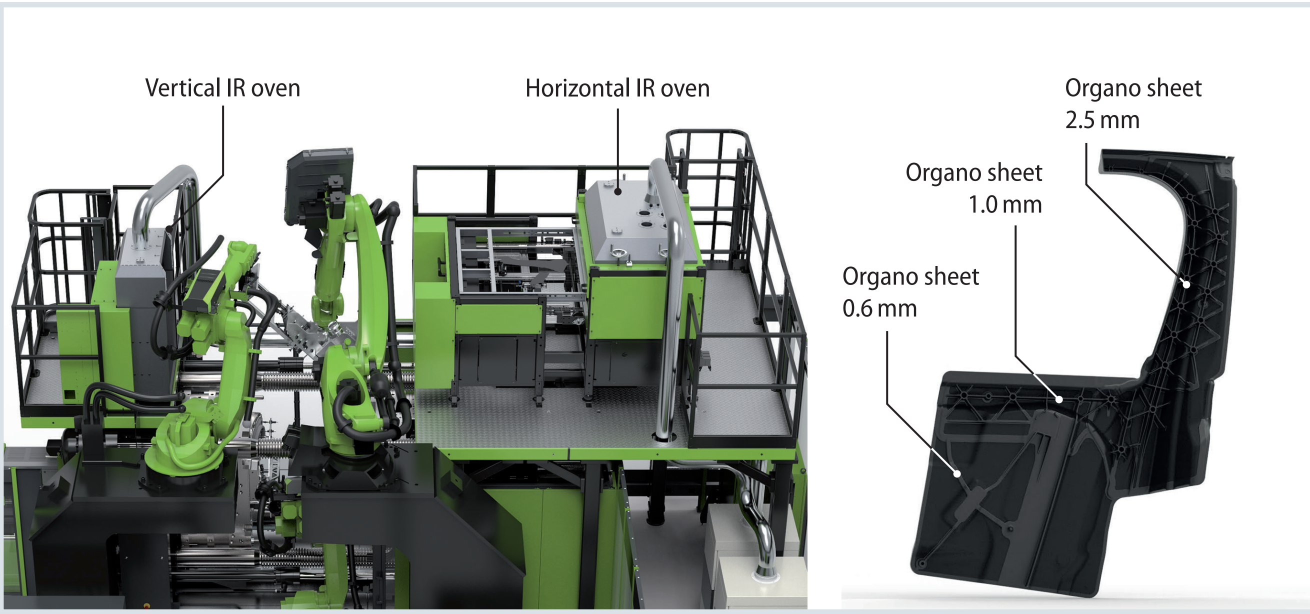
Software-Based Control of IR Ovens

Efficient and Precise Heating up of Thermoplastic Composites

Infrared heating technology has become established as the standard in the processing of thermoplastic composite materials. It makes it possible to heat flat organo sheets of up to about 3 mm thickness within the cycle times characteristic for injection molding processing. The focus is on process control. On the one hand, it is important that the heating process is fast, on the other hand, the material must not be overheated. It is also important to achieve excellent temperature homogeneity. Simultaneous processing of blanks with different thicknesses is a particular challenge.



Three organo sheets of different thickness are heated in two IR ovens in the production of a door structural part © Engel

There are two main reasons why thermoplastic composites are continuing to gain in importance, especially in lightweight automotive design. Firstly, the consistent thermoplastic approach makes it possible to efficiently integrate the forming and functionalization of fiber-reinforced components, which reduces unit costs. Secondly, the use of exclusively thermoplastic polymers makes it easier to develop recycling strategies. Returning composite components to the material loop at the end of their service life is one of the major tasks in the development of new vehicle concepts.

In the established one-step process for the production of thermoplastic composite components, the materials in the form of plate-shaped blanks are located in magazines. They are removed from the magazines by a robot and conveyed to an infrared (IR) oven. After heating, the now malleable composite material is picked up again by the robot and deposited in the mold of the injection molding machine. It is reshaped and reconsolidated by the mold closing movement; immediately afterwards, the desired detail geometries are added by injection molding. After completing the cooling phase, which is required above all for the injection-molded areas, the ready-to-fit composite part is removed from the mold. One of the most important advantages of thermoplastic composites is that the cycle time for producing a technical component is only 40 to 80 s. A thermoset composite solution would require at least a few minutes for this.

