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Efficient Production of Thick-Walled Parts

Thick-Walled Lenses

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**Thick-Walled Lenses.** Injection molding is demonstrating its versatility again in the production of challenging optical plastic parts such as LED lenses for automotive headlights with tolerances in the micron range. A new development in multilayer injection molding allows productivity for the production of thick-walled lenses to be increased even further.

The markets for plastic optical parts differ significantly from region to region. While imaging optical parts for mobile appliances predominate in Asia, in Europe the main focus is on the production of thicker lenses for LED lights. Since the cooling time during injection molding increases with the square of the wall thickness, the biggest challenge is to develop economic processes. With a typical thickness of 30 mm for automotive headlamps, cycle times of at least 20 min are to be expected with standard injection molding processes [1].

One possibility for cycle time reduction is multilayer technology, in which the thick-walled parts are built up from multiple successive layers. The multilayer structure can be generated by overmolding a first layer at either one or both sides, or by subsequently bonding together two previously independent layers by means of an interlayer (Fig. 1).

In general, the individual layers are all produced on the same injection molding machine. The use of separate injection units for the three layers is already a first step towards short cycle times. This ensures that the process steps of injection, holding pressure and metering take place simultaneously and independently of one another.

**What are the Benefits of Multilayer Technology?**

Approximation formulas for cooling time and productivity can be derived from theoretical considerations (see box p. 6) and the results illustrated in dependence on the number of layers (Fig. 2). The literature [1–3], however, shows that this rule of
thumb provides too optimistic results for estimating the cooling time saving.

However, multilayer molding offers the possibility of maintaining the mold regions for those surfaces that subsequently have to be overmolded at a lower temperature, since, in an ideal case, the surface quality of the internal layers does not affect the quality of the lens that is produced. If this potential is used for the manufacture of the preform, the estimated cooling time reduction agrees well with simulated and practical results. For optimizing the layer thickness distribution, it is advisable to carry out simulations.

From Figure 2, the following statements can be derived:

- For the cooling time per cavity, it is unimportant whether overmolding is performed on one or both sides. In both cases the cooling time is reduced to the same degree as the number of layers increases.
- Overmolding on one side requires a larger number of cavities, and therefore more space in the mold, compared to overmolding on both sides.
- Productivity is a suitable key indicator for an economic comparison, because it includes the assumption of equal numbers of cavities.
- It is only with a large number of layers that overmolding on one side improves productivity to a significant extent. However, the productivity actually obtained is affected by the times for mold opening, mold closing, mold transfer/rotation and injection.
- For overmolding a preform on both sides, on the other hand, the productivity increases significantly starting with a three layer structure.
- The sandwich option, consequently, has an advantage over overmolding on one side. This alternative also improves the contour accuracy, since sink marks in the preform due to shrinkage can be compensated by overmolding. Shrinkage of the thinner outer layers is thus responsible for the contour accuracy. This effect is also present for overmolding on one side, but of course only on one side. The quality of the other surface must therefore meet requirements immediately after molding, since it does not contain a corrective top layer.

Where there is light, there is also shadow: despite all the advantages of the sandwich alternative, it must not be overlooked that it requires a more complex mold technology. Retaining the preform in the cavity and transportation from one cavity to another is challenging, while a rotary table is sufficient for one-sided overmolding. The simultaneous filling of the outer layers should be well balanced – pressure differences between the top and bottom layers can cause the preform to fracture.

Both methods can offer further benefits. Cold-runner sprues or thin-walled exterior regions limit the possible maximum holding pressure time. With very thick-walled parts, the sink marks can thus only be counteracted by increasing the holding pressure. This in turn requires machines with relatively high clamping forces. Extreme wall-thickness ratios can, in some cases, only be achieved through multilayer molding. The result is a gain in design freedom.

With the cycle time, the residence time of the material in the barrel and hot runner also decreases. That has the benefit of reduced yellowing and therefore greater transmission. The maximum residence times recommended by the material manufacturers can be maintained. The Title figure shows a series application of the
three-layer sandwich process, production of LED headlamps at Automotive Lighting Reutlingen GmbH.

**Shorter Cycle Times thanks to Longer Cooling Times**

Investigations have shown how multilayer molding can increase the profitability of the production of thick-walled parts. It takes advantage of the fact that several thin layers will cool more rapidly than one thick layer. This can increase productivity by approximately a factor of two. However, the resulting cooling times of several minutes are still comparatively long for injection molding.

Considerations about the layer distribution generally assumed that, with a three-layer sandwich structure, the preform and the top layers must be cooled to below the glass transition temperature at the end of the cooling time. However, tests have shown that the preform can be removed much earlier. It must only be ensured that its solidified outer layers are sufficiently strong to withstand the internal pressure and prevent deformation during demolding. If the preform is immediately overmolded in the next station, no cycle time reduction would be gained, on the contrary: the still-hot inner regions of the preform would be further distanced from the mold wall and the cooling time would be extended.

A new process therefore includes a cooling stage outside the mold between the injection shots. Cooling in air does not influence the cycle time. Depending on the duration of the external cooling, the preform can have a lower average temperature during overmolding than a preform in conventional sandwich technology. As a result, the preform absorbs more heat from the top layers and thereby reduces the cooling time. This effect can be further increased by making the preform thicker and the top layers thinner.

**Process Sequence with External Cooling**

The new process sequence is as follows: A preform for some cycles externally cooled to a predefined temperature is inserted into the mold again and overmolded. A new preform is then produced simulta-

Fig. 4. For a process comparison, a cuboidal polycarbonate part (40 x 38 x 20 mm) was used (figure: Bayer MaterialScience)
is still 220°C. With this new process the total cooling time in the mold can be cut in half. Since the number of required cavities is the same compared to the known sandwich process, the productivity increases by the same factor by which the cooling time decreases.

