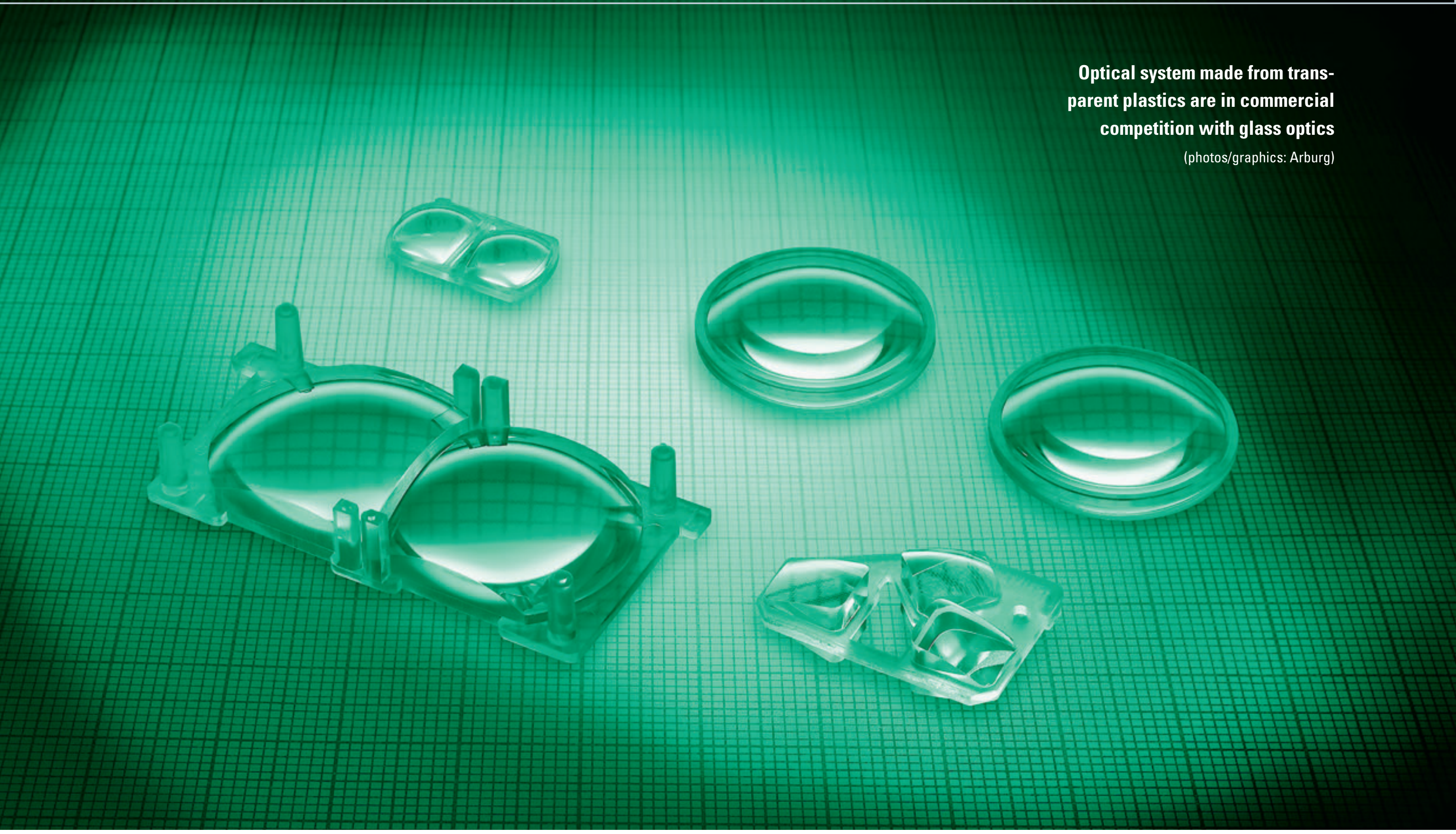

Optical system made from transparent plastics are in commercial competition with glass optics
(photos/graphics: Arburg)

For True Insight

Optical Parts (1). Glass is being increasingly substituted with plastics in the field of optics, too. Since the varying wall thickness of such parts does not conform to the design guidelines applying to polymers, injection coining is coming into use as an alternative to classic injection molding. The production of function parts requires understanding not only of processing technology and mold making, but of optics and metrology as well.

