

Experimental Investigation and Numerical Simulation of Injection Overmolding of Film-Based Electronic Components

Annika Lenger^{1,*}, Thomas Lucyshyn¹, David Zidar¹, David Schaubroeck², Frederick Bossuyt², Jonas Groten³

¹ Polymer Processing, Department of Polymer Engineering and Science, Montanuniversität Leoben, 8700 Leoben, Austria

² Center for Microsystems Technologies (CMST), Ghent University and imec, 9052 Gent, Belgium

³ Joanneum Research Forschungsgesellschaft mbH, 8160 Weiz, Austria

* Correspondence: annika.lenger@unileoben.ac.at

Introduction: In-mold electronics (IME) enable the integration of electronic functions directly into injection molded polymer components [1]. By combining conductive structures and electronic components with polymer films, complex electronic functionality can be integrated into three-dimensional plastic parts [2]. This technology offers significant potential for the development of lightweight and multifunctional components with a high degree of design freedom and is particularly attractive for applications such as human-machine interfaces [3].

Despite these advantages, the manufacturing of IME components remains challenging. During the injection overmolding process, the film stack and the integrated electronic components are exposed to high thermal and mechanical loads caused by the hot polymer melt, injection pressure, and melt flow. [4] These loads can result in deformation or displacement of the film and may also cause detachment, damage or failure of the integrated electronic components [5]. A better understanding of the relationship between the injection molding process and the resulting loads on the integrated electronics is therefore required to improve process reliability and enable the robust design of IME components [6]. The objective of this work is to investigate the influence of injection molding process parameters and the positioning of electronic components on the loads acting on film-based electronics during overmolding. In particular, the influence of melt temperature and the position of electronic components relative to the injection gate is analyzed. The resulting thermal and mechanical process loads are evaluated using numerical injection molding simulations and compared with the experimentally observed film deformation and component behavior. The study is based on the hypothesis that the local position of an electronic component within the mold significantly affects the thermal and mechanical loads acting on the component even when only small changes in its distance from the injection gate are introduced [7]. Furthermore, it is hypothesized that experimentally observed changes in film deformation and component behavior can be correlated with the local process conditions predicted by numerical simulation [8].

Film design: The investigated IME structure consisted of a multilayer polymer film stack with integrated conductive tracks and mounted electronic components. As shown in

Figure 1 the outer layers of the film stack were made of polycarbonate Lexan 8010 film (Saudi Basic Industries Corporation, Riyadh, Saudi Arabia) with a thickness of 125µm. On this film a graphical layer made of using the non-conductive ink NOR-IPHAN® HTR N 990/010 NC—Tiefschwarz (Proell GmbH, Weissenburg, Germany) as well as conductive tracks using LOC-TITE® ECI 1010 E&C (Henkel AG & Co. KGaA, Düsseldorf, Germany) silver ink were printed. LEDs (LW Y1SG-BFOO-EKFM-1, ams OSRAM AG, Premstätten, Austria) were mounted on the film with a conductive glue LOCTITE® ABLESTIK 2030SC (Henkel AG & Co. KGaA, Düsseldorf, Germany) prior to overmolding.

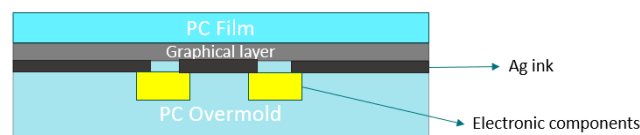


Figure 1: Film stack schematic

Experimental setup: The prepared film stacks were placed in the injection mold on a fully electric Arburg Allrounder 470 A Alldrive (Arburg GmbH + Co KG, Loßburg, Germany) injection molding machine equipped with a 25 mm screw. A Wittmann Temprow plus D 160 (WITTMANN Technology GmbH, Wien, Austria) temperature-control unit was utilized to regulate the mold temperature. The mold temperature was set to 100°C, the injection speed was set to 70 cm³/s, the packing pressure 400 bar for 15 s and the residual cooling time to 50 s. The melt temperature was 300 °C for the first and 340 °C for the second run (Table 1). For overmolding a polycarbonate PC Lexan OQ1028 (Sabic, Riyadh, Saudi Arabia) was dried for 5 hours at 120 °C before overmolding. The film stacks were overmolded in a rectangular plate mold with a wall thickness of 3 mm and a film gate with a cold runner. The films were fixed in the mold using temperature-resistant adhesive tape on the film edge facing the flow front. A small part of the lower area of the film was covered during overmolding to keep the contacts free from the polymer.

