Less Granules Stock Means More Quality

The Principle of Starve Feeding: Injection Molding Ultrahigh Purity Light Guides

In cars, LEDs are taking over ever more applications and are increasingly used as differentiating design elements. They increase the geometrical variation, which poses new challenges to manufacturers of light guides. In order to ensure a high luminous efficiency even with complex geometries and elongated structures, Engel has developed a new plasticizing process for manufacturing light guides. This increases the homogeneity and purity of the melt, thus opening up new freedom for light designers.

The transformation of the automobile also strongly affects the vehicle interior. Light is gaining in importance as a design element © Engel

A good light guide transmits the light from a given source over long distances without noticeably decreasing its intensity or changing its color. This presupposes a very smooth surface over the entire transmission distance to ensure total internal reflection of the light. The light can thus only escape at particular points, which are equipped with prism-like structures for this purpose. Correspondingly, the injection molding process is required to provide high-precision reproduction of the part surface and high homogeneity and purity of the plastic melt. In general, injection molding offers great advantages for manufacturing light guides. It combines freedom of design with cost efficiency.

Engel Austria GmbH, headquartered in Schwertberg, Austria, took on this task together with development partners. Last year, the injection-molding machine manufacturer presented an injection molding process optimized for processing polymethyl methacrylate (PMMA) to an audience of specialists. It allows the production of ultrahigh-purity light guides, and therefore LED solutions with even longer and more complex structures – for example for outline lighting.

PMMA is among the materials preferred by the automotive industry for manufacturing light guides, especially for innovative lighting concepts in the vehicle cockpit (**Title figure**). In order to take into account auto manufacturers' requirements from the start, demo light guide structures were provided by Volvo Car Corporation (**Fig. 1**). All the trials were conducted using a family mold from Inevo – which was part of the INglass Group at the time of the project.

Starve-Feeding Reduces the Shear Load

Three light guides with different lengths and different shapes were produced in one shot (**Fig. 2**). The longest of the three light guides is gated at two points. An Altuglas V825T LPL-grade PMMA was processed (manufacturer: Altuglas International, part Arkema Group). To maximize the light yield, the following development aims were pursued:

- A surface roughness of below 25 nm – greater roughness means that short-wave (blue) light, in particular, is not completely reflected, but is refracted so that the emerging light has a yellowish (warmer) color;
- to permit no contaminants – any contamination leads to scattering of the light;

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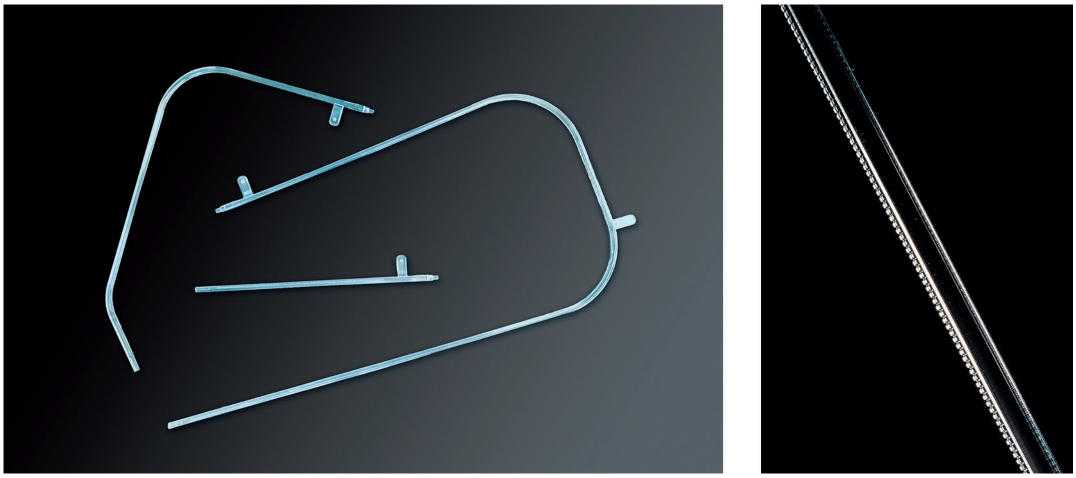

Fig. 1. The aim of the development was to obtain a high optical quality in complex light guide shapes. The fine structures on the top of the demo parts (right) serve for outcoupling of the light © Engel

- to eliminate or exclude (micro)cavities, since they, too, cause light scattering.