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The technical advantages of plastics are the reason why they are increasingly replacing glass for optical applications **(Title photo)**. Their potential as substitutes for optical function surfaces comes from their design freedom, capability for integrating several functioning parts, low materials cost and low specific weight. Injection molding enables them to be produced in a single processing step with high quality and for a comparatively low price.

A very high level of competency in several engineering disciplines is required to produce such articles. When optical components are being designed and developed, calculation methods and polymer materials to be processed are the major issues. The shaping process requires considerable know-how in mold and processing technology. If consistent quality assurance is to be achieved, a good foundation in the science of metrology is also necessary. For the producers of molded parts, optical articles represent a considerable challenge. Besides the usual standard of dimensional accuracy, optical functions have top priority.

Optical Function as a Sign of Quality

Injection molded optical parts can be classified by their type of use. The distinction here is between imaging and non-imaging optics, whereby the non-imaging ones can be termed illumination optics and the imaging ones image process-

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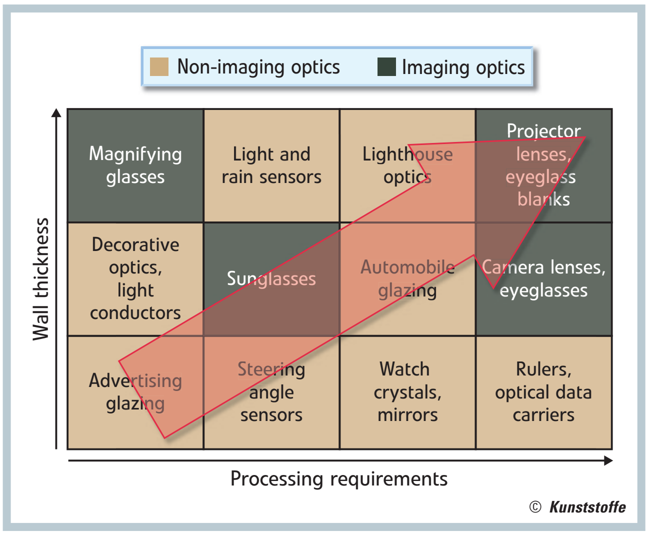


Fig. 1. Optical parts can be classified according to their application as imaging and non-imaging optics

ing optics **(Fig. 1)**. Depending on wall thickness and process requirements:
- the demands on optical function are greater,
- injection coining becomes increasingly more attractive as an alternative and
- the measuring system becomes more complex.

Examples of non-imaging optics included headlights glazing or watch crystals. Outside geometry and transparency of the part are the main criteria. The situation is similar with light conductors that transport rays coupled into them from a light source and coupled out at one or more pre-defined points. Imaging optics also transport light rays, but in order of input. Individual image pixels are projected through the optics in such a way that a sharp image appears on the target.

Boundary layers where light is coupled in and out have to be very precisely shaped in order for both imaging and non-imaging optics to perform their optical function. This requires a very high degree of molding accuracy. Internal stresses can also influence the light path, thus impairing part quality. In other words, not external geometry, the usual criterion of molded part quality, but optical function is crucial. And the criterion for optical function is refractive index.

Component wall thickness is a critical parameter. It determines cooling time and thus has considerable influence on shrinkage effects. That is why component designers make every effort to keep wall thickness as small as possible. Part thickness distribution should also be approximately uniform in order to control shrinkage.

Contrary to Polymer Design Engineering

Optical components are rarely designed from the point of view of polymer engineering. They have functionality in that they conduct light. One of the consequences is products with thick walls and great differences in wall thickness. For the injection molding process, that in turn means comparatively long cycle times.

For the resulting part geometry to conform to reference geometry, shrinkage effects have to be considered in detail when the part is being designed. The high molding precision required plus the phenomena involved in thick-walled parts make it essential to have comprehensive knowhow of the entire processing chain. Classic injection molding paired with conventional mold temperature control run up against their limits then. That is why concepts from variothemic mold control and injection coining are increasingly coming into use.