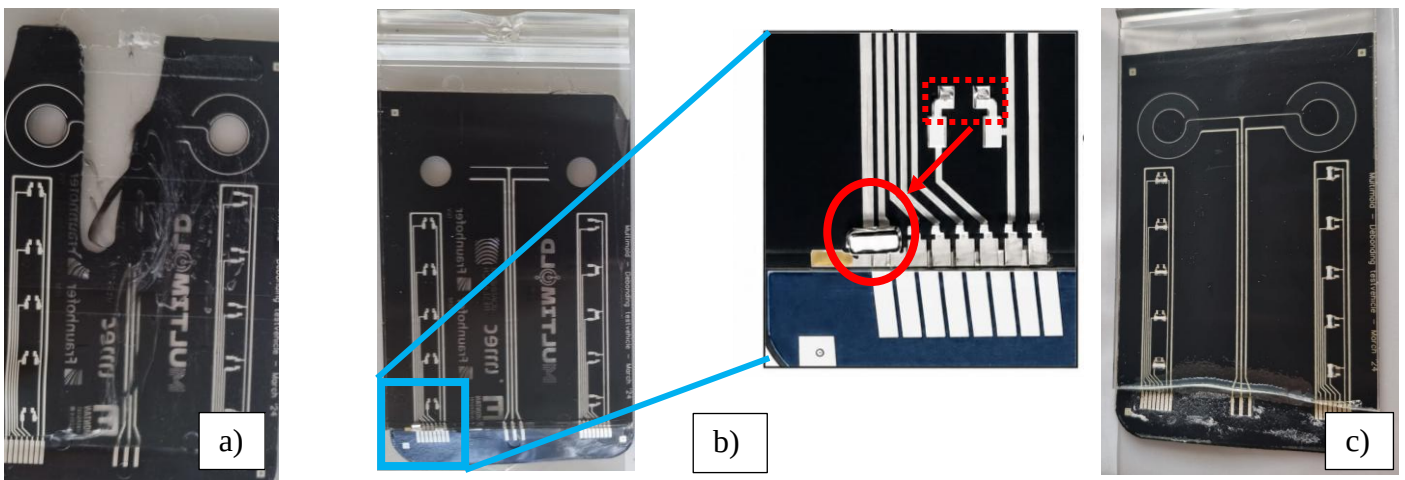
Table 1. Temperature profile for different melt temperatures

Nozzle [°C]	Zone 4 [°C]	Zone 3 [°C]	Zone4 [°C]	Hopper [°C]
300	290	280	270	30
340	330	320	310	30

Injection molding simulation: For the numerical injection molding simulation, the commercial injection molding simulation software Autodesk Moldflow Insight 2026 (AMI) was used. The numerical model reproduced the geometry of the film stack, the electronic component locations, and the injection molding cavity used in the experimental investigations. The same material combinations and process conditions as in the experiments were applied to enable a direct comparison between numerical and experimental results. The material data was taken from the AMI material database. The global edge length was set to 1.14 mm with a minimum number of 10 elements through the thickness for the injection-molded part. The film and the LEDs were modelled as part inserts. The simulation results were evaluated locally at the positions of the integrated electronic components. Particular attention was paid to the temperature history and the resulting thermal exposure of the components. In addition, the flow-front progression and local pressure were analyzed to characterize the mechanical and flow-induced loading during overmolding. For the simulation of the influence of the component position a different mold geometry was used.

