Manufacture of a Rear License Plate Light in a Highly Integrated Production Cell

What Is the Most Suitable Material Combination?

The aim of this joint project is to develop a production cell in which a rear license plate light can be manufactured with hybrid processes without any additional steps such as bonding. Some of the necessary analyses and pre-testing of the material combinations resulting from the structure of the product – plastic housing and optics plus metal conductive tracks – are presented in this article.

The process chain in the production of LED lighting systems is at present split into many individual complex steps for producing the housing and the LED contacts and for mounting a front lens system and a cooling element, which is why production is increasingly being carried out in low-wage countries. The long process chain also means high technical, logistical and time requirements (for example through handling and transport). Furthermore, pre-processing and post-processing steps are needed between the individual stages, so that sources of error can arise along the entire process chain. Contamination during transport as well as assembly and adjustment errors can mean losses in the subsequent light output and can also result in rejects [1–4]. The aim of the described research project is to develop and validate an LED lighting system that can be manufactured in a highly integrated, automated and

Lighting solutions on various products.

© Mentor

resource-saving production process in Germany.

The technical approaches for the new shortened process chain devised at the Institute for Plastics Processing (IKV) in Aachen, Germany, involve combining innovative production technologies with new materials. With this integrated approach, newly developed electrically insulating and thermally conductive plastics are used for the housing and also as a cooling element for the lighting system. In the three-dimensionally shaped housing, LED circuits and contact pins are inserted. Subsequently, these are electrically connected by the integrated metal plastic injection molding process (IMKS) by means of a conductive track consisting of low-melting solder.

Through the greater design freedom when positioning an LED compared with conventional circuit board, an optical component with a free-form geometry can be placed over the LED and encapsulated by injection molding so that it is media-tight. The IMKS process developed at IKV allows the production of plastic parts with integrated conductive tracks in one mold on an injection molding machine [5, 6]. At the same time, the light-conducting front lens is produced within the production cell. Finally, the lens is placed on the housing and molded in with the housing material so that it is impermeable to media. After the integrated process, the finished lighting system can be used without any post-processing steps.

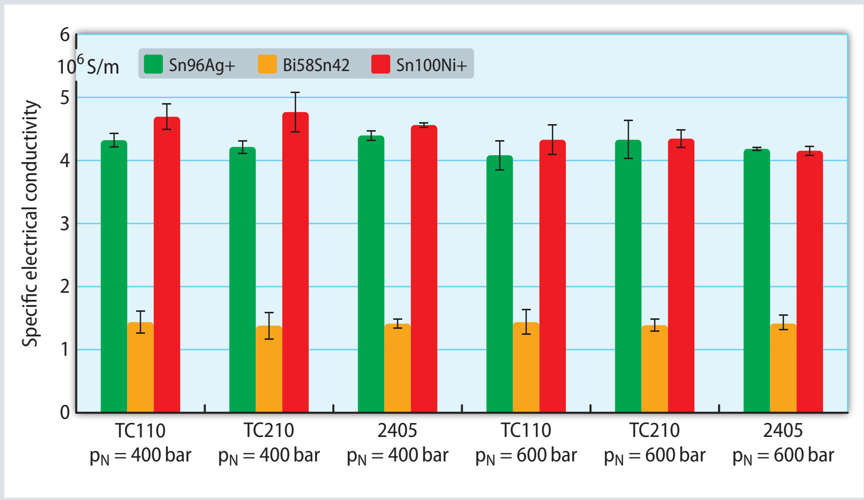

Fig. 1. Specific electrical conductivities of all material combinations from a metallic solder and a standard or thermally conductive plastic. Source: IKV; graphic: © Hanser

