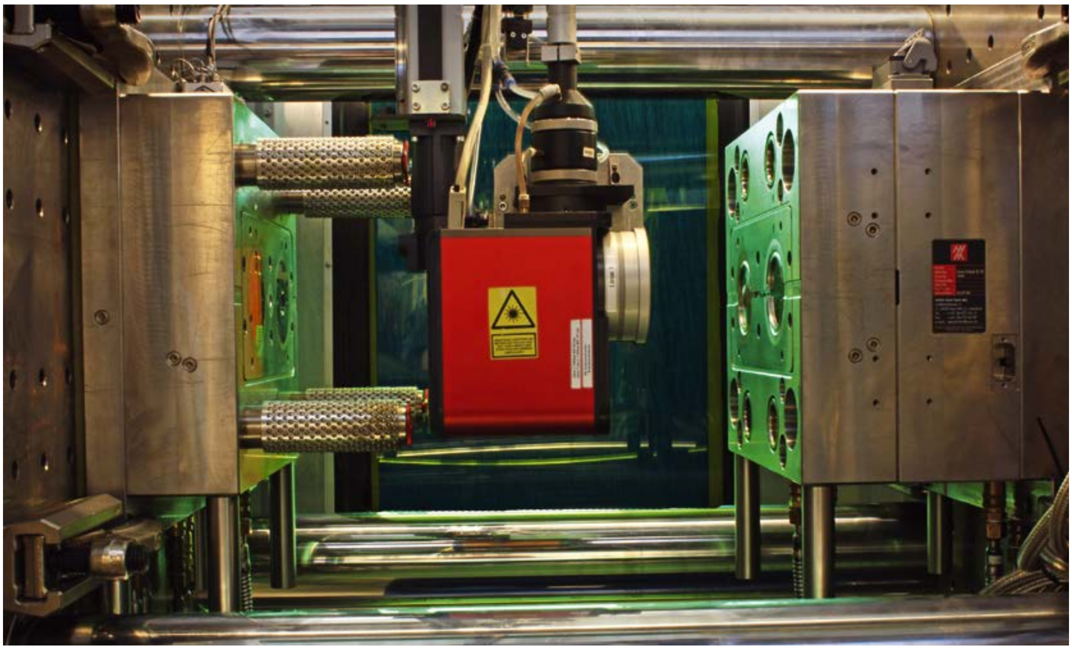
SPECIAL:
VARIOTHERM TEMPERATURE CONTROL

Laser-Based Dynamic Mold Temperature Control

A Laser-Based System Developed at the IKV Permits Localized Heating of Mold Cavities

Injection molded precision parts must meet the ever-increasing requirements for surface quality, mechanical properties and dimensional accuracy. At the same time, the integration of functions and processes is continuing apace. For particularly high quality requirements, dynamic mold temperature control offers the possibility of reconciling contradictory goals. A laser-based system now makes large-scale energy input unnecessary by focusing on the selective heating of localized mold regions.



An external laser scanner is interposed between the mold platen in order to locally heat up individual areas of the cavity at the stationary side (figures: IKV)

In thermoplastic injection molding, the part properties depend essentially on the thermal conditions during the shaping and solidification of the plastic melt. In most cases, a high mold wall temperature has a beneficial effect on the filling behavior in the cavity, and therefore on the part quality [1]. However, these high temperatures result in long cooling and cycle times.

A practical solution to these conflicting goals is offered by variotherm temperature control, which combines high mold wall temperatures in the injection phase alternating with low mold wall temperatures in the cooling phase. Consequently, the cavity is kept at a basic temperature level and only heated to a higher temperature for the injection phase. However, the dynamics of the temperature control are crucially important to the quality of the products and the economics of production.