IR Oven Supports Fast Hot Handling

The sequence from bringing in the material into the mold to overmolding is particularly time-critical. As soon as the heated composite blank is removed from the IR oven, it begins to cool down. However, to overmold with detailed geometries, there must still be sufficient heat in the material to achieve good adhesion between the composite material and the injected thermoplastic.

Transporting the heated composite blank, known as hot handling, needs to be professionally planned, tested and implemented with the aid of suitable » automation solutions. The design and positioning of the IR oven are also crucial. Engel Austria GmbH, Schwertberg, Austria, offers IR ovens, developed and produced in-house, in both horizontal and vertical orientation with optional single-sided or double-sided heating panels in various designs.

For thin materials, a vertical IR oven positioned on the stationary mold mounting platen of the injection molding machine often offers advantages. The thinner the material, the faster it cools down. The spatial proximity of the IR oven and the mold shortens the move paths and reduces the handling time accordingly. Single-sided IR ovens are often sufficient for heating up thin materials with wall thicknesses of up to 1 mm. In addition, the single-sided design of the vertical IR oven facilitates accessibility and rapid removal of the heated blank.

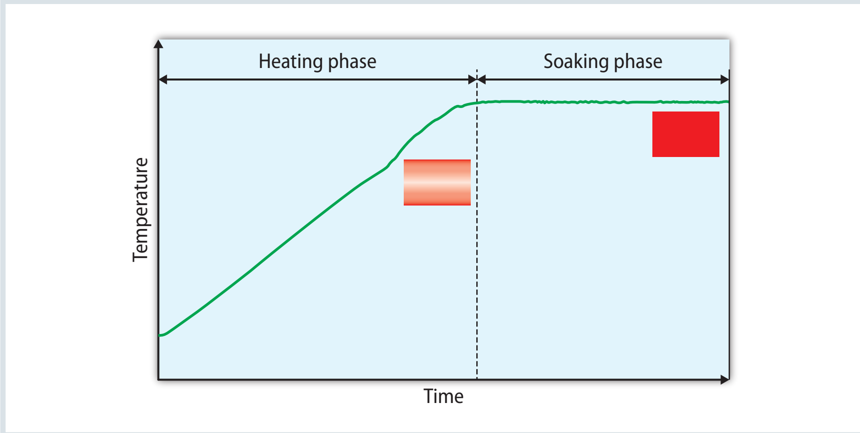


Fig. 1. The surface temperature is monitored using pyrometers during the entire heating process. A double-sided IR oven is equipped with six pyrometers as standard equipment. The picture shows an example of the temperature curve at one measuring position during the heating phase and the soaking phase Source: Engel; graphic: © Hanser

Efficient Heating of Thick Semi-Finished Products

The fact that infrared radiation, which has a high energy density, is excellently suited for heating up thermoplastic composite semi-finished products is attributable to the structure of the plate-shaped materials. The blanks typically consist of several individual layers, between which there are no cavities after stacking and consolidation. This ensures that the heat is conducted rapidly from the surface to the core. As infrared radiation acts quickly and is, at the same time, a zero-contact method, preforms of various thicknesses can be heated up to well above the melting point of the matrix polymer without causing adhesion problems.

The depth to which the electrons are excited depends on the wavelength of the IR radiation and the absorption behavior of the material. Typical thermoplastic matrix materials have relevant absorption bands in the range of a wavelength of 2 to 3 µm [1]. Medium-wave infrared radiators achieve a high radiation intensity in this range, which is why they are first choice for heating up thermoplastic composites. This allows a penetration depth of up to 0.5 mm to be achieved. Rapid heating occurs in this layer just below the surface.

With thicker organo sheets in particular, it can happen that the core is not yet sufficiently heated although the surface has reached its target temperature. The heat required to melt the core area can only be transferred into the material by conductive heating. Plastics and glass fibers are relatively poor heat conductors, which is why soaking the core area takes some time. To ensure that the core area has reached the required temperature, the surface is kept at the set temperature for a defined, empirically determined time.

