Replication quality assessment and uncertainty evaluation of a polymer precision injection moulded component

Baruffi, Federico; Calaon, Matteo; Tosello, Guido; Hansen, Hans Nørgaard; Prantl, Manfred; Miller, Nathan

Publication date: 2017

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Replication quality assessment and uncertainty evaluation of a polymer precision injection moulded component

F. Baruffi¹, M. Calaon¹, G. Tosello¹, H. N. Hansen¹, M. Prantl², N. Miller³

¹ Technical University of Denmark, Department of Mechanical Engineering, Kgs. Lyngby, Denmark
² Alicona Imaging, Raaba, Austria
³ Flann Microwave Limited, Cornwall, United Kingdom

Abstract
Precision injection moulding holds a central role in manufacturing as only replication process currently capable of accurately producing complex shaped polymer parts integrating micrometric features on a mass scale production. In this scenario, a study on the replication quality of a polymer injection moulded precision component for telecommunication applications is presented. The effects of the process parameters on the component dimensional variation have been investigated using a statistical approach.

Replication fidelity of produced parts has been assessed using a focus variation microscope with sub-micrometric resolution. Measurement uncertainty has then been evaluated, according to the GUM considering contributions from different process settings combinations and mould geometries. The analysis showed that the injection moulding manufacturing process and the utilized measurement chain are indeed capable of providing the high precision needed for the production. The calculated uncertainties are compatible with the imposed part requirements.

Case study
• Objective ⇒ precision IM process optimization and tolerance verification using a process-related uncertainty evaluation method
• Precision injection moulded component for telecommunication applications [1]
  • U-shaped
  • Material: liquid crystal polymer (LCP)
  • 4 functional geometrical features (Figure 1) acquired
  • ±11 μm tolerances on the measurements

Fig. 1. Geometry of the component and nominal dimensions

Experimental setup
• Injection moulding machine: Engel EVC 80/50
• Design of experiment (DOE)
  • Full factorial 2⁴ design (Table 1) with three repetitions
  • Measurements were performed with a focus variation optical microscope
  • Magnification: 10×
  • Lateral resolution: 1.0 μm
  • Stitching operation + automatic measurement routine
• Measurement output:

\[ \Delta = D_{\text{polymer}} - D_{\text{mould}} \]

Table 1: Experimental moulding conditions

<table>
<thead>
<tr>
<th>Process parameter</th>
<th>Low level</th>
<th>High level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melt temperature [°C], Tₘold</td>
<td>330</td>
<td>340</td>
</tr>
<tr>
<td>Mould temperature [°C], Tₚress</td>
<td>90</td>
<td>110</td>
</tr>
<tr>
<td>Holding pressure [bar], p_hold</td>
<td>175</td>
<td>275</td>
</tr>
<tr>
<td>Injection flow rate [cm³/s], v_i</td>
<td>22.5</td>
<td>47.5</td>
</tr>
</tbody>
</table>

Fig. 2: Main effects plot of \( \Delta_{\text{Y}_1} \)

Uncertainty evaluation method
• Experimental results
• DOE analysis
• Significant process parameters \( x_i \)
• Regression ⇒ model equation: \( \Delta = f(x) \)

\[ u(\Delta) = \sqrt{\sum_{i=1}^{N} \left( \frac{\partial f}{\partial x_i} \right)^2 u^2(x_i)} \]

Fig. 3: 1.° order regression plane

Results

Fig. 4: Replication quality assessment

Acknowledgements
This research work was undertaken in the context of MICROMAN project ("Process Fingerprint for Zero-defect Net-shape MICROMANufacturing", http://www.microman.mek.dtu.dk/). MICROMAN is a Marie Skłodowska-Curie European Training Network supported by Horizon 2020, the EU Framework Programme for Research and Innovation (Project ID: 674801).

References

Conclusion
The replication assessment for a precision injection moulded component was carried out using a DOE approach. The most influencing process parameters have been selected as variables for building the model equation. The expanded uncertainty was calculated using the GUM [2]. The main advantage of this method is that the sources of uncertainty related to the manufacturing process are properly weighed by means of the model equation. Results show that the calculated uncertainties are comparable with the tolerance requirements, proving that the adopted method is applicable to the specific precision task.