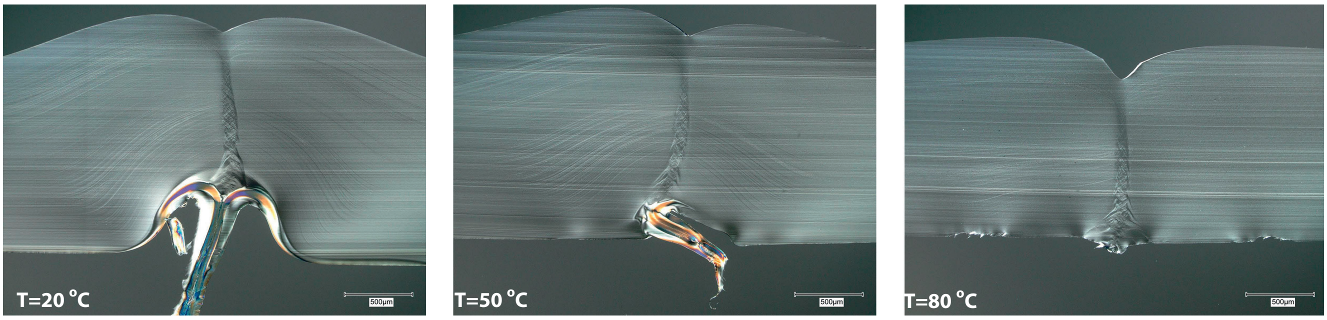

Fig. 6. Polarization micrographs of the weld line at different cutting edge temperatures Source: IKV

Due to the increase in temperature of the cutting edge, no cold plugs are formed, as the plastic is no longer suddenly quenched when it comes into contact with the tool. The simulation of the weld line shows that the plastic remains at a high temperature level for a longer time by increasing the temperature of the cutting edge. This is particularly advantageous for the diffusion, crystallization and adhesion process of the molecules, as they determine the weld line strength, whereby a higher cutting edge and thus material temperature leads to a better weld line. Tensile tests have also shown that the mechanical strength of the weld is improved [11, 12].

However, heating and cooling the cutting edge by resistance heating doubles the cycle time, although this disadvantage can be partially compensated by more effective ways of introducing energy. Examples of technologies with higher heating rates are laser or induction heating.

Conclusion

A variothermal temperature control was successfully integrated into an existing modular extrusion blow molding tool. It was shown that variothermal temperature control of the cutting edge can improve the quality of the component. Simulations and practical tests with LDPE showed that a high cutting edge temperature improves the geometry of the pinch seam and the morphology of the plastic.

Variothermal temperature control prevents the formation of a cold plug and reduces the shrinkage potential of the weld line. The reduction of shrinkage has a positive effect on component quality. Variothermal temperature control reduces the temperature gradient across the thickness of the component. This results in a uniform weld line that is less susceptible to mechanical failure due to the reduction of the notch effect. As a result, the component quality is improved and the material consumption is reduced.

In subsequent studies, the concept of variothermal temperature control will be transferred to other materials such as polypropylene (PP) and critical areas of the blow-molded product. One example is the embedding of inserts, as they are often used in fuel tank production. Another example is the improvement of surface quality. The aim of variothermal temperature control is to produce high-gloss surfaces and improve structures such as lettering. ■

Design of Experiment						
Materia	LDPE					
Cutting edge temperature	20 °C		50 °C		80 °C	
Temperature control type	v	c	v	c	v	c
Process parameter						
Melt temperature	190 °C					
Extruder speed	6.1 rpm					
Cycle time	72 s					

Table 1. Experimental design of the machine parameters for blow molding tests with variothermal (v) and conventional (c) temperature control Source: IKV, graphic: © Hanser

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