Infrared radiation is the most efficient method for heating up organo sheets. In terms of heat conduction, the layer near the surface is a kind of internal heat source that no longer has to overcome thermal transfer resistance, as is the case in pure contact or convection heating. Especially compared to convection heat-

Fig. 2. A double-sided horizontal IR oven with 1100 x 600 mm payload area: the radiators are combined into groups to allow for control on the basis of a specific temperature measurement © Engel

ing, infrared heating achieves significantly shorter heating times. In general, IR ovens are suitable for all relevant matrix polymers, including the high temperature plastics PAI, PPS, PEKK, and PEEK.

Highest Temperature Homogeneity with Optimum Material Protection

The challenge in heating with infrared radiation is to achieve an optimum combination of high efficiency and good temperature homogeneity without degrading the material due to local overheating. The target or setpoint temperature, which is usually well above the melting temperature, may at most only be slightly exceeded. To ensure this, the surface temperature is monitored using pyrometers during the entire heating process. The measured data are fed back into process control. **Figure 1** shows an example of the temperature curve for a single measuring position during the heating and soaking phase for a semi-crystalline thermoplastic, such as polypropylene or polyamide.

Virtually linear progressions until the crystallite melting point is reached are characteristic of this. The heating rate is determined by the power per unit area of the radiator, the absorption coefficient, and the heat capacity and thermal conductivity of the thermoplastic composite. The heating rate decreases when it approaches the crystallite melting point – for polyamide 6 this is approx. 223 °C. Part of the supplied energy is used for melting the spherulites. Once the matrix material has melted, the heating rate increases again and even becomes more dynamic than below the crystallite melting point. The molten polymer has a lower density and heat capacity and responds accordingly with faster heating. Close to the desired temperature, the control for the soaking phase kicks in and limits the further temperature increase to prevent overshooting.

The slightly irregular curve around the crystallite melting point is due to the processes involved in melting the thermoplastic matrix material. Due to the temperature distribution over the material's cross section and the temperature-dependent absorption coefficient, the effects are spread over a larger temperature and time range.

In order to obtain a completely linear heating process, the heating rate can be limited to a certain value and promoted to a control parameter. However, it is in the interest of process efficiency and also of material protection to fully utilize the heating power of the IR radiators in the heat-up phase as long as no significant local temperature deviations and also no overheating of the composite surface are detected.

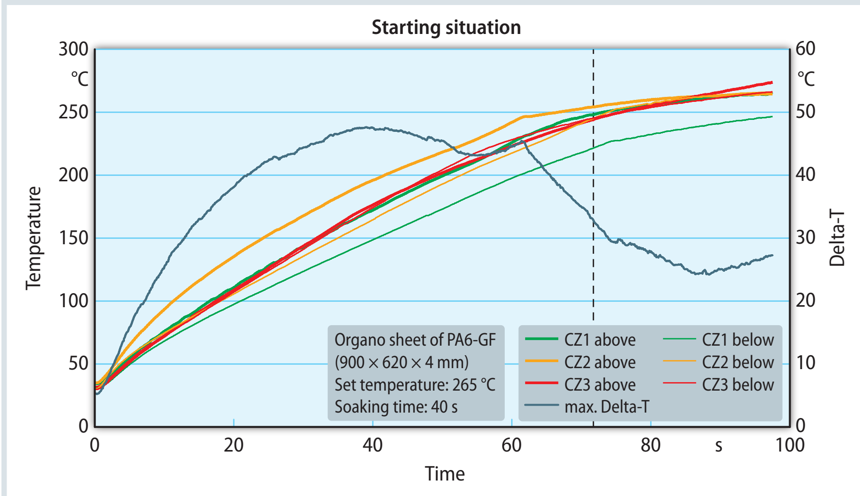


Fig. 3. In the experiment, thermal inhomogeneities were specifically induced (initial situation). The resulting heating curves were then optimized by automatic process control (CZ = control zone) Source: Engel; graphic: © Hanser