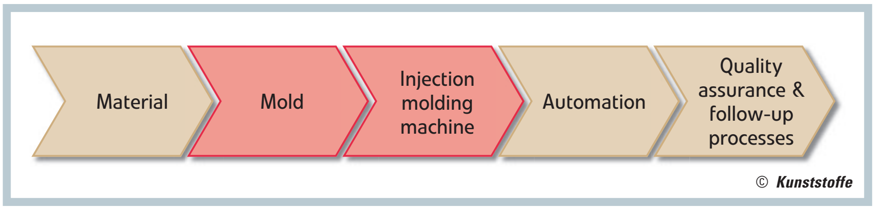


Fig. 2. To produce optical parts by injection molding, the processing chain must be considered in its entirety prior to startup

The production of high-quality optical components cannot do without a holistic approach to the production chain and the system technology involved in it **(Fig. 2)**. In addition to the injection molding step itself, it includes prior materials conditioning and subsequent operations such as removal, quality assurance and other follow-up processes. They can be coating, assembly or packaging steps.

Material Leaves Processors Little Freedom

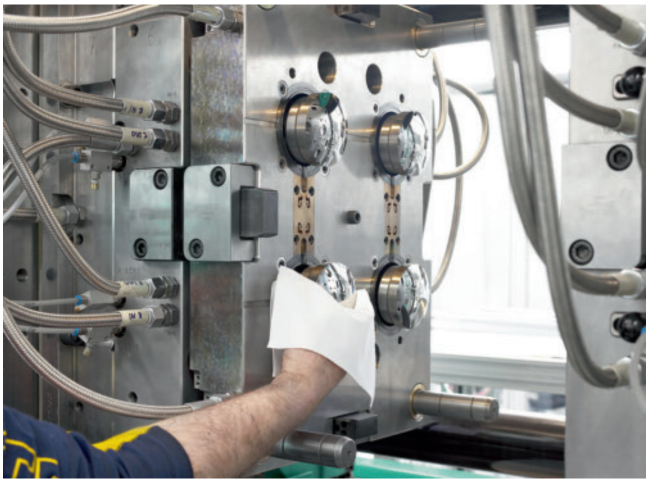
In transparent parts, any type of contamination, inclusions or streaking are spotted immediately as defects in the part. Investigations usually do not turn up clear causes. That is why fundamental rules such as cleanliness and reproducibility must be maintained in all processing steps. That is why measures derived from cleanroom technology are utilized in many cases.

The processor has little freedom with respect to materials. Optical and mechanical raw material properties are tuned to each particular application. Some materials manufacturers supply special charges in so-called optical grades for which they guarantee special purity and absolutely no dust in the material. Dust particles can lead to problems, since such particles either exhibit different plasticating behavior from that of the granulate, or do not melt down at all. Then they will be transported along with the melt and can, under certain circumstances, end up as contaminations in the part.

For the granule drying system as well as the materials conveyor system, it is crucial that their design seals out dust, and that the conveyor system neither acts abrasively on the material nor is eroded by the same. The path from the granulate container to the screw intake should be short and clear. For applications requiring a high degree of cleanliness, such as the production of ophthalmic lenses for eyeglasses, so-called dust arresters are often mounted between the material separator and the intake zone.

Short Paths to Tempering

Sophisticated optical parts require a mold technology adapted to their quality criteria. High and long holding pressure phases as well as high temperatures are a matter of course. Thus sufficient stiffness is demanded when configuring and design- →



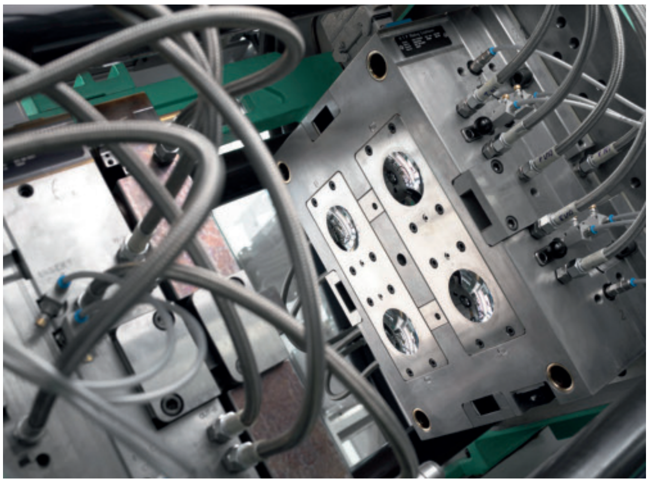


Fig. 3. Exchangeable mold inserts enable rapid product change; their highly accurate function surfaces are machined with diamonds for precise shaping

ing the injection molds. Both corrosion resistant and standard tool steels equipped with chemically isolated anti-corrosion coatings are used for mold construction.

