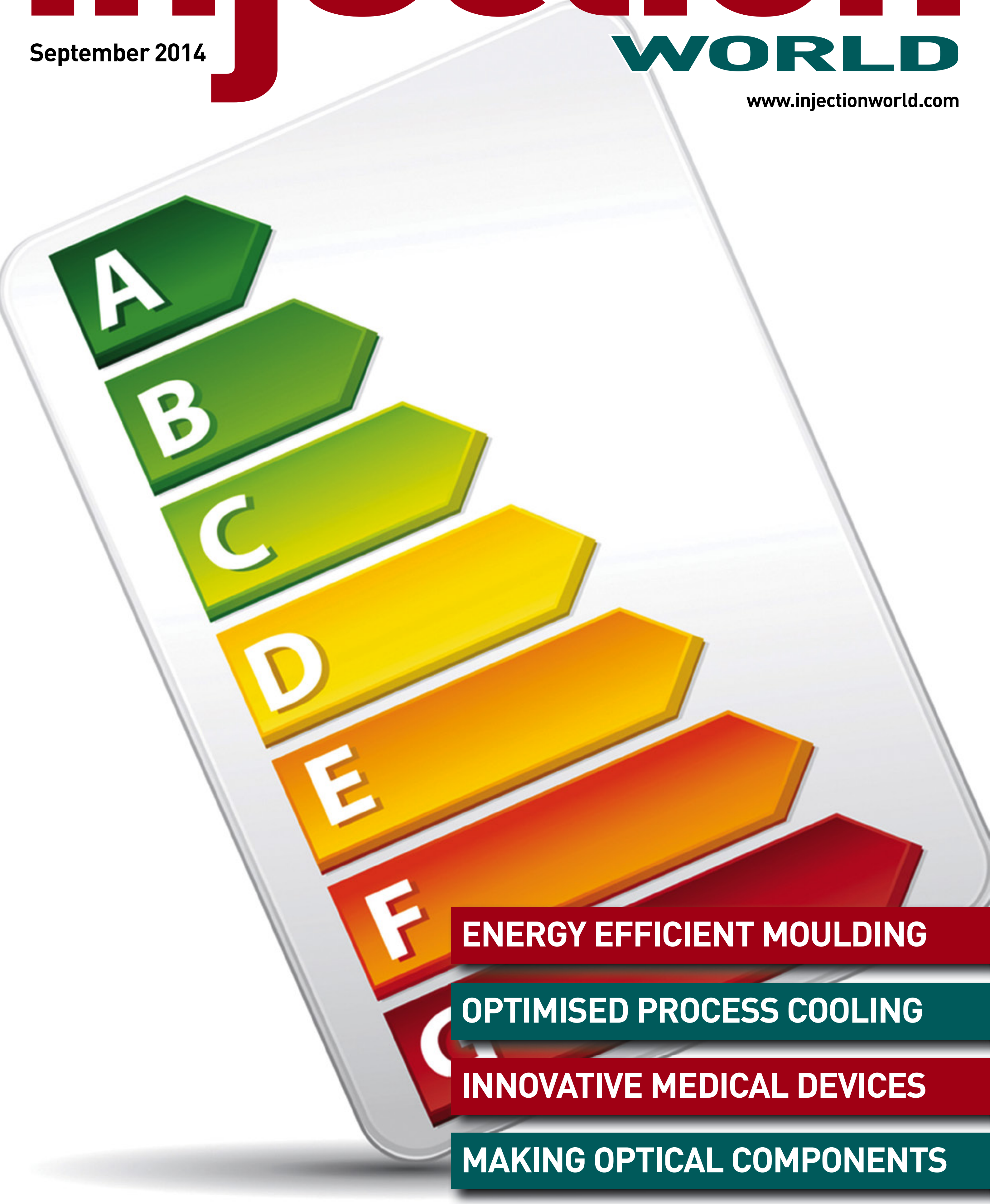
ISSN 2052-9376

injection WORLD

September 2014

www.injectionworld.com



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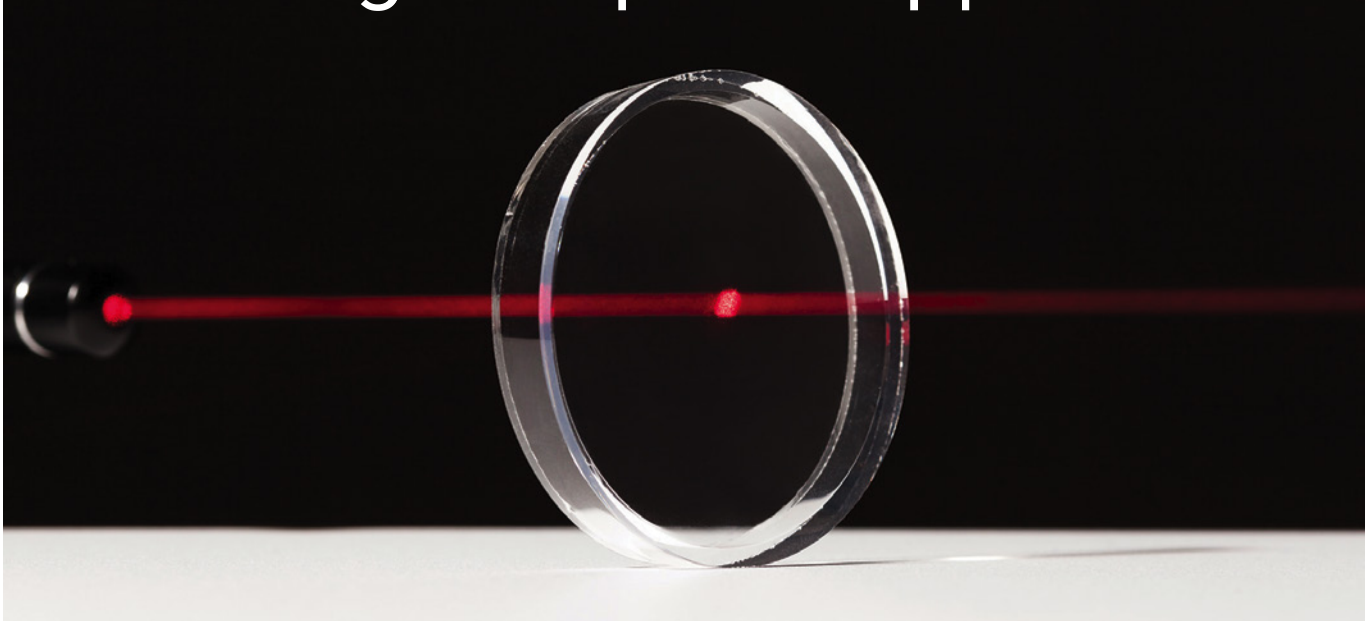
Moulding for optical applications



Polymer producers and processing specialists are working hard to deliver cost effective solutions for production of high performance LED optics. **Peter Mapleston** looks at some of the latest resin and process innovations

Production of optical quality components has long been a significant – and growing – high value niche for injection moulders. Now, the introduction of LEDs for lighting applications is opening up even more opportunities as this new energy-efficient technology replaces traditional incandescent and fluorescent bulbs. Plastics producers and moulders are likely to benefit not just from the growth in LED production, but also from the substitution of metals and glass in componentry intended both to reduce cost and to create designs that would be impossible – or at least very difficult – to achieve in traditional materials.

Lenses and light guides are already being injection moulded from materials such as polycarbonate, polmethylmethacrylate, and cyclo-olefinic copolymers. But as LED technology moves into higher-power applications such as automotive and exterior lighting, the need for materials with improved thermal properties is increasing and the response is coming in the form of new material options, such as optical-grade liquid silicone rubbers.

Multilayer moulding

Standard injection moulding runs into problems in production of lenses, which can often have wall thicknesses of more than 10 mm, since low-stress and dimensionally accurate lens cooling takes a relatively long time. Cycle times can extend to 20 minutes or longer, which is obviously uneconomic in industrial production. The multilayer process, in which the lens is manufactured in multiple work steps, helps remedy the situation since each step requires a relatively short cooling time.

KraussMaffei says polycarbonate (PC) producer Bayer MaterialScience (BMS) and Evonik Industries, which makes polymethylmethacrylate (PMMA), are both using its CX series injection moulding machines within research projects designed to further develop the multilayer process. Many of these use 'variothermal' heat-balancing of the injection mould to improve lens surface quality.

KM cites the collaborative research project SkForm, in which it and various partners from industry and academia have been pursuing the goal of creating functional surfaces by quickly and precisely changing mould temperatures in defined areas of the mould using GWK's Ceramic Power Heater. Helmut Gries, chief customer officer at GWK, confirms that the company has "very interesting" applications in main LED headlight production installed "in all German premium cars." The projects are covered by non-disclosure agreements, however.