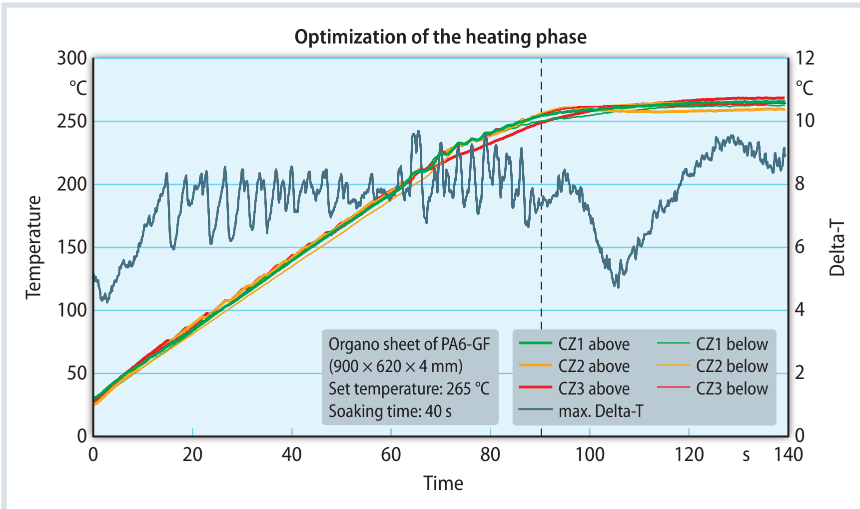


Fig. 4. Automatic optimization of the heating behavior leads to a more uniform, almost linear temperature rise Source: Engel; graphic: © Hanser

Controlling a Large Variety of Operating States

IR ovens might be set up to provide optimum temperature homogeneity for a specific operating point, for example, when it is loaded with 70 % of the nominal payload area in the form of a rectangle. However, since the real operating point usually deviates significantly, this is not meaningful. A system with a very good basic characteristic in terms of thermal homogeneity is more useful. The software of the Engel IR ovens is therefore capable of optimally controlling a large variety of operating states and influencing variables, which enables excellent thermal homogeneity over a wide range of applications.

The IR oven design principle assumes a full load, i.e., the use of the entire radiator area minus the defined edge width. The IR oven shown in **Figure 2**, for example, has a radiator area of 1250 x 750 mm and a nominal payload area of 1100 x 600 mm. Radiators that are not required can be switched off individually. In addition, several radiators are usually combined into groups and the whole » group of radiators is controlled on the basis of a specific temperature measurement.

The possible causes of thermal inhomogeneities are complex. Among other factors, the influence of the control zones on each other, extend and shape of load in the payload area, the ambient conditions, and the transient behavior of the IR oven all play a role.

Precise control of the IR heating process is an essential part of process control in the manufacture of thermoplastic composite parts. In Engel system solutions, the IR oven control is therefore integrated into the injection molding machine control unit. This allows the process parameters and measured values of the IR oven to be documented along with the production data from the injection molding process.

Reaching Targets Simultaneously with All Control Zones

Due to the multitude of possible causes for thermal inhomogeneities, each control zone (CZ) has a different heating characteristic in practical applications. In an experiment, thermal inhomogeneities were specifically induced (**Fig. 3**). It was demonstrated that this results in clear differences in the heat-up rate. The desired temperature is reached at different times and stabilization of the surface temperature at the desired temperature is delayed. This situation served as the starting point for automatic heating behavior optimization.