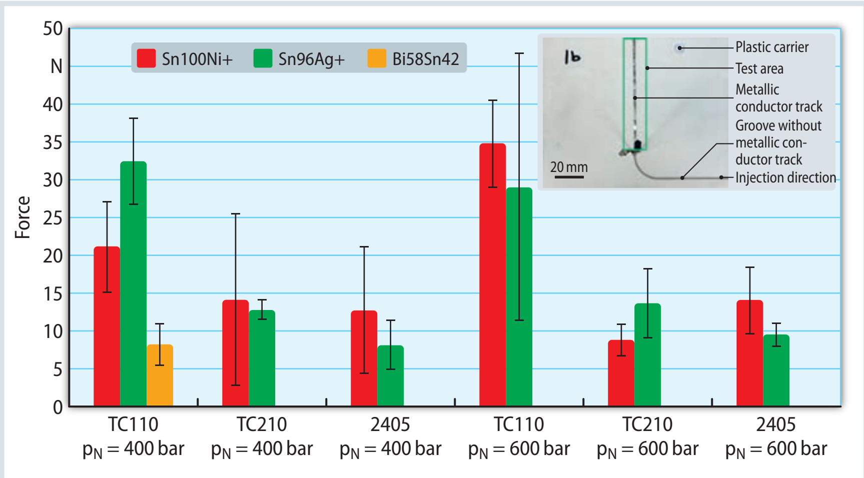

Fig. 2. Necessary pull-out forces for all material composites. Both the metallic solders can withstand the highest extraction forces in combination with TC110. Source: IKV; graphic: © Hanser

New Production Concept Shortens Process Chain

The housing, electrical connection and optical component are the parts occurring in the most common LED applications. For this reason, the developed production concept can be adapted variably for the manufacture of a variety of lighting applications, for example in the automotive sector, construction industry and street lighting. The production concept aims to shorten the process chain with higher value and without costly assembly steps. Furthermore, the aim is to eliminate pre-treatment and post-processing steps and to save material.

The new approach is based on various preliminary studies. These involve the material combination consisting on the one hand of the newly developed plastic (housing) and the metallic solder (conductive track) and, on the other, the material combination consisting of the newly developed plastic (housing) and the plastic for optical applications (front lens).

For this, a square plastic carrier with a conductive track geometry containing a curve was first selected as the test specimen, because curves are also present in the circuit for the later demonstrator. In addition to the standard housing material Makrolon 2405, two thermally conductive plastics Makrolon TC110 and Makrolon TC210 (manufacturer in each case: Covestro) were used for the plastic carrier. The three solders Sn96Ag+, Sn100Ni+ (Felder Löttechnik) and Bi58Sn42 (Tamura Elsold) were examined as potential materials for the conductive track.

In order to establish what influence the injection molding process parameters have on the resultant composite properties, the holding pressure during the production of the plastic carrier was systematically varied. The parts were first subjected to electrical load tests and then to tensile tests in order to determine the influence of mechanical loads on the bonding properties between the plastic carrier and the conductive track.

How Conductive Are the Test Specimens?

With the electrical load tests, the specific electrical conductivity and the heating of the component were determined under constant current load of the »

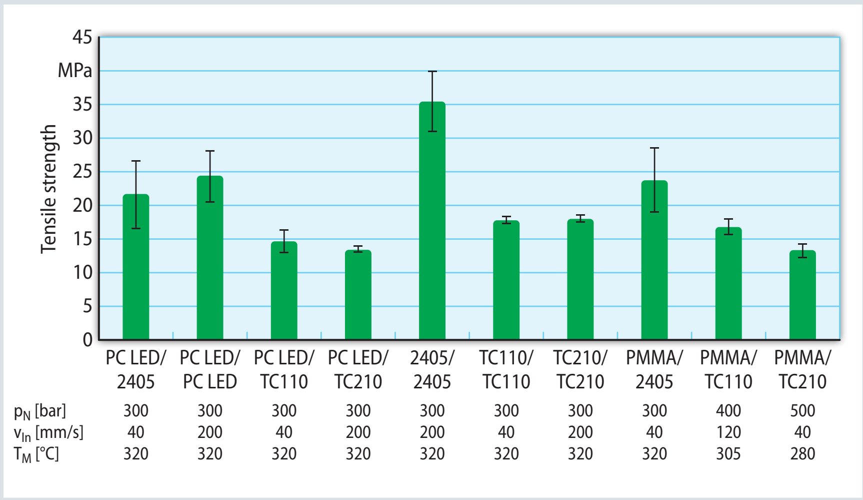

Fig. 3. Tensile strength of the produced 2-component specimens with declining bond strength in increasing thermal conductivity of the materials. Source: IKV; graphic: © Hanser

respective material combination. To measure the electrical conductivity, the respective specimen was fixed and connected through two cap electrodes at the beginning and end of the conductive track. For the present application, conductivities in the range of 4 to $5 \cdot 10^6$ S/m are necessary. The material combinations consisting of the conductive track material Sn100Ni+ and the two thermally conductive plastics proved to be highly promising (**Fig. 1**). During the tests, the solder Bi58Sn42 was found to be unsuitable for this particular application.