Malte Röbig, a researcher in the optical components

Main image: a precision lens moulded in Lumisil LR7600 optical grade LSR from Wacker

Right: Arburg produced this three-layer PC lens on a 60s cycle, one tenth that required for a conventional single-layer alternative

injection moulding department at the **IKV** plastics processing institute in Aachen, Germany, points out that the long cooling times typically found in optical processing can result in a high thermal load on the melt due to lengthy residence times in the plasticising unit. "In the worst case, the material is thermally damaged," he says.

The IKV has been studying a variant of multilayer moulding as part of a German government-sponsored research project. Its version uses core-back mould technology to create space for each successive overmoulding layer by the retraction of cores in the fixed and moving halves. "One and two-layered lenses as well as sequentially or simultaneously constructed three-layer lenses can be produced," says Röbig.

The total cooling time of all individual layers is significantly less than the conventional cooling time of a single-layered optic. To exploit the full potential of the process, he says simultaneous production of the outer layers is recommended. "By this technique, a cycle time reduction up to 30 % is possible," Röbig claims. Moreover, the moulding accuracy and surface quality increase because of the reduced potential for shrinkage in the various overmoulded layers.

This project echoes work at **Bayer MaterialScience** (and previously reported in *Injection World*). BMS continues to develop multilayer technology for optical parts and has a production cell at its Technical Service Centre in Leverkusen that includes an injection moulding machine, a mould with an intricate system of dynamic mould temperature control, and an optical test stand used to test the quality of lenses moulded in its Makrolon polycarbonate.

Below: Schematic of a three-layer thick section lens produced by Arburg on an 8-station Weber 'multi-timed' mould

Bayer has also cooperated with injection moulding machine maker **Arburg** and mould maker Weber in a demonstration project (seen at this year's Arburg Technology Days) for overmoulding that uses an innovative "multi-timed" eight-station rotary mould from Weber to produce a 25mm thick lens.

The mould features several injection and cooling stations, as well as a removal station. Polycarbonate is injected in several layers by a vertical, size 70 injection unit and the horizontal, size 400 injection unit. Arburg says that in conventional production, the cycle time for such a multilayer component is around 180 seconds compared to around 10

minutes if the lens was produced as a single layer. However, in the demonstration cell carrying out the individual processes simultaneously means a lens is completed every 60 seconds.

Engel demonstrated its most recent efforts in multilayer technology for thick-walled lenses at K 2013, using intermediate cooling carried out away from the machine to cut in-mould cooling times by 25-50% compared to conventional multilayer production. The project, carried out with partners Bayer MaterialScience and Krallmann Group, demonstrated production of an optical lens in Makrolon LED 2245 polycarbonate.

The company says its work has shown that overmoulding on one side of the lens improves productivity to a significant extent only when using a large number of layers. However, when overmoulding a preform on both sides (effectively a sandwich moulding) a significant increase in productivity is seen even with a three-layer structure. This approach also improves the contour accuracy as sink marks in the preform caused by shrinkage can be better compensated.

Engel says that it is 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, the company says its tests have shown that the preform can be removed much earlier that that. The only requirement is to ensure that the solidified outer layers are sufficiently strong to withstand internal pressure and prevent deformation during demoulding, the company says.

If the preform is then immediately overmoulded, the still-hot inner regions of the preform end up further away from the mould wall, and cooling time actually becomes longer, the company says. So its latest approach includes a cooling stage outside the mould that can last for several moulding cycles.

Right: Automotive Lighting produces the LED headlamp of the latest Mercedes S Class using three-layer moulding on an Engel Duo moulding machine

Cooling in air takes longer than it does in the mould, but does not influence the cycle time, says Engel. Depending on the duration of the external cooling, the company says the preform can have a lower average temperature during overmoulding than in conventional sandwich technology. As a result, it absorbs more heat from the top layers and so reduces the cooling time. This effect can be further increased by making the preform thicker and the top layers thinner, it says.