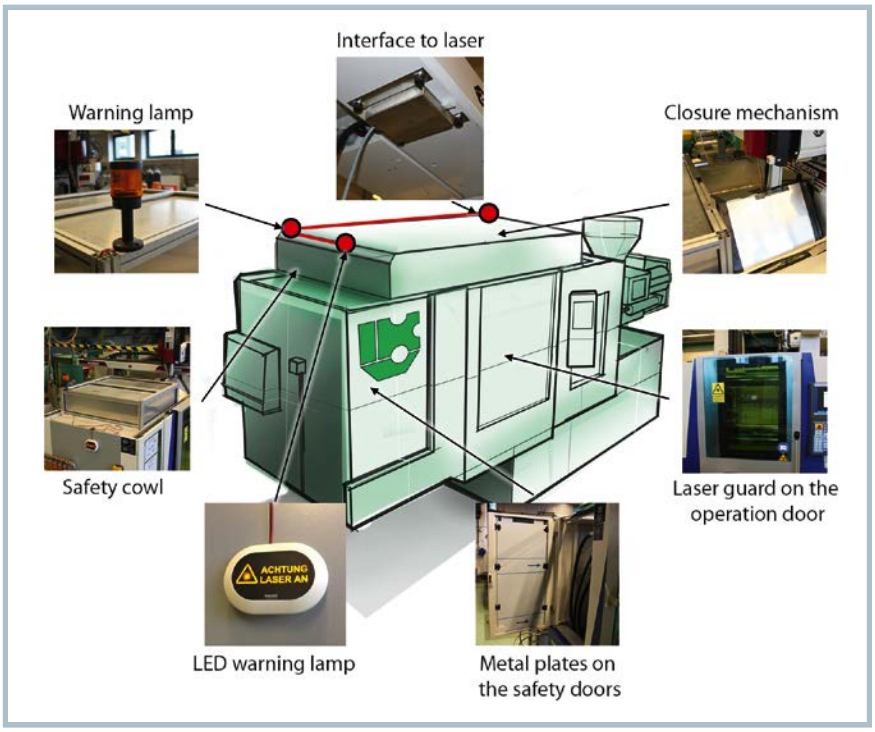


Fig. 1. Only a holistic safety concept permits robust and safe use of the system in practice

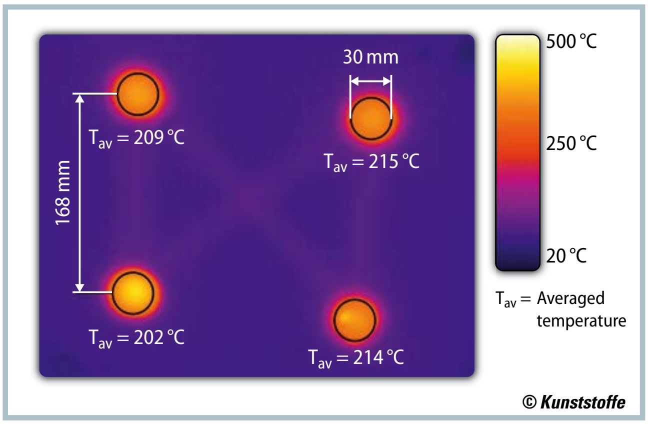


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Fig. 2. Quasi-simultaneous irradiation: the laser scanner selectively heats up individual points on the cavity surface

Variotherm and Flexible at the Same Time?

Principally, variotherm processes employ fluid-based basic temperature control of the mold, which ensures the cooling of the cavity. For heating the cavity surface, various processes are available. A range of systems are commercially available, with individual advantages and disadvantages. A key feature of the established processes is that they are tied to a specific mold and part. However, this makes them far less flexible in application.

For example, fluid-based variotherm temperature control in the mold presupposes that the temperature-control channels conform to the part contour, or product-specific inductors must be purchased for plant technology based on induction heating. In addition, heating generally takes place on a large scale. Localized heating is not possible [2, 3]. For this reason, the Institute of Plastics Processing (IKV) at RWTH Aachen University developed a flexible laser-based system for variotherm temperature control of mold cavities.

High Heating Rates and Safety Requirements

Laser-based plant technology, with its high power density, is particularly suitable for high heating rates up to 300 K/s. A system for using mold-integrated (internal) laser heating in the injection molding process has been developed and tested at the IKV. Integrating laser optics and temperature measurement technology, as in this case, into the injection mold permits highly dynamic heating without the need for handling, right up to the injection stroke [4].