The precise optical function surfaces can usually be changed with mold inserts **(Fig. 3)**. Their surfaces, such as sculptured shapes, lens arrays or reflector prisms, are usually machined in with diamonds for precise shaping. Although the mold inserts are exchangeable, effective temperature control must be ensured.

As in cleanroom technology, superfluous surfaces should be avoided where contaminations can be deposited. Electric und hydraulic lines as well as cooling circuits should not be dragged along by mold motions. In order to supply the mold through short lines, the moveable clamping platen is equipped with appropriate interfaces **(Fig. 4)**.

Mold temperatures and other sensor inputs are recorded and monitored in the machine control. Cooling equipment data are transmitted via standard interfaces to machine control and thus to QS evaluation. To enhance processing stability, it is advisable to control media flow. The cooling equipment should be equipped with a suction mechanism for use when cavities are exchanged or the mold is dismounted.

Series of Articles

This is the first of two articles on this topic. In a second article, the authors will delve more deeply into all possible versions of the mold and processing technology for making optical parts by injection-coining. The sequel will appear in ***Kunststoffe*** international 11/09.

Coordinating all Machine Quantities

There is no typical machine concept for optical applications. The suitable design is rather derived for each case from part size, required coining pressure, as well as the necessary mold and processing technology.

The mold is the central item when configuring machine size. Mold size and holding pressure requirements determine platen area and coining pressure and thereby primarily the size of the machine. The injection unit is modular and adapted to specific requirements. The criteria here are shot weight, the polymer to be use, expected cycle time and necessary injection pressures. The shot weight height and the expected injection pressure are relevant when selecting screw diameter. An ideal shot weight lies between 20 and 80 % of the maximum output of the screw selected. The dwell time of the polymer in the melt can be determined by screw diameter and cycle time. The latter has to lie within the limits prescribed by the manufacturer for the particular raw material.

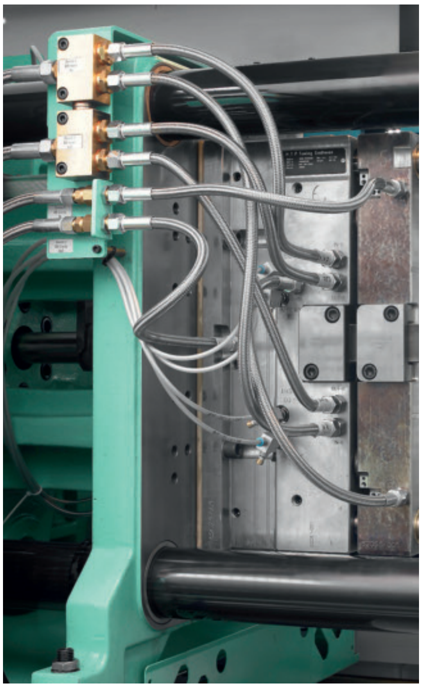


Fig. 4. Cooling hoses are mounted directly on the moveable platen to prevent them from being moved by mold travel and to keep the supply lines as short as possible

In actual practice, compromises often have to be made especially where dwell time is involved. When part walls are thick, long cycle times are often the result and lead to correspondingly long melt dwell times in the plastication cylinder. Potential consequences include thermal oxidation together with increasing yellowing of the material, i.e., a finished part quality impaired by them.

Mainly highly wear resistant versions of the cylinder module, screw and non-return valve are used as components in the plastication unit. In addition, wear-protected (chromium nitride coated) screws and non-return values are utilized for processing polymers that tend to adhere and can thereby form so-called black spots in the part.

The Right Production Surroundings

Fundamentally speaking, optical component production is not limited to one particular machine technology. State-of-the-art injection molding machines are equipped with control and sensoring systems that fulfill the necessary conditions for the required process reproducibility. For injection coining, further going machine technology is required. The drive technology must be capable of realizing

Fig. 5. Flowboxes are integrated in the production cell for opthalmic lenses

the envisaged coining function and be freely and flexibly programmable via machine control. Generally speaking the rule is: the design of the coining mold determines the coining function on the machine side.