The key technical feature is the principle of starve-feeding, for which Engel has developed its own software. This allows the amount of granules fed to the screw to be deliberately reduced compared to the amount that the machine would draw during a conventional injection molding process. In the feed zone of the screw, the cylinder is thus only partially filled with granules. The material is compressed in the direction of the screw tip and fills the cylinder in that region completely (**Fig. 3**). Less material in the cylinder means reduced torques and therefore a lower shear loading of the melt, which reduces the degradation. To prevent oxidative material degradation at the same time, the melt cylinder is flushed with nitrogen via the feed zone.

Plant Concept with Inline Quality Testing

The tests during the development project were performed on an injection-molding machine (type: Engel e-motion 310/120 TL) with a screw and non-return valve specially designed and coated for processing PMMA. The all-electric machine series combines efficiency with high dynamics and precision. The latter is particularly important for demolding the very fine structures on top of the demo parts, which are used for outcoupling the light (**Fig. 1, right**).

Of the quality-relevant ancillary equipment, the Luxor EM-A 60 granules dryer and the dosing unit with type Minicolor dosing disk (manufacturer: Motan Colortronic GmbH, Isny, Germany) particularly deserve mention. To take into account the different flow-path lengths of the three light-guide geometries, the development partner HRSflow – the hot-runner manufacturer is a member of the Italian INglass Group – tested different gating systems with electrically operated non-return valves. It used the FlexFlow system, which permits the needle valves to be actuated individually, depending on the screw position.

To ensure a high part quality, an inline quality test was integrated into the plant concept (**Fig. 4**). For each shot, the smallest rod-shaped light guide, with a length of 15 cm, was tested in each case. Immediately after demolding, they are placed in a test station with LED light source by a robot. A Radiant Vision Systems (model IC-PMI8; manufacturer: Konica Minolta Sensing Europe B.V., Nieuwegein, Netherlands) measures the change of the correlated color temperature, CCT).

Correlated Color Temperature Confirms the High Light-Guide Quality

The CCT describes how the human eye perceives the light color. The light color

Fig. 2. Three optical waveguides with different lengths and different shapes were produced in a family mold © Engel

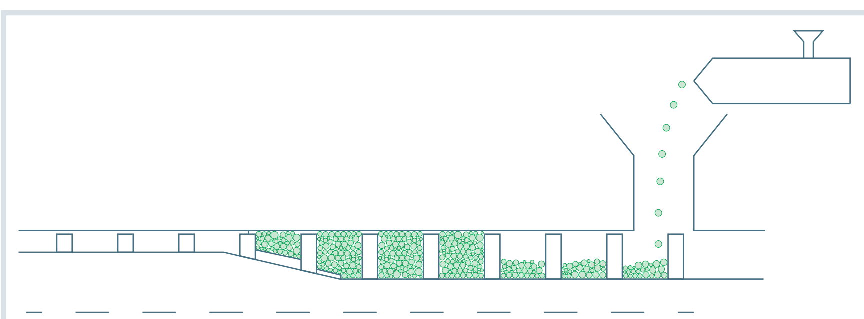

Fig. 3. The key to a high luminous efficiency is starve feeding of the melt cylinder