The rapid solidification rate of polycarbonate is beneficial for short cycle times. Simulations for polymethyl methacrylate (PMMA) with adjusted melt and mold temperatures generated a total cooling time that, at 314 s, was almost twice as long. Figure 6 compares the cycle times and productivity of the three processes for the processing of polycarbonate.

**Record Cycle Time**

Tests and simulations demonstrate that, for the manufacture of thick-walled parts with external intermediate cooling, the cooling time in the mold can be reduced by 25 to 50 % compared to conventional multilayer molding – depending on the geometry of the part. At K 2013, the injection molding manufacturer Engel – together with its project partners Bayer MaterialScience and the Krallmann Group – will be demonstrating the potential of this process live for the first time. The production of an optical lens from PC (type: Makrolon LED 2245) in record time will be demonstrated.

![Fig. 5. Simulated maximum temperature within the part in dependence of time for a single-layer process (top), a three-layer sandwich process (center) and the new three-layer sandwich process with external intermediate cooling (melt temperature 280 °C, mold temperature outer layers and single-layer variant: 120°C, mold temperature inner layers: 70°C). The graphics also include the temperature distribution in the part interior after 164 s (figure: Bayer MaterialScience)](image)

![Fig. 6. Simulated cooling time per mold station and the calculated productivity for different manufacturing processes (material: PC). The single-layer part is used as a reference (100 %) for comparison (figure: Engel)](image)

**REFERENCES**


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Cycle Time and Productivity – Considerations on the Layer Structure

What layer sequence is most appropriate, how many layers are necessary and what savings potential can be expected? These questions can be answered with a few considerations that apply to one-sided and two-sided overmolding, but not to the bonding of two preforms (Fig. 1).

Since the heat removal from the connecting layers follows relatively complex laws, this alternative will not be considered.

First, two assumptions are made: Firstly, known mold concepts (index plate, rotary table, sliding table) are used. Ideally, a further preform is manufactured simultaneously with the overmolding of one preform. From this the requirement, known from multicomponent injection molding, follows that the cooling times of all layers must be the same.

Second, it should be noted that only the layer manufactured first is cooled on both sides (layer 1 in Fig. 1). The following layers only have contact with the mold wall on one side, while the preform borders on the other side, which, for the sake of simplicity, is regarded as an ideal insulator. To obtain the same cooling time in all stations, the following layers, which are cooled on one side, should be only half as thick as the first layer, which is cooled on both sides.

On the assumption that the first layer of a part produced from n layers is only half as thick as all the following layers, the layer thicknesses $s_n$ of the first layer and $s_f$ of the following layers are as below, where $s_{total}$ describes the total thickness of the part:

$$s_n (n) = \frac{2}{n+1} s_{total}$$  \hspace{1cm} (1)

$$s_f (n) = \frac{1}{n+1} s_{total}$$  \hspace{1cm} (2)

The cooling time is proportional to the square of the wall thickness. The cooling time $t(n)$ of the first layer (which is cooled on both sides), corresponding to the cooling time $t(1)$ of all further layers (which are cooled on one side) is described by the following equation:

$$t(n) = t(1) \times \left(\frac{2}{n+1}\right)^2 s_{wave}^2$$  \hspace{1cm} (3)

During overmolding on one side, n stations in the mold are necessary, i.e. as many stations as layers. In the sandwich variant, in which two layers lying one behind the other are produced simultaneously as in a stacked mold, only $(n+1)/2$ stations are necessary. In this case, the number of layers $n$ must be odd.

Overmolding on two sides, compared to on one side, does not at first offer a cooling time reduction, but provides the advantage of the stack mold, i.e. a saving of platen area and clamping force.

The relative cooling time per mold station, i.e. the cooling time compared to that of a single-layer part, is:

$$\frac{t(n)}{t(1)} = \left(\frac{2}{n+1}\right)^2$$  \hspace{1cm} (4)

The number of parts $T(n)$ per unit time corresponds to the reciprocal of the time per part, i.e. the reciprocal of the cycle time. Instead of the cycle time, the cooling time is used here, which is permissible to a first approximation for very thick-walled parts. From the reciprocal of equation 4, the relative number of parts is thus obtained:

$$T(n) = \frac{t(1)}{t(n)} = \left(\frac{n+1}{2}\right)^2$$  \hspace{1cm} (5)

However, the cooling time or number of parts are only conditionally suitable as values for an efficiency comparison. These values do not take into account the fact that multilayer processes require a larger number of cavities. However, increased efficiency can be expected from larger numbers of cavities anyway. If with single-layer processes, for example, twice the number of cavities is available, the number of parts per unit time would also be twice as high.

The productivity is therefore used for the further assessment. It is defined as the ratio between the produced parts and the production factors necessary for this, in this case the cavities. To obtain the relative productivity of multilayer molding compared to the single-layer method, equation 5 only needs to be divided by the number of cavities – i.e. by $n$ in the case of overmolding on one side and by $(n+1)/2$ in the case of overmolding on both sides:

$$\frac{P(n)}{P(1)} = \frac{1}{n} \left(\frac{n+1}{2}\right)^2$$  \hspace{1cm} (6)

for overmolding on one side

$$\frac{P(n)}{P(1)} = \frac{n+1}{2}$$  \hspace{1cm} (7)

for overmolding on both sides