What Is the Bond Strength of the IMKS Specimens?

In order to examine the maximum tensile strength of the material composite, the specimens were first prepared by cutting out the section from the injection point of the conductive track to the curve of the plastic carrier (**Fig. 1**). To measure the bond strength between the metallic track and the plastic carrier, tensile tests were carried out on a tensile testing machine (type: Z150; manufacturer: ZwickRoell), which pulled out the conductive track from the plastic carrier at a defined speed of 2 mm/min.

In the tensile tests, the material combination with Bi58Sn42 was found to be the most unsuitable alternative (**Fig. 2**). Only in combination with TC110 and a holding pressure of 400 bar was it actually possible to measure the pull-out force of the conductive track from the plastic carrier, with the other specimens, the track broke off prematurely during preparation of the specimen. In the measurement of the tensile strength, the solders Sn100Ni+ and Sn96Ag+ together with TC110 proved to be the most promising material combinations. It can be assumed that the fillers, which are contained in the thermally conductive plastics and ensure that the heat is better distributed, produce a better bond with tin than with bismuth.

For the front lens, the project consortium selected as potential optical materials a PC (grade: Makrolon LED 2245; manufacturer: Covestro) and a PMMA (grade: Plexiglas 7N; manufacturer: Röhm). The selected materials were fundamentally tested at IKV. First of all, the mechanical tensile strength between the material pairs was examined with tensile bars in line with DIN EN ISO 527 A1 [7]. The tensile bars from the optical and housing components were produced in the same sequence in line with the later production of the technology carrier, i.e. the optical component was injected first and subsequently the housing component (machine type: emotion 160/440; manufacturer: Engel). In order to better categorize the results of the tensile tests, tensile bars from one material with two injection points were tested for all the selected plastics.

Composite Strength of the Optical Materials

In the tests, the injection molding parameters of the second component were varied. The parameters with a particularly large influence on the bond strength were identified (in literature and in preliminary trials) as the holding pressure, the injection speed and the melt temperature [8]. To examine the tensile strength, the tests were carried out in line with DIN EN ISO 527–1 with a strain rate of 1 %/min [9].

The results show a better tensile strength of the PMMA compared with PC (**Fig. 3**). The bond strength of the housing materials decreases with an increase in the thermally conductive fraction. This is visible when using both PC and PMMA as the optical component. In comparison, the bond strength of 2-component tensile bars made of one material is higher than those made of two different materials. Presumably, the higher tensile strength with PMMA tensile bars can be explained by the lower melt temperature of the PMMA. Compared with the basic strength of the material, the strength declined significantly. For example, Plexiglas 7N has, according to the datasheet, a break-

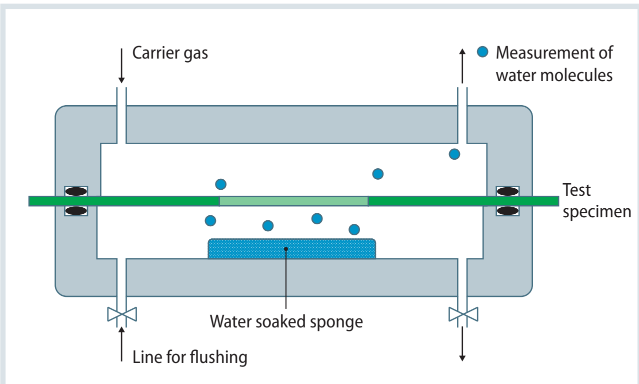

Fig. 4. Schematic illustration of the test set-up for the WVTR measurement. Source: IKV; graphic: © Hanser