Source: Engel; graphic: © Hanser

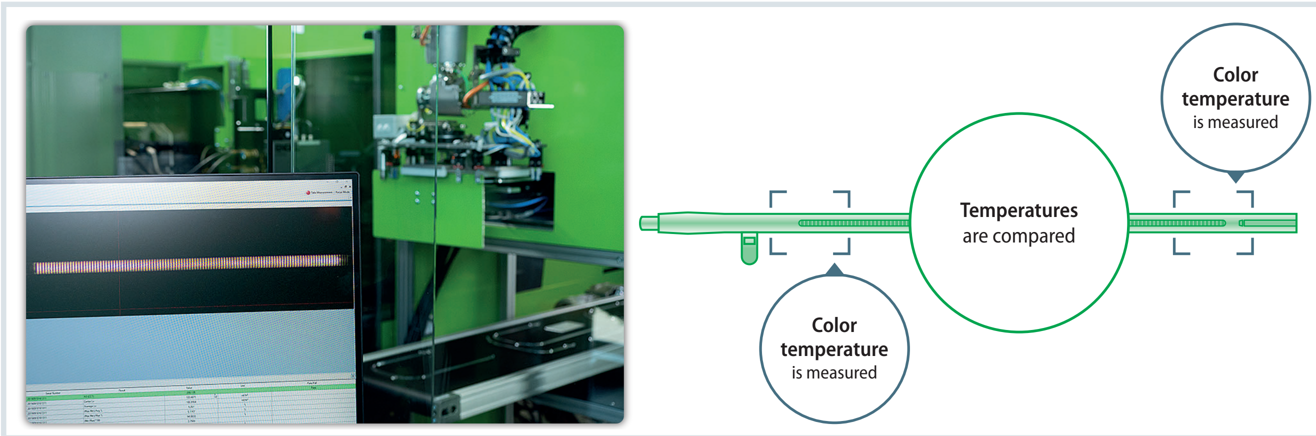

Fig. 4. Inline quality testing records the CCT value of the light guide both close up and at a distance from the light Source: Engel; graphic: © Hanser

depends on the object temperature – with the black radiator as reference – and, in the case of LEDs, on the characteristics of the light source. Temperatures below 3000 K are perceived as warm colors, while those over 3000 K as cold colors. The quality of the light guide is all the better the less the CCT value departs from the reference value (light color of the LED source).

The series of trials clearly shows the beneficial effect of starve feeding on the quality of the injection molded light guide (**Fig. 5, left**). The dosing unit was used to vary the amount of material fed in the individual trials, less material always being fed than the machine would have drawn from the hopper in conventional injection molding. The best results were obtained when the melt cylinder was filled to a moderate degree (e.g. 65 %). If the material feed is further reduced, the optical quality decreases again. This is because the metering times are longer with decreasing material feed, which significantly increases the shear loading of the melt.

Nitrogen purging has an additional beneficial influence (**Fig. 5, right**). In the trials, the feed zone was flooded with 0.2 l of nitrogen per minute in order to displace the oxygen and prevent oxidation of the molten plastic.

Finding Optimum Process Parameters

For process optimization, the project partners additionally investigated which other process parameters influence the optical quality of the light conductor (**Fig. 6**). The left diagram » shows the influence of the circumferential speed of the plasticizing screw. Although a circumferential speed of 0.3 m/s is specified for the PMMA material used, the trials show that an even slower plasticizing rate significantly improves the optical quality.

During injection of the plastic melt into the mold, on the other hand, a higher speed leads to a better light guide quality at first. However, if the injection speed if further increased, the quality decreases again. This is because, as the speed increases, the pressure and therefore the shear loading also increase.

The well-known fact that the mold temperature has an influence is also confirmed by the trials. A higher mold temperature improves the reproduction of the surface, which increases the CCT constancy. As regards the ancillary equipment, the beneficial effect of the dust removal should also be mentioned. The smaller the amount of dust in the granules and the melt, the lower also the degree of scattering in the light guide.

