Trends in Automotive Headlamps

Challenges and Opportunities for Thermoplastics

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Highly developed lighting systems increasingly require materials with properties that can satisfy modern design requirements. This opens up potential applications for plastics, particularly engineering and high-temperature thermoplastics.

Modern developments in automotive headlamp systems are characterised by partly contradictory demands for increased service reliability, reduced fuel consumption thanks to aerodynamic design, compactness, and modern styling adapted to the vehicle model. To meet these trends, the paraboloid headlamps previously used almost exclusively have been supplemented by two types with optimised light efficiency (optical properties, losses) and space requirement: projection (ellipsoid, polyellipsoid) and free-form headlamps.

Along with new developments in halogen lamps, gas discharge lamps are now also available, which provide a higher spectral energy distribution in the visible range. One of their advantages is that the entire headlamp is not heat stressed as much as with halogen lamps. The question of which headlamp to use with which lamp in the vehicle ultimately depends on setting a balance between the space available and the lighting performance and styling requirements.

Material Choice Depends on Requirements

With the development of the systems, the requirements on the materials also grew. The materials used in this range must now satisfy considerably stricter requirements regarding manufacturing tolerances, versatility of processing to different designs, heat deflection temperature, mechanical strength and, in particular, surface quality of the parts. Thanks to the optimised light efficiency of free-form headlamps, their glasses can usually be designed without ribs. Hence, crystal-clear headlamp glasses of polycarbonate (PC) or glass are now used. This has further increased the surface requirements on the visible elements such as the reflector and bezel (Figures 1A and B). Where possible, old established materials such as metals, glass or thermosets are being replaced with more lightweight thermoplastics, which are simpler and more versatile to process. This allows the direct reproduction of complicated geometries by injection moulding, and the parts can be used immediately without secondary processing.

The material selection for the individual components of the headlamp system depends on the functional requirements. Only front headlamp systems are discussed here. They vary greatly from one vehicle model to another, but are basically built up from the following elements:

- housing,
- lighting unit (lamps, reflectors and brackets),
- headlamp bezels (not always existing as a separate element), and
- lens, diffuser or cover.

The material is chosen to meet the necessary heat resistance and surface quality. These factors depend on the design and assembly requirements. The range of thermoplastics extends from polypropylene to high-temperature (HT) materials polysulphone and polyetherimide (Fig. 2).

Housing: The decisive factors for the housing are mechanical strength and heat resistance. For large headlamps, glass fibre-reinforced polypropylene (PP-GF) is usually sufficient to meet the heat-resistance requirements. For other integrated headlamp housings with more complex requirements, and housings for small fog lamps subject to higher temperatures, higher quality thermoplastics are available. Preferred materials include polybutylene terephthalate (glass fibre-reinforced PBT; e.g. Ultradur from BASF AG) or even poly(arylene ether sulphone) (PES, PSU; e.g. Ultrason E or S from BASF), which give designers wider scope.

Lighting unit: The lighting unit is of course subject to extremely high temperatures. The reflectors are therefore made of either sheet metal or metallised injection moulded thermoset (BMC) or amorphous HT thermoplastic (PC-HT, PEI, PSU, PES). Only unreinforced amorphous high temperature thermoplastics or painted thermosets meet the required narrow tolerances and also have a surface quality suitable for metallisation of the injection moulded-part. Semicrystalline materials are not used here. If optical requirements are low and/or peak temperatures > 220 °C are expected, sheet metal can be used.

BMC and HT thermoplastics, on the other hand, are in intense competition with one another for reflector applications. Thermosets are much less expensive, but a HT thermoplastic offers crucial advantages for the manufacture and design of a reflector, including:

- processing advantages – shorter cycle times, no secondary processing (e.g. painting, deflashing), very low proportion of rejects,
- excellent surface quality, parts can be metallised directly,
- significant weight savings (up to 50%) through lower density and design with lower wall thickness,
- greater freedom of design (complex geometries with functional elements), and
- recycling.

Despite the disadvantages mentioned above for production costs, BMC is still preferred for larger reflectors, since the much lower material cost is the deciding factor.

According to the reflector type and the peak temperatures required, various high-temperature thermoplastics are in competition with one another. Larger reflectors with temperatures up to 180 °C still allow the use of PSU, while small, compact reflectors up to 195 °C require higher-quality PC-HT grades, and for temperatures up to 210 °C, only PEI and PES can be used. The

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aforementioned advantages over BMC apply to all these thermoplastics. However, they differ from one another particularly as regards the processing, i.e. flow properties, ease of metallisation and service temperature resistance. Compared with PC-HT and PEI, the BASF materials Ultrason E and S offer advantages such as:

- higher long-term temperature resistance (up to T = 180 or 220 °C for Ultrason S and E),
- higher iridescence temperature (up to 212 °C for Ultrason E),
- better flow under the particular processing conditions,
- better metal adhesion compared with PEI (favourable for metallisation), and
- higher impact resistance.