Influence of melt temperature on part integrity: The influence of melt temperature on the integrity of the film-electronics assembly was investigated using 44 samples for the overmolding at the lower melt temperature (300°C) and 31 samples at the higher melt temperature (340°C). The only parameter changed was the temperature profile of the plasticizing unit as shown in table 1. At the lower melt temperature, damage of the film stack and detachment of the integrated LEDs were observed in the majority of specimens, whereas a smaller fraction remained intact. In contrast, all of the specimens produced at the higher melt temperature remained intact. Table 2 shows that at the lower melt temperature, 36 of 44 specimens were damaged, corresponding to a damage rate of 82%, while none of the specimens were damaged at the higher melt temperature.

Characterization of the observed damage: Figure 2 shows representative specimens for the two process conditions. At the lower melt temperature, the observed damage included severe deformation and distortion of the film as well as detachment of the LEDs from the film surface. At the higher melt temperature, no visible film failure or LED detachment was observed.

**Figure 2:** a) Film distortion, b) LED detachment, c) intact specimen**Table 2.** Experimental damage distribution of overmolded specimens

Melt temperature [°C]	Total specimens	Damaged	Intact	Damage factor [%]
-----------------------	-----------------	---------	--------	-------------------

300	44	36	8	82
340	31	0	31	0

Numerical analysis of the investigated process conditions: To further investigate the different component behavior observed experimentally, numerical injection molding simulations were performed for the two investigated melt temperatures. The simulations were carried out using the same mold geometry, material combination, gate position and component arrangement as in the corresponding experiments. The local process conditions in the vicinity of the integrated electronic components were evaluated to identify differences between the two process conditions. Particular attention was paid to the temperature history at the position of the LED. The maximum simulated temperature reached at the LED was 210°C at the lower melt temperature and 230°C at the higher melt temperature. The simulated flow behavior and local pressure conditions were additionally evaluated to assess whether changes in the melt flow contribute to the different experimental results. Depending on the investigated melt temperature, differences in the local process condition at the electronic component were observed. Figure 3 shows the different pressure loads the LEDs experience at the different melt temperatures. These results indicate that the thermal and mechanical loading of the integrated components is governed by the local flow and heat transfer conditions during overmolding rather than by the nominal melt temperature alone. The numerical results were compared with the experimental observations. Under the lower melt temperature, a high proportion of the specimens exhibited film deformation and LED detachment, whereas no failures were observed at the higher melt temperature. The simulation results provide an indication of the different local process conditions associated with these two experimental outcomes.