Because of the complicated mold-specific beam-guide optics and the static beam position, however, the internal process is inflexible and involves high mold costs. Based on these findings, the laser-based temperature control was developed into a mold-external process, adapted at the IKV injection molding pilot plant, and investigated for its suitability for different application cases.

To ensure safe operation of the plant, a safety system tailored to the injection molding machine was built around the unit (**Fig. 1**). Besides warning light signals, and a protective circuit integrated in the injection molding machine control, the system consists primarily of radiation shielding. In particular, complete shielding against both the primary radia- »

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References & Digital Version

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Pros & Cons

After an internal laser system for variotherm temperature control integrated into the mold, the IKV has now also designed a flexible external system, which is traversed into the mold parting plane by a handling robot at the beginning of a cycle. Both systems have their pros and cons.

Internal solution

Pros: What speaks in favor?

- No handling system required
- Heating until the beginning of injection
- Encapsulation of the laser beam from the surroundings

Cons: What speaks against?

- Complicated beam guidance optics in the mold
- High mold costs

External solution

Pros: What speaks in favor?

- Lower mold costs, since no adaptations on the mold are necessary
- Can be retroactively fitted
- Quasi-simultaneous irradiation of different cavity areas is possible

Cons: What speaks against?

- Cooling of the cavity during the handling time
- Complicated safety system around the system

To-Dos before Start of Production

The newly designed laser system permits mold-independent, local variotherm temperature control. The quasi-simultaneous heating can, in particular, be used to avoid local part defects, such as weld seams. The high system costs of the laser system pay off thanks to the fact that it is independent of the mold, since they can be offset by the expensive mold modifications that would otherwise be necessary. In addition, the laser-based system can be used to inexpensively identify the potential of variotherm cooling technology in existing molds. Before the technology is ready for series production, the following points must be dealt with:

- Increasing the mold and handling travel velocity in order to minimize secondary processing time.
- Use of mold coatings to improve absorption and increasing the dynamics of the process.
- Individual feasibility analysis of the individual user based on the feasibility analysis performed in this project.

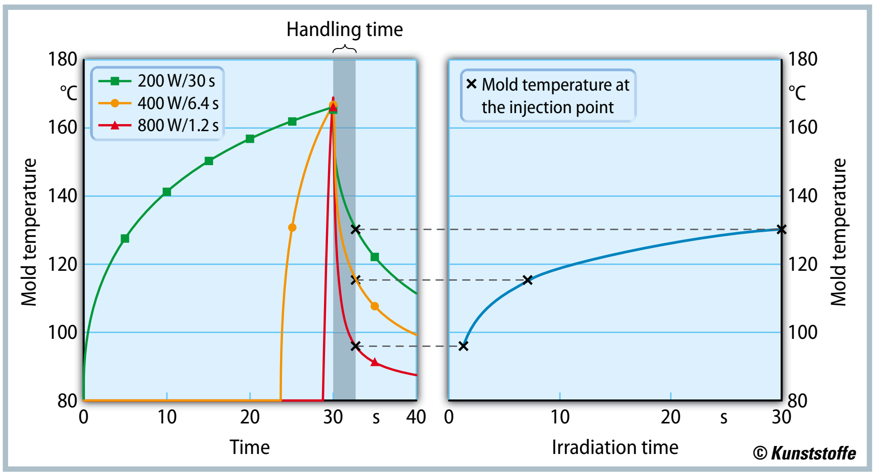

Fig. 3. Different irradiation times lead to different injection temperatures despite maximum temperatures