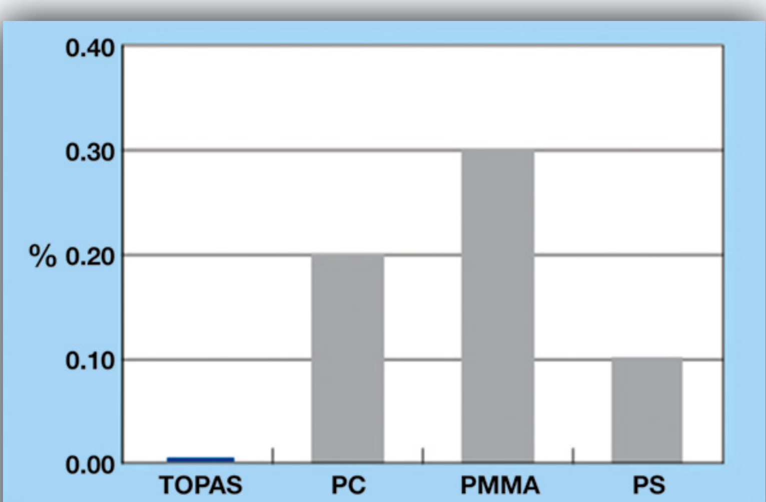
Polycarbonate developments

Styron, the plastics business spun off in 2010 from Dow, considers the LED lighting market one of its essential growth areas, according to senior account manager William B Marshall. He says the company has put considerable effort into developing new polycarbonates for the market, and now offers both clear and diffusion grades—the biggest application area for polycarbonate in LED lighting—as well as highly reflective types.

Next month, the company will launch a new transparent PC grade (still without a commercial name at the time of publication) offering a UL 94 V-0 flammability rating at 1 mm. Marshall says this will enable customers producing LED lighting—mostly for outdoor applications that use higher-power LEDs and therefore require better fire resistance than LEDs for internal use—to make thinner PC lenses, so saving material and improving optics.

Styron already offers two high-clarity grades aimed specifically at LED applications. Calibre 301-58LT for interior applications is said to have one of the highest light transparencies of any polycarbonate, with a transmission rate of over 90% even at a thickness of 3 mm. It also has very good flow properties (MFR is 58 g/10 min under 1.2 kg at 300°C).

Calibre 301-58LT is already being used in various



Water absorption of Topas COC compared with alternative optical thermoplastics *Source: Topas*

refractive optic applications and light guides. Marshall cites its use in optics for an MR16 LED lamp, which he says is intended for applications such as museums requiring high quality lighting. The resin is also available in custom versions for applications that require UV protection, and also for diffusion applications.

The second grade, Emerge 8430-7LT, contains an additive package to improve ignition resistance. It has a V-0 rating at 1.5 mm, and a UL f1 rating, which makes it suitable for outdoor use. Marshall says its light transmission of around 88-99% is very good for a V-0 PC containing additives. The product also has a very high relative thermal index (RTI) of 130°C.

Exploiting a niche

Tim Kneale, president of **Topas Advanced Polymers** in Florence, Kentucky (a joint venture between Japanese companies Daicel and Polyplastics), says its Topas cyclo-olefinic copolymers (COCs) are finding increasing use in parts with high aspect ratios such as light guides for mobile devices, as well as in highly detailed parts, all of which exploit the resin's very good flow properties.

Kneale sees COCs, which are copolymers of norbornene and ethylene, sitting in the performance spectrum between polycarbonates and liquid silicone rubbers. "Topas outperforms PC, but LSRs have better high temperature performance," he says.

There are currently three grades of Topas aimed at optical applications, the most recent addition being Topas 5013L-10. Kneale says the new grade has won strong early acceptance because it features an internal mould release that delivers an "exceptional" balance of properties and easy processing. "The boost in processability from the internal mould release has made this new grade the go-to choice for components with high aspect ratios, precision details, and other moulding challenges," he says.

Two other grades, 6013L-17 and 6013S-04, both have higher deflection temperatures under load (130°C under 0.45 MPa load, compared with 127°C for 5013L-10), as well as higher glass transition temperatures. All grades have visible light transmission of 91%, low birefringence (less than 20 nm, which is similar to PMMA and modified grades of PC) and a high Abbe number of 56 (which indicates low dispersion). In addition, COCs absorb virtually no water in ambient conditions.

Optical grade LSRs

Suppliers of liquid silicone rubbers are making strong progress in development of products that have excellent clarity to match their very high temperature resistance. LSRs come at a premium that some see as limiting them to a niche in the overall LED lighting market, but LSR producers see that niche getting bigger all the time. **Momentive** Performance Materials, for example, says its Silopren LSR 7000 series offers an alternative to both glass and thermoplastics in optical applications. "It represents the best combination of properties, such as heat resistance, and UV resistance, compared to glass, with the productivity and design freedom of thermoplastics," says global program manager HeeSeok Hwang.