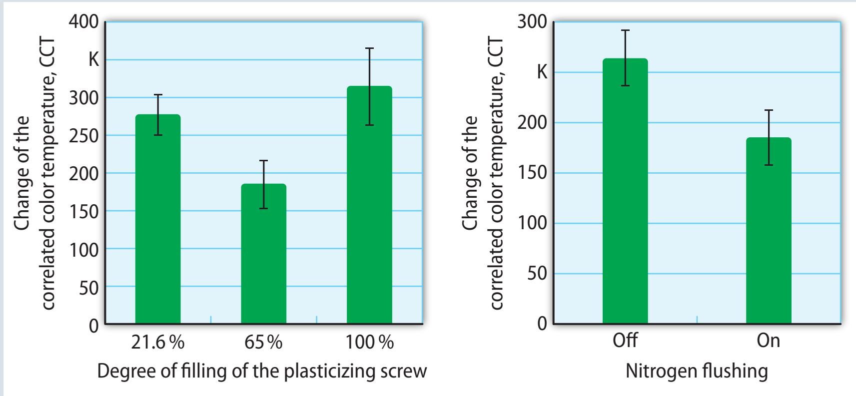

Fig. 5. The starve feeding has a positive influence on the quality of the light guide. The best results are obtained when the melt cylinder is filled to 65 %. Flushing of the feed zone with nitrogen increases the melt purity. The smaller the change of the correlated color temperature CCT, the higher the quality of the light conductor Source: Engel; graphic: © Hanser

Conclusion

The newly developed plasticizing process from Engel opens up new horizons in lighting technology. Starve feeding in combination with an optimized process guide allows long and complex-shaped light guides to be produced in very high optical quality. This can be assessed and permanently with the aid of an inline measurement system.

All-electric injection molding machines are principally used for manufacturing light guides, which is why Engel opted for the e-motion series in this development project.

However, the new plasticizing technology can in principle be combined with the most diverse types of injection molding machines and drive technologies.

At the request of customers, Engel integrates the associated ancillary systems into the plant concept. The technology is not linked to particular brands of ancillary systems. ■

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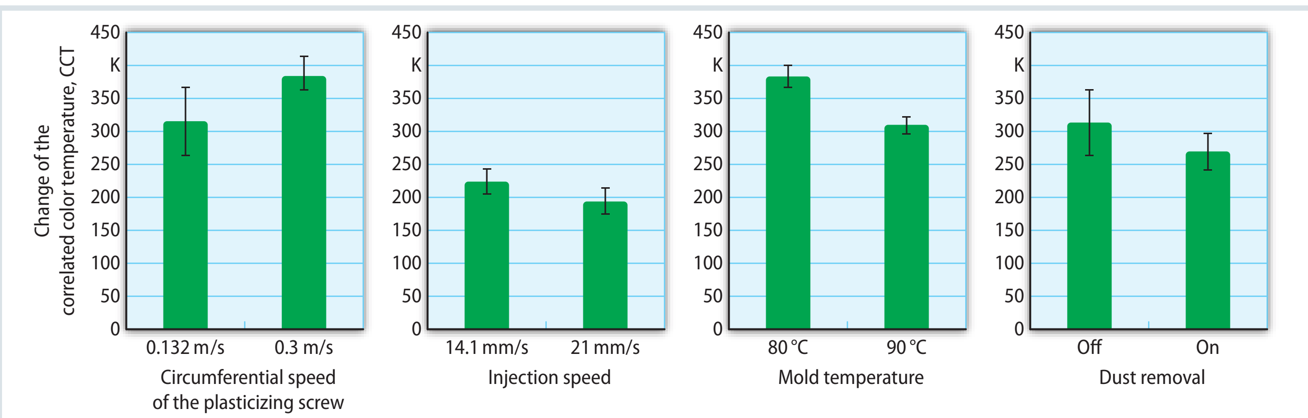

Fig. 6. To optimize the process, further parameters were varied and correlated with the optical quality of the light guide. The biggest influence on the injection molding result is shown by the circumferential speed of the plasticizing screw, the injection speed of the melt, the mold temperature and the dust removal from the pellets Source: Engel; graphic: © Hanser