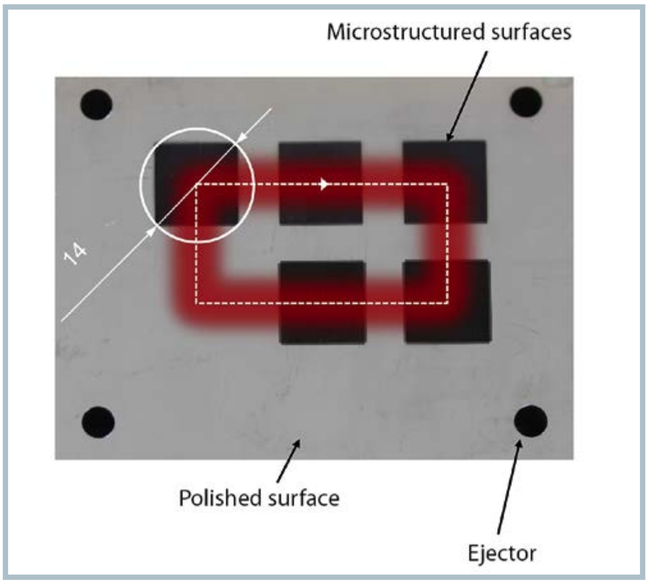

Fig. 4. The heating study for heating microstructured surfaces is based on a rectangular laser path

tion and secondary radiation (scattering) must be ensured here.

The Laser-Based Heating Process

The plant technology is based on a diode laser system type LDF 1500-2700 (manufacturer: Laserline GmbH, Mülheim-Kärlich, Germany), which transmits the laser beam via an optical waveguide to a 2-D laser scanner (type: Rhino31; manufacturer: Arges GmbH, Wackersdorf, Germany). The central wavelengths are around 940/980 nm ± 10 nm. The laser scanner travels into the parting plane with a handling system. Here, the laser beam is outcoupled via the laser scanner onto the cavity with a maximum output power of 2.7 kW, at a beam waist diameter of 4.2 mm in the focal plane (160 mm) and a beam parameter product of 180 mm•mrad.

With the aid of the laser scanner, the travel path of the laser beam can be adapted to the old geometry in a working field of 240 x 240 mm². The beam caustic additionally permits the beam diameter to be varied. This can essentially be adjusted by means of the distance between the laser scanner and cavity. For this purpose, process planners can use the following relationship:

$$a = f + d_o \cdot \frac{\sqrt{d^2 - d_o^2}}{4 \cdot BPP}; \quad BPP = \varphi \cdot \omega_o$$

a: distance between cavity and laser scanner; f: focal length; d_O: beam waist diameter; d: nominal diameter; BPP: beam parameter product; φ: beam divergence half angle; ω_O : $d_O/2$

Moreover, the beam guide velocities and jump rates of up to 25,000 mm/s permit a quasi-simultaneous and adjustable irradiation of discrete quality-relevant cavity regions (**Fig. 2**). Due to this flexible external guidance of the laser beam, it can be operated independently of the mold. When irradiation is completed, the laser scanner is moved out of the parting plane and the mold is closed. During this time – which is termed the handling time below – the heated cavity surface cools down until the start of injection. This effect must be taken into account in the temperature control of the system.

Highly Flexible Heating Characteristics

The dynamics of the temperature change is mainly dependent on the area-specific laser power and the irradiation time. Short irradiation with high power requires high temperature dynamics, because the radiation in the used wavelength range is almost completely absorbed within a few nanometers [5]. With increasing radiation time, deeper layers are also heated by thermal conduction. However, this slows the cooling after the end of irradiation.

In the handling time of about 3 s, the cavity already cools down partly again. The irradiation time and power must therefore be chosen so that, although the desired temperature is achieved during injection, the cavity surface is not damaged by excessive temperatures (**Fig. 3**). In concrete terms, that means that the annealing temperatures of the steel used must not be exceeded in series operation. The handling time is thus the reason why the full potential of laser-based temperature control cannot be utilized yet.

To allow the laser system to be used in production even without thermographic measurement processes, applications-specific performance characteristics are determined. For this purpose, the radiation time is kept constant at 30 s and the laser power is varied. The illustrated characteristic curve refers to a 500 mm^2 cavity surface with five differently microstructured fields. Three fields have linear structures (50, 100 and 200 µm) and two fields have peaked structures (50 and 100 µm). The beam diameter is 14 mm. The microstructured region is heated by different laser tracking paths. Based on this heating study, the rectangular shape at a travel velocity of 8,000 mm/s was chosen for the further evaluation (**Fig. 4**).