Momentive's Silopren LSR 7070 grade has been formulated take on glass and thermoplastics

Architectural LED lighting is predicted to be a key growth market. LSI Industries installed this LED 'necklace' lighting system on New York's Verrazano Narrows bridge, cutting energy use by more than 70% over the previous mercury vapour illumination

Hwang says there are trade-offs for optical part designers when choosing a thermoplastic rather than glass for a lens due to inferior thermal, UV and chemical resistance. However, he says the Silopren LSR 7000 series grades "combine the physical property benefits of silicones, the ease and high productivity process advantage of LSR, and a typical optical transparency of 94%." Abbe number is around 50.

Materials close to the LED have to withstand harsh UV and blue light radiation in combination with a temperature of up to 150 °C for 100,000 hours, the lifetime of a typical LED system. The inorganic backbone of LSR positions them well to survive this extreme environment - silicone-based casting resins have, in fact, been used for some time for sealing LED semiconductors on circuit boards while acting at the same time as an integrated light feed-out.

"The Silopren LSR 7000 series provides outstanding thermal, UV, and blue light stabilities, which make this material an ideal candidate to consider for the production of lenses for high power LEDs in professional lighting, automotive lighting, and other lighting applications," Hwang claims.

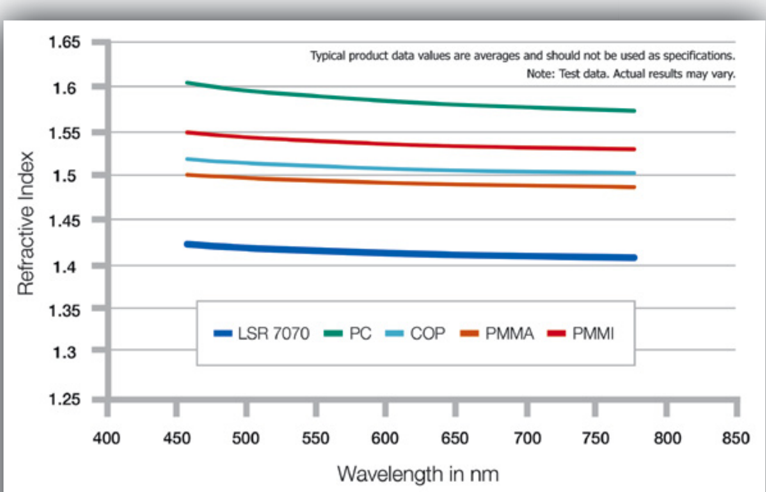


Chart showing the refractive indices of a variety of lens polymers. Glass has an RI of 1.50-1.55, depending on type *Source: Momentive*

Both thick and thin-walled parts are easier to produce with LSRs than with thermoplastics, as are parts with sharp changes in wall thicknesses, says Momentive. LSR parts do not retain any frozen-in stresses either, so they can be made free of birefringence. And while the company acknowledges that LSRs generally cost more than thermoplastics for optical injection moulding applications on a per-kilo basis, it says the materials can help reduce overall production cost by improving processing efficiencies with faster cycle times and simpler moulds, and by decreasing the need for thermal management controls in LED lamps due to their better heat resistance.

Momentive has LSR grades with hardnesses ranging from 5 Shore A (very soft) to 90A, which has the look and feel of polycarbonate if not quite the same hardness. Hwang says a lens made with a 70 Shore A grade of Silopren with a diameter of 70 mm and thickness of 13 mm can be produced in one shot without any sink marks or voids, something that is difficult to do with thermoplastics.

"One of the distinctive features of the Silopren LSR 7000 series is that its outstanding optical properties are virtually unaffected after heat exposure to 150°C for 6480 hours. Unlike organic plastics, the optical transparency hardly changes," he says.

The Kunststoff-Institut für die Mittelständische Wirtschaft NRW (**KIMW**, the plastics institute for the SME economy in North-Rhine-Westphalia, Germany), has investigated the influence of production conditions and processing parameters on the moulding properties of lenses made of various thermoplastics and LSR 7000.

Above: A variety of optical lenses and light guides moulded in optical grade LSRs from Momentive

Lens design was characterised by thin and thick sections up to 9mm thick that need to be filled through 1.7mm thin sections.

Thermoplastics lenses were moulded using an embossing core and the variotherm temperature control system in order to reduce built-in stress within feasible cycle times. The LSR lenses were produced using a simple LSR injection mould with conventional electrical heating. Hwang says the tests confirmed that "geometrically perfect, stress-free parts can be produced from LSR even without using expensive temperature control technology and without complex injection-compression processes." He says it was also shown that the LSR offered a very broad processing window.