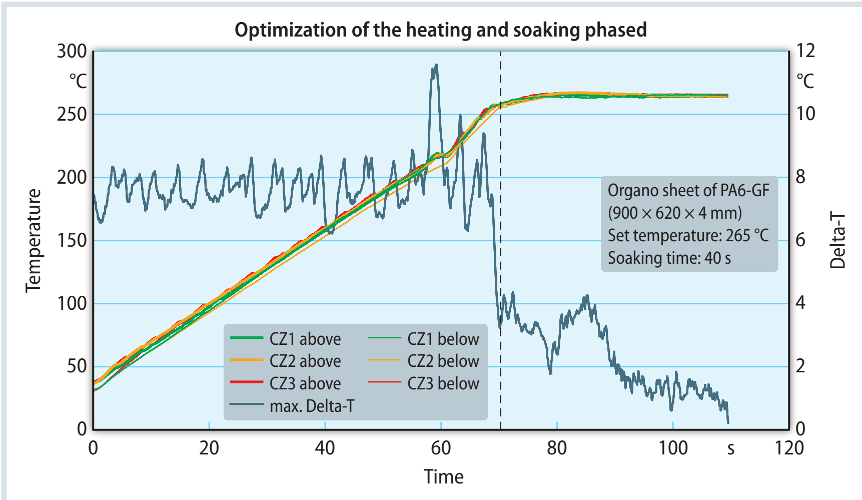


Fig. 5. Software-supported optimization of the control parameters ensures high control quality in the heating phase Source: Engel; graphic: © Hanser

The improved behavior is shown in **Figure 4**. The control strategy relies on comparisons between the current actual temperatures in the respective control zones. The heating curves now show a uniform, almost linear progression. Stabilization in the area of the temperature setpoint has improved significantly compared to the initial situation.

In the case of a control zone that reaches its temperature setpoint early at full radiator power, the radiator power must be reduced early in the heating phase. Automatic reciprocal optimization and coordination of the control zones means that the radiator power of all affected control zones is continuously adjusted to keep the deviations within an adjustable narrow tolerance band. This results in a uniform heating rate for all control zones and all control zones reach the temperature setpoint at the same time.

What is of particular importance here is that the process control strategy does not require a lead control zone. The values measured by all the pyrometers are permanently considered and a highly dynamic heating process is implemented in all control zones; the process is adapted to the specific behavior of the matrix material during heating, melting and further heating of the material in the melt phase.

When the surface temperature approaches the temperature setpoint, further granular adjustment during process control must prevent the surface temperature from overshooting. High temperature consistency in the soaking phase ensures that the target temperature in the core area is reached at a precisely predictable time. Heating up of the thermoplastic composite can therefore be terminated after a defined, and shortest possible duration; this in turn contributes towards protecting the material.

Especially in the soaking phase, it is crucial to keep temperature deviations low to avoid local overheating and degradation of the material. For this purpose, the control parameters must be adjusted in the best possible way. For example, if the material, the blank size or the thickness of the material is changed, the control parameters for the soaking phase also need to be readjusted. A separate measuring cycle can be utilized to automatically optimize the control parameters. Doing so delivers information on the existing control behavior and based on these, the control parameters are recalculated and adjusted. This results in the excellent control quality shown in **Figure 5**.

Heating up Semi-Finished Products of Different Thicknesses Together

The **Title figure** shows the fully automated production cell for a door structure component made of three organo sheets of

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References & Digital Version

- You can find the list of references and a PDF file of the article at *www.kunststoffe-international.com/archive*

German Version

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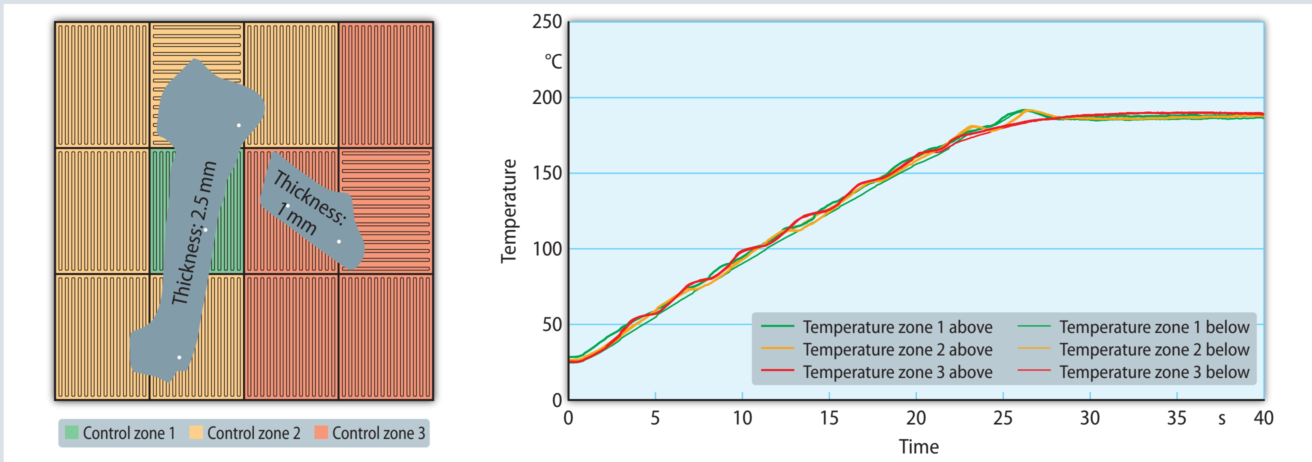