In this case, a maximum temperature of 340 °C and a resulting temperature during injection of 240 °C could be achieved. Since there is a linear relationship between the resulting temperatures and the laser power, target temperatures can be interpolated for the experiments with constant irradiation time (**Fig. 5**). A linear relationship can be confirmed for both structured and unstructured cavity surfaces.

Precise Reproduction of Microstructures

Already during the heating trials, the significantly better absorption degree of the microstructures compared to the surrounding polished cavity surface can be seen. The absorbance is a crucial factor for the heating process and depends on the roughness of the surface and on any structuring that has been performed. On the microstructured surfaces, a 2.38-times higher heating rate could be achieved. Coatings can additionally be used to further increase the absorbance [6, 7]. The results make clear that the power of the laser-based additional temperature control must be precisely adjusted to the particular mold, since not only the geometry to be irradiated, but also the absorbance, is specific to the mold. »

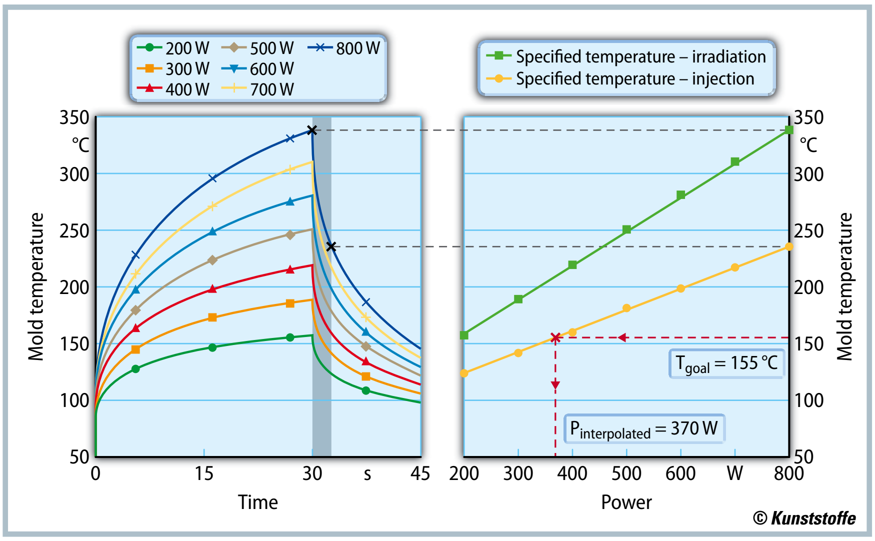

Fig. 5. There is a linear relationship over seven data points in the range under consideration between the set laser power and the defined temperatures

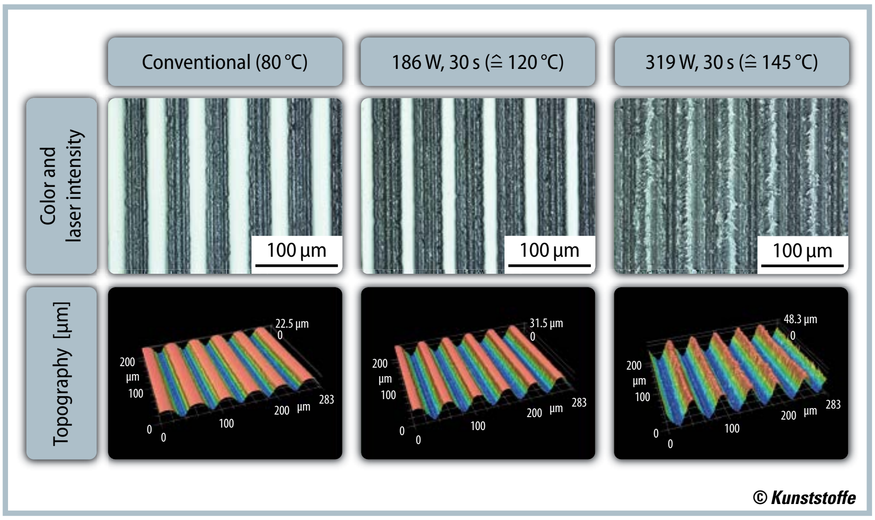

Fig. 6. Reproduction of microstructures in dependency on the mold temperatures obtained during the injection of polycarbonate. The mold wall temperature was varied in three steps by increasing the laser power