The lenses were then exposed for 700 hours at 85°C and 85% humidity. "The lenses made of LSR 7070 were the only ones to deliver a perfect light pattern and that exhibited no deformations or cracks, unlike lenses made of PC, PMMI [polymethylmethacrylimid, an acrylic with higher temperature resistance than PMMA] or PMMA," Hwang says.

Cycle times for producing lenses in LSRs are similar to those for thermoplastics. Processing with LSRs does require investment in new equipment, but Hans Winkelbach, global marketing and technology leader for elastomers at Momentive, says he does not detect resistance in the market to this.

Momentive is currently involved in a research project on production of LSR primary optics for LEDs at the IKV, together with lighting specialist Hella and processor Elmet Elastomere Produktions- und Dienstleistungs. The partners have designed an optical component and constructed a special injection mould in which an LED board is inserted and then overmoulded with LSR. The project involves analysis of optical performance, moulding precision, and the bond strength between the LED board and the LSR, as well as long-term properties. The moulding of microstructures on the surface of the LSR lens will also be tested.

Flexing design opportunity

Lighting is also a key target market for silicones producer **Dow Corning**. "Our advanced silicone technologies are opening up once-unimaginable new design options for brighter and more reliable solid-state lighting," says Hugo da Silva, global industry director for LED lighting at the company. "Our conversations with current and prospective customers indicate that this versatile materials technology has only just begun to show its potential for enabling exceptional breakthrough designs."

Dow Corning's optical-quality Moldable Silicones (which the company emphasises are separate from its broad portfolio of thermal management materials) deliver much higher thermal stability than thermoplastics and even epoxies. "This means their mechanical and optical properties remain reliably consistent at temperatures of 150°C and above, where organic optical materials such as epoxies and thermoplastics tend to turn yellow and brittle," says da Silva.

"This is a very important advantage given the general industry trend toward solid-state lamp and luminaire designs that pack LEDs together more densely. The increase in drive currents of next-generation LEDs is also a factor contributing to higher temperatures, and the need for mouldable materials with greater thermal stability," he says.

Da Silva says that because it is a flexible material by nature, silicone allows many designs not possible with harder materials. These include undercuts, very precise micro optical features and multi-functional parts such as gasket integration. He also points out that the easy processability of silicones complements design flexibility. "For example, these materials support manufacture of large and thick optics that are often a challenge with other materials," he says.

Earlier this year, the company launched a new grade in its Moldable Silicone range, MS-1001. It differs from existing offerings in offering a faster cure time and a higher hardness—Shore D 25 after cure—that Dow Corning claims will enable "breakthrough LED lighting designs that demand thinner optical parts, finer details and excellent reproduction of mold features." The new grade is said to be well suited for LED secondary optics applications, such as light pipes and light guides that diffuse, focus and distribute light.

Meanwhile, **Wacker**'s new Lumisil LR 7600 LSR product line, which was introduced at K 2013, has also been developed specifically for the manufacture of optical components. Among various potential applications, the company cites camera-assisted adaptive automotive front lighting. Currently only offered on luxury cars, development within the automotive industry is aimed at providing systems that are affordable on smaller cars, too.

Adaptive lighting requires an optical system, consisting of several optical elements, that gives the light emitted by the lamp the right shape and directs it to where it is needed. The company says that because optical elements made of Lumisil LR 7600 can be produced cost-efficiently on a large-scale, the new liquid silicone can make a significant contribution in this area, as well as more general LED lighting in car interiors.

Wacker highlights the importance of the refractive index of lens and light guide materials, describing it as "the key variable underpinning how the optical components are designed to handle light." It says the front camera of an adaptive front-lighting system can only supply distortion-free images if it is optically coupled to the windshield with a suitably shaped component made of a highly transparent material and that, ideally, the material will have the same refractive index as the windshield.

Silicone elastomers meet these and other requirements. Not only are they are heat stable, they are for example extremely oxygen- and ozone-resistant, and remain permanently elastic at low temperatures without the need for plasticisers. Their refractive index is similar to that of quartz glass.

"In the future, it may even be possible to put the elasticity of the cured rubber grades to technical use in adaptive systems," a spokesperson for Wacker says. "One conceivable option is an optical system comprising flexible elements that undergo reversible mechanical deformation in use in adaptive front-lighting systems."

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