PC-HT and PEI have a slight advantage in density and UV stability. Where the materials are largely comparable, which one is used ultimately depends on the cost calculation, made according to the material price and material-dependent geometry (part weight) and processing technique (process costs).

Headlamp bezels: Thanks to the introduction of clear glass lenses, which are now used in most modern auto models on the European market, the bezels have become extremely important. Modern bezels are usually completely metallised. Apart from their basic functions for adapting the headlamp to wing or engine bonnet geometries, and in lighting, the other principle requirements are in the field of styling. The main requirements on headlamp bezels are:

- ease of processing,
- outstanding surface quality,
- easy metallisation,
- resistance to climatic effects and moisture,
- heat resistance, and
- dimensional stability.

In addition, other functional units, such as reflectors for indicator lamps, are also integrated into the bezel.

To meet this catalogue of requirements, a wide range of thermoplastics, from engineering polymers and polymer blends through to HT polymers are used. Examples include polyamide, polycarbonate, blends based on PBT and PC, and polysulphone. Polyolefins have only limited suitability because of inadequate resistance of metal layer and lower resistance to heat cycles. Of these thermoplastics, PBT, such as Ultradur B 4520, has proved advantageous, since it combines a balanced range of polymer properties with excellent processing characteristics. Because of the very low water absorption, PBT shows excellent dimensional stability together with high continuous service temperatures. This is well above that of polymer blends. It is therefore possible to integrate other functions making severe thermal demands, as mentioned above.

For the solution of particular thermal requirements, HT thermoplastics, such as Ultrason E or S 2010 is used, however, its use is limited for economic reasons. The BASF AG portfolio thus offers Ultradur and Ultrason, which allow the integration of functionality and design, together with reduced weight and cost efficiency.

Lenses & covers: The lenses of projection reflectors naturally have a critical optical function for illuminating the road, but headlamp covers must be classified into those with and without patterning. In the latter case, they only serve to protect the reflector unit. They are without exception made of glass or PC.

Examples of headlamp and fog lamp reflectors in which Ultradur and Ultrason are used for the bezel, or housing and reflector are shown in Fig. 3 and the title photo. BASF AG offers a series of thermoplastic grades suitable for use in headlamp systems. Apart from standard grades, for example, those with improved demoulding properties are also available.

Vacuum Surface Finishing

Headlamp bezels and reflectors or other plastic substrates can be provided with a reflective metal layer easily and quickly using vacuum coaters.

The metallisers can be easily integrated into production. Sputtering systems like the DynaMet (Fig. 4) from Leybold Optics, Alzenau, can even be linked directly to other stations, such as injection moulding machines. The reflective layers applied in vacuum systems are very thin, so that coating processes such as evaporation, sputtering and plasma CVD (chemical vapour deposition) can even be used for coating heat-sensitive polymer grades. In the case of polymers releasing significant amounts of gas, and parts with very rough surfaces, a lacquer base coat should be applied. The engineering polymers PBT and PES, PSU discussed here do not require a base coat, since the substrates already have a very high surface quality.

To ensure good adhesion properties, most engineering polymers are pre-treated by plasma processes such as glow discharge. This removes water vapour and activates the surface. Plasma processes can be integrated into the vacuum system, thereby substantially reducing production times and costs. There are general restrictions on polyolefins as well as some special polymers such as PMMA and POM.

Increasing cost pressure is intensifying efforts to find alternatives for lacquering. Plasma CVD is a suitable alternative since this vacuum process does not involve overheads for expensive pollution control measures like those required for lacquering equipment, slurry disposal or solvent vapours. The process can be carried out with the same equipment as for plasma cleaning. The gaseous starting substances used are organic silicon compounds, such as siloxanes, which are excited and decomposed in the plasma. This results in