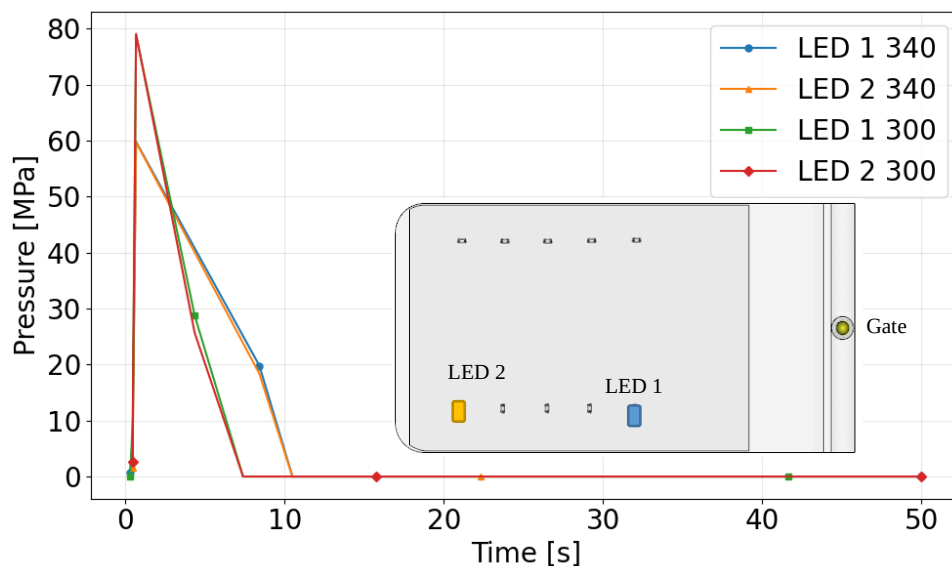


Figure 3. Pressure over time at 300°C and 340°C melt temperature

Influence of component position on thermal loading: In addition to the influence of the melt temperature, the effect of the local positioning of the electronic components within the mold cavity was investigated numerically. For this purpose, three LEDs in two different arrangements as shown in Figure 4, that also changed the distance to the injection gate were considered while keeping the melt temperature, mold geometry, material combination and other process parameters constant. The component positions were rotated around the center point of the triangle they form to keep the area illuminated by the LEDs the same. The simulated temperature histories at the two LED positions are shown in Fehler! Verweisquelle konnte nicht gefunden werden. Figure 5.

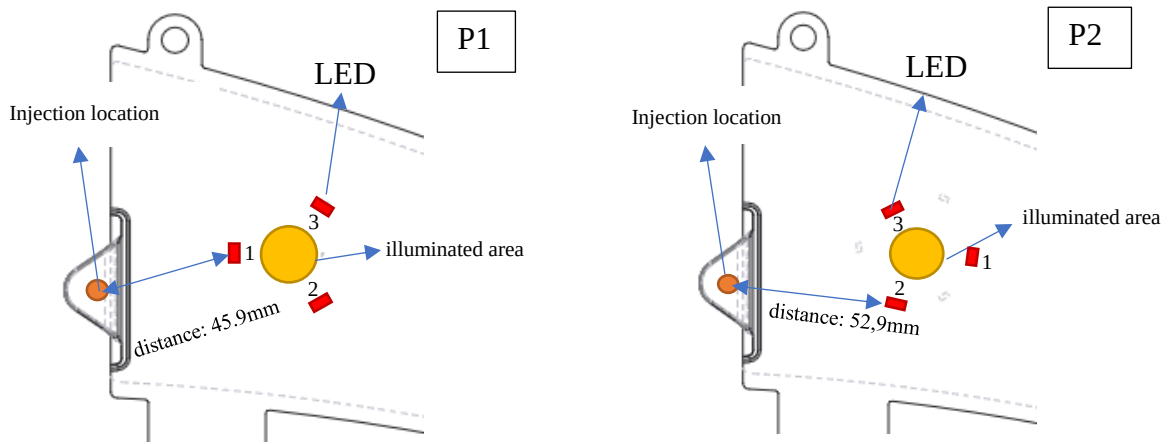


Figure 4: LED Positions: P1 and P2

Despite identical nominal process conditions, a distinct difference in the temperature evolution was observed. The LEDs located at position P1 reached a maximum temperature of approximately 238°C, whereas the LEDs at position P2 reached 215°C in the numerical simulation. This behavior can be attributed to local flow and heat transfer conditions during the filling process. The position of the electronic component relative to the injection gate determines the time at which the polymer melt reaches the component as well as the local melt temperature and flow conditions experienced by the component. Consequently, components subjected to the same nominal processing conditions may experience substantially different thermal histories depending on their position within the cavity. The observed positional dependence is particularly relevant for the design of reliable IME components. Small changes in the location of an electronic component relative to the injection gate can result in significant variations in the local process conditions.