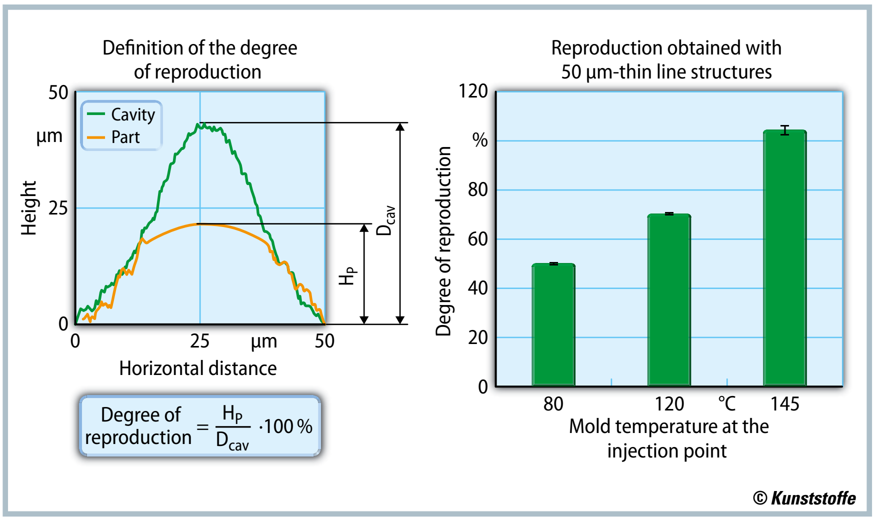

Fig. 7. Reproduction of microstructures and quantitative recording of the degree of reproduction (H_P = Height of the part, D_{cav} = Depth of the cavity). Right: the degrees of reproduction achieved for 50 µm-thin line structures

To validate the laser-based plant technology, the reproduction of microstructures using polycarbonate (PC, type: Makrolon LED 2245; manufacturer: Bayer MaterialScience AG, Leverkusen, Germany) was investigated. The mold wall temperature was varied in three steps by increasing the laser power. This can delay a solidification of the melt in the edge region, and thereby achieve improved reproduction (**Fig. 6**).

To record the reproduction, color and laser-intensity recordings of a confocal laser microscope (type: VK-X200; manufacturer: Keyence Corporate, Osaka, Japan) are evaluated. To quantify this, the degree of reproduction is used, which relates the reproduction actually achieved in proportion to the specified reproduction (**Fig. 7**). From the graph, the achieved degrees of reproduction for 50 µm-thin line structures can be read.

The reproduction visualized here of 100 % at 145 °C mold temperature can be explained by stretching the structures during demolding, which shows the increasing demolding forces with increasing mold temperature. In the case of brittle materials and high mold temperatures, the non-destructive demolding of the structures can be completely prevented. However, the stretching can also be deliberately used for manufacturing microstructured parts with higher aspect ratios.

Summary

The results for reproducing microstructures make it clear that the laser-based process for targeted variotherm temperature control and quasi-simultaneous heating of discrete mold regions is possible. Because of the effect of the rapid laser heating close to the surface, the cavity can also be rapidly cooled with a fluid-based basic temperature control. Since the external design of the laser system unavoidably involves a cooling of the cavity, this must be very precisely matched to the process. The aim here is to reduce handling, and therefore irradiation, times.

Because of the high-energy laser beam, the system requires the integration of a special protection concept. The goal of further R&D work is, against the background of system flexibility, to extend the safety concept, if possible to make the laser scanner usable from both sides, and to improve the temperature dynamics while retaining the same flexibility. ■