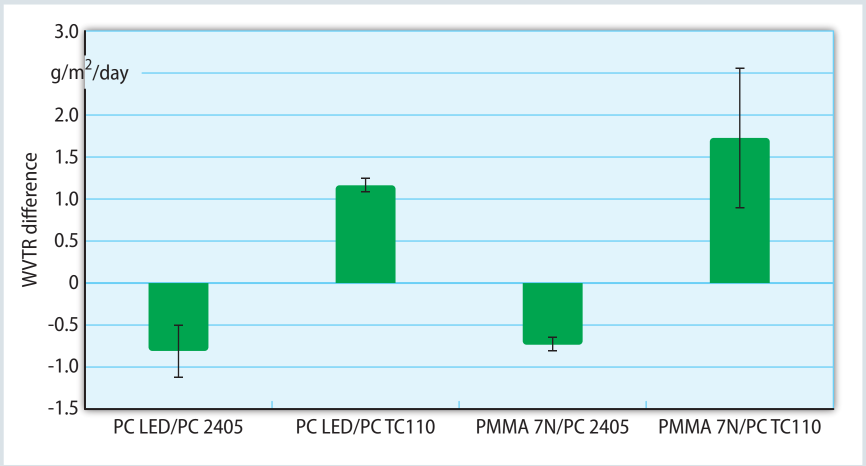

Fig. 5. Results of the WVTR measurements of the 2-component specimens as a function of the material area percentages. Source: IKV; graphic: © Hanser

ing strength of 73 MPa and Makrolon LED 2245 of 60 MPa.

Media Tightness of Two-Component Parts

To examine the media tightness, Heinze Kunststofftechnik produced mold inserts for simple specimens on the same injection molding machine. First of all, an external ring with a surface area of 55.71 cm^2 (~87.5 %) was injection molded from the optical materials. Subsequently, the ring with a surface area of 7.91 cm^2 (~12.5 %) was molded on in the center with a housing plastic. The same process parameters were used as with the tensile strength test.

The specimens were examined in a WVTR chamber (Water Vapor Transmission Rate) (**Fig. 4**). The specimen is clamped media-tight in the measuring chamber so that the chamber is subdivided into a lower and an upper area. A sponge full of water is placed below the specimens. After flushing both chambers with carrier gas, the quantity of water molecules that diffuse through the specimen is measured.

The WVTR measurement approaches a constant value that serves as the WVTR value for evaluation. In order to distinguish the material-specific water permeability from the permeability of the joining zone, circular disks from one material are first examined, each produced with the process parameters of the maximum and minimum tensile force. Now, the WVTR values as a function of the area percentages of the individual materials are deducted from the measurements of the two-component specimens, so that the differences because of the butt joint are shown (**Fig. 5**).

In the case of the specimens with PC TC110, an influence of the butt joint was found on the media tightness averaging 1.44 g/m^2 per day. However, the two-component specimens with PC 2405 showed a better WVTR value than the single materials. This leads to the assumption that the butt joint does not have any influence on the media tightness.

Outlook

In the preliminary tests, the metallic solder Bi58Sn42 proved unsuitable for this particular application. Therefore, only the other two solders were used in the following tests. The thermally conductive plastics showed highly promising results and more precise studies are currently being carried out at IKV. The bond strengths of the optical two-component specimens correspond to the strength data of the specimens from one material with two injection points. The media tightness corresponds to that of the basic plastics. For this reason, the material pairs can on principle be used for lighting in the exterior application.

Following the fundamental studies described here, further analyses will be carried out at IKV on the conductive track layout and the electrical contacting of inserts. With the newly constructed mold for producing a demonstrator, near-application tests are to be performed on the bond strength, contacts and positioning of the optics. This will be reported separately by IKV. ■

Info

Authors

Univ.-Prof. Dr.-Ing. Christian Hopmann is the holder of the Chair of Plastics Processing at RWTH Aachen University and head of the Institute for Plastics Processing (IKV) in Industry and Craft at RWTH Aachen University, Germany.
Ingrid Sturm, M.Sc., is leader of the multi-component technology team at IKV; ingrid.sturm@ikv.rwth-aachen.de
Jonas Gerads, M.Sc. RWTH, is leader of the optical components team at IKV.

Acknowledgments

The project on which this report is based was funded by the Federal Ministry of Education and Research under ref. no. 13N14627. The authors would also like to thank

- Covestro AG, Leverkusen, Germany,
- Engel Austria GmbH, Schwertberg, Austria,
- Felder GmbH Löttechnik, Oberhausen, Germany,
- Heinze Kunststofftechnik GmbH & Co. KG, Herford, Germany,
- Mentor GmbH & Co. Präzisions-Bauteile KG, Erkrath, Germany,
- Röhm GmbH, Darmstadt, Germany,
- and Tamura Elsold GmbH, Ilsenburg, Germany,

for their support and for providing test materials.

References & Digital Version

You can find the list of references and a PDF file of the article at ***www.kunststoffe-international.com/archive***

German Version

Read the German version of the article in our magazine ***Kunststoffe*** or at ***www.kunststoffe.de***