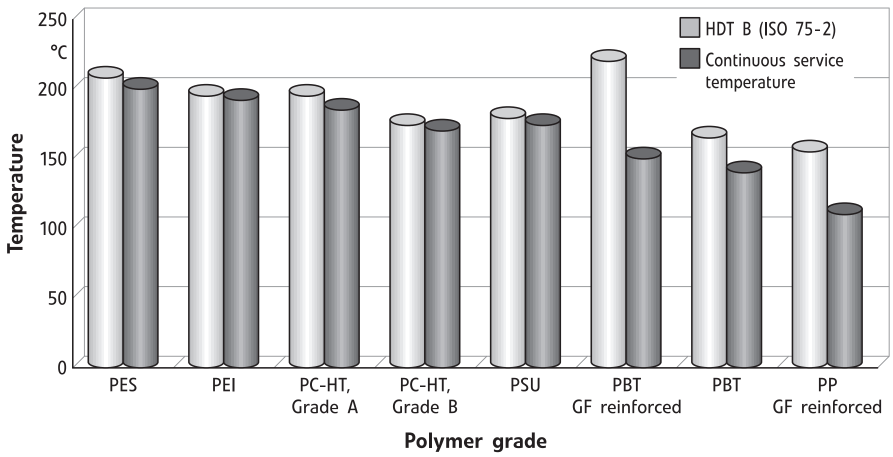

Fig. 2. Heat deflection temperatures HDT-B (ISO 75-2, source: Campus 4.5) and continuous service temperature ranges for some thermoplastics

macromolecular networks, which are deposited uniformly as non-porous layers, even on complicated substrates.

For pure corrosion protection of aluminium reflective layers, e.g. on headlamp reflectors, a layer thickness of 25 to 50 nm is sufficient. Wipe resistance can also be obtained with extremely hard, yet still very thin polymer layers. If scratch resistance is required, a layer top-coat lacquer is still necessary. But Leybold Optics' R&D department is working on the development of industrially viable vacuum processes for producing transparent scratch-proof layers.

Automotive headlamps are usually metallised with aluminium. Two vacuum coating processes are available for this: Traditional metallising in single-chamber batch-type coaters, and sputtering in-line DynaMet systems, which can be easily automated and metallise headlamp reflectors in continuous operation.

Discontinuous or Continuous

Evaporation coating has the advantage of relatively low machine costs, and therefore low investment costs. That is why single-chamber vacuum systems are still widely used. Thermal evaporation is a very reliable high-quality process. However, the discontinuous operation means that the parts must be temporarily stored before and after metallisation. The evaporator sources (filaments) must be replaced at regular intervals, and the aluminium must be refilled after each batch. In addition, comparatively bulky, custom-made fixtures and masks must be fabricated, stored and kept stocked for each type of substrate.

A much simpler solution from the point of view of handling, and therefore ease of automation, is a continuous sputter system such as the DynaMet 4V shown in Fig. 4. This very compact unit consists of four processing stations in a circular arrangement. The reflectors are loaded onto a substrate holder fixed to an indexing drum in the centre. They are loaded and unloaded in the first chamber, pre-treated in the next, then metallised and finally provided with a top coat (Fig. 5). The process is fully automatic, and loading and unloading can also be automated. The cycle time – about 36 s – is of the same order as injection moulding machines or lacquering robots. This, together with the automatic handling system supplied as standard accessory, allows the system to be used inline with other production stations (Fig. 6).

The coating processes used in such continuous multi-chamber systems are the PE-CVD technique for pre-treatment and post-treatment, and the sputtering process for metallisation. In the sputtering process, the coating material is eroded from a metal plate – the target – by ion bombardment, and deflected onto the substrate. The process is very easy to control. The coating qualities that can be produced meet maximum demands for uniformity and adhesion. Another great advantage of this process, apart from productivity and quality, is its versatility. It is not only possible to deposit aluminium, but also a wide variety of other metals and metal alloys. This opens up opportunities for both engineers and designers to go beyond the function of an aluminium reflective layer, e.g. coloured reflective layers. Corrosion protection coatings or scratch resistant coatings can be deposited in the same system without breaking the vacuum.

Outlook

Innovations in vehicle lighting, such as a central light source (with the light distributed to the lenses by fibre optics), increased use of LEDs, sensor-controlled pivoting lighting units or predictive light control via (GPS-based) satellite navigations systems are currently under development and still require legal approval and clear legal specifications and guidelines [1 to 4].

Furthermore, as part of the process of reducing complexity, we can expect increased integration of headlamp components into highly developed lighting systems that will place extremely high demands on the material.

It is not yet clear what effects these new trends will have on the use of plastics. But such "intelligent lighting systems" are certain to provide entirely new challenges and opportunities for thermoplastics.

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Fig. 1A. Headlamps: front – constructed of a clear cover, lighting unit (reflector of metallised Ultrason E, lamps) and housing; rear – installed headlamp, constructed of semi-ribbed glass, cover (metallised Ultradur B 4520), lighting unit and housing

Fig. 1B. Fog lamp: constructed of a clear cover glass, lighting unit and housing (Ultrason E)

Fig. 3. Examples of headlamp covers of metallised Ultradur B4520 Q112

Fig. 4. Continuous sputtering system DynaMet 4V for fully automatic vacuum coating of reflectors

Fig. 5. Top view of the DynaMet 4V: loading and unloading, pre-treatment, metallising and top-coat in a circular arrangement

Fig. 6. Linking the DynaMet plant to other production stations