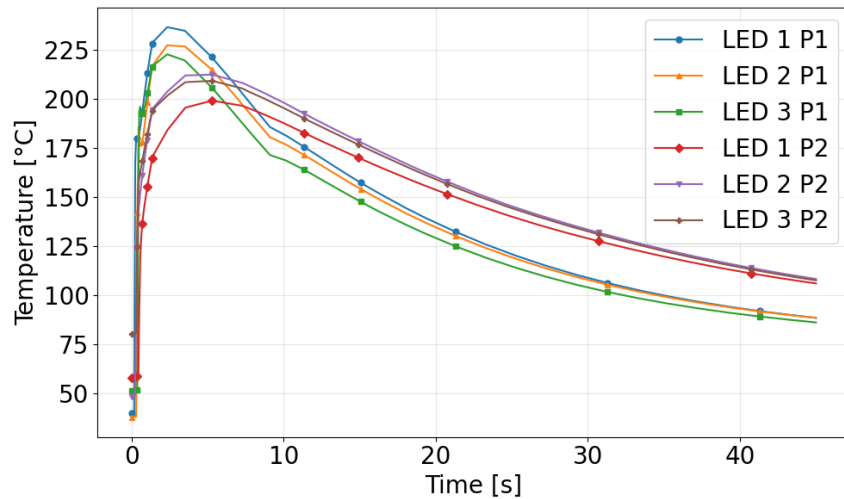


Figure 5: Temperature over time at LED position P1 and P2

Conclusions and Outlook: The results demonstrate that both melt temperature and electronic component position influence the behavior of film-based electronics during overmolding. The local position of the components relative to the injection gate can result in significantly different thermal histories even under identical nominal process conditions. Therefore, process parameters and component positioning should be considered as coupled influence factors when assessing the reliability of IME parts. The numerical simulations show potential for identifying critical component positions and process conditions prior to manufacturing. Future work will focus on correlating simulated process loads with experimentally observed damage and extending the investigation to additional components and process conditions.

Keywords: In-mold electronics, injection molding, simulation, Moldflow, overmolding

Acknowledgment: This work was conducted by the MULTIMOLD Project. MULTIMOLD is funded under the HORIZON Innovation Actions by the European Health and Digital Executive Agency.

AI Use Disclosure: Generative AI (OpenAI ChatGPT, GPT-5.6 Sol) was used to support language editing and text and picture refinement. All scientific content reviewed and verified by the authors.

References

- [1] M. Beltrão, F. M. Duarte, J. C. Viana, and V. Paulo, "A review on in-mold electronics technology," *Polymer Engineering & Sci*, vol. 62, no. 4, pp. 967–990, 2022, doi: 10.1002/pen.25918.
- [2] Mona Bakr, Yibo Su, Frederick Bossuyt, and Jan Vanfleteren, "Effect of overmolding process on the integrity of electronic circuits," (n.d.).
- [3] E. Izadi Vasafi, A. Rajkumar, T. Zhiltsova, and V. Neto, "Integration of Printed Electronics in Polymer Injection Moulding: Materials, Process Challenges, and Simulation Insights," *Int. J. of Precis. Eng. and Manuf.-Green Tech.*, 2026, doi: 10.1007/s40684-026-00900-x.
- [4] M. Hubmann *et al.*, "Influence of Injection Molding Parameters on the Peel Strength between Plasma-Treated Fluoropolymer Films and Polycarbonate," *Polymers*, vol. 15, no. 6, 2023, doi: 10.3390/polym15061568.
- [5] J. Schirmer, M. Reichenberger, A. Wimmer, H. Reichel, S. Neermann, and J. Franke, "Evaluation of Mechanical Stress on Electronic Assemblies During Thermoforming and Injection Molding for Conformable Electronics," pp. 1–8, (n.d.), doi: 10.1109/MID50463.2021.9361624.
- [6] M. Hubmann *et al.*, "Process Optimization of Injection Overmolding Structural Electronics with Regard to Film Distortion," *Polymers*, vol. 14, no. 23, 2022, doi: 10.3390/polym14235060.
- [7] M. Heinle and D. Drummer, "Measuring mechanical stresses on inserts during injection molding," *Advances in Mechanical Engineering*, vol. 7, no. 5, 2015, Art. no. 1687814015584479, doi: 10.1177/1687814015584479.
- [8] J. Schirmer, M. Reichenberger, S. Neermann, and J. Franke, "Conformable Electronics: Thermoforming and Injection Molding of Electronic Components," pp. 1–6, (n.d.), doi: 10.1109/ISSE51996.2021.9467588.