Only in a relatively few cases is a facility with cleanroom conditions a prerequisite for optical component production **(Fig. 5)**. To ensure appropriately clean surroundings nonetheless, one of the following options/additional equipment can be selected:

- A cleanroom flowbox over the locking unit to avoid contaminations in the cavity area,
- raised machine feet for better access to clean beneath the machine,
- short supply lines for mold cooling by mounting the hoses firmly and directly on the mounting plates,
- a uniform and bright machine color to ease recognition of contaminants,
- liquid-cooled drive to minimize dust swirls, and
- minimized machine and mold surfaces, e.g., by completely encapsulating hydraulic blocks.

Defined Cooling to Room Temperature

Robot systems integrated in machine control for demolding the parts belong to any holistic production concept. Grippers take the parts from the cavity, or ejector systems pass them to removal grippers **(Fig. 6 left)**. Current technology includes everything from simple pneumatic gripper axes all the way to servo axes moving in sync with the ejector.

The main criterion for robot technology is the scope of follow-up processes as well as the type of part buffer storage. This can vary from depositing them directly onto a conveyor belt, **(Fig. 6 right)** to depositing them according to a defined pattern or to fitting them in trays for stacking and destacking devices. Further processing steps can follow; not uncommon are defined cooling paths, for instance. Then the parts coming from the mold at very high temperatures are set down in defined cooling places. On these, the molded parts can cool uniformly to room temperature before measuring devices check and document quality. Depending on the application, steps can follow for assembly with additional parts or deposition in suitably protected surroundings.

Conclusion

The manufacture of optical parts by injection molding is a segment developing quite rapidly at this time. However, their production requires comprehensive knowledge not only of injection molding and mold making, but of optics and relevant metrology as well.

For thick-walled as well as for optical parts, injection coining is often utilized. Vis-à-vis classic injection molding, this process offers significant advantages especially for such articles; however, it presumes high-level, complex mold and machine technology. Moreover, the processing technology is considerably more extensive and presumes expert knowledge required both for working out and validating processes as well as for supervising volume production. ■

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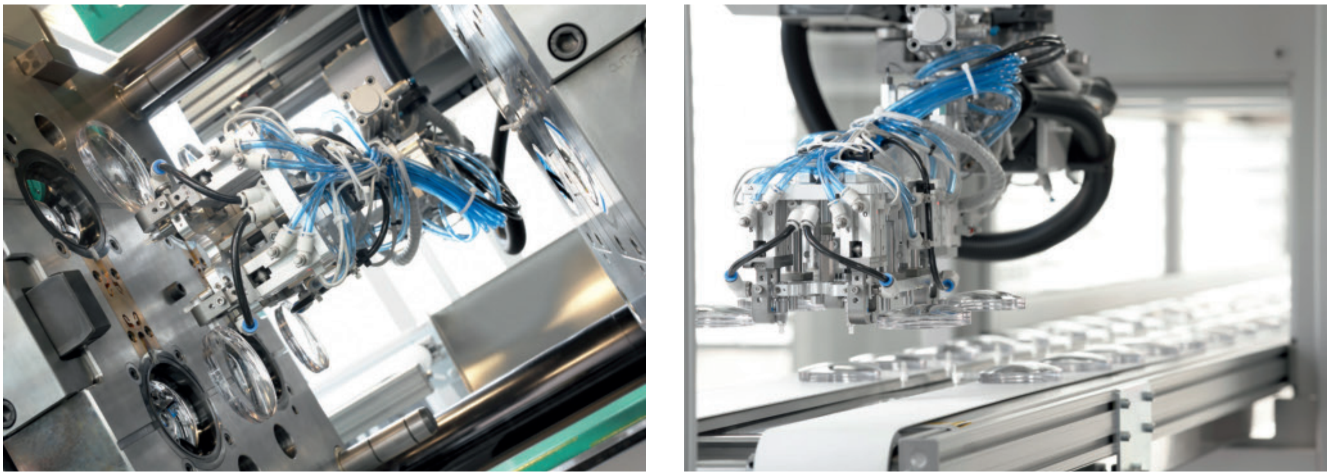

Fig. 6. The parts are carefully removed by grippers (left) and deposited directly on the conveyor belt (right)