Fig. 6. Thanks to automatic process optimization, the two organo sheets reach the temperature setpoint at the same time despite of their different thicknesses Source: Engel; graphic: © Hanser

different thickness. The blanks with thicknesses of 1.0 and 2.5 mm are heated together in a horizontal IR oven (Fig. 6). Under standard conditions the thinner organo sheet would heat up far faster than the thicker one. However, limiting the maximum permissible temperature deviation between the control zones ensures a uniform and even temperature profile. The two blanks reach the temperature setpoint simultaneously. A single-sided oven with a vertically arrangement is used for the 0.6 mm organo sheet. The main focus here is on particularly fast hot handling, because the very thin composite blank cools down very quickly. The three blanks are brought together in the mold. Within a cycle time of 70 s, they are processed to create a composite part with load optimized design.

Conclusion

In combination with automation, infrared heating technology is key to optimum processing of thermoplastic composite materials. Innovative strategies for controlling the heating processes make it possible to achieve rapid and highly precise heating processes in order to process organo sheets of different thicknesses in a single step. The machine operator is supported by automatic optimization routines for fine tuning. Software-supported determination of suitable control parameters leads to very constant surface temperatures during the heating phase. External influences are automatically eliminated by control actions before they lead to critical process deviations. ■

Ultra Helix 250 T2 Nozzle from Husky

Direct Gating for Small Parts

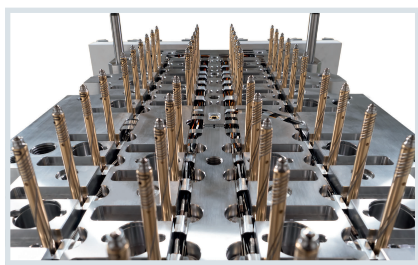
Husky Injection Molding Systems Ltd., Bolton, ON/Canada, released the new addition to the Ultra Helix valve gate nozzle lineup. The advanced design of these nozzles minimizes wear, providing industry leading gate quality and longevity as stated in a press release. The award-winning Ultra Helix 250 T2 was specifically developed to extend the benefits of the Ultra Helix technology for small part weights with difficult to access gate locations.

With a 12 mm nozzle bore, the Ultra Helix 250 T2 allows for direct gating in locations not achievable with larger nozzles. The pitch spacing down to 15 mm enables the highest cavitation density and smallest mold footprint.

The new nozzle's extended maintenance interval PX actuation is designed for applications with leakage prone resins like TPE and PE. The addition of a stem seal paired with enhanced thermal management heater technology improves performance and significantly optimizes maintenance requirements. This results in lower risk and cost of ownership.

The Individual Pneumatic option offers pitch spacing down to 25.4 mm, providing ease of access for maintenance with the ability to individually access valve stems without removing the backing plate. Both the plate actuated UltraSync-P or servo driven UltraSync-E options can achieve 15 mm pitch spacing.

Applications are high quality precision parts from medical barrier closures and flow regulation valves to personal care products, food and beverage packaging and flip top closures. The part weights being produced range from less than 0.1 g to over 4 g and are being made from resins that are prone to leakage like PP, HDPE, LDPE, TPE and TPV, in both single injection and multi-material applications. According to the company, the Ultra Helix 250 T2 is already demonstrating its superior performance for small part weight with difficult to access gate location applications in both Individual Pneumatic and UltraSync actuations.



Multi cavity hot runner system with Ultra Helix 250 T2 nozzles © Husky