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

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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.

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 measurands

![Geometry of the component and nominal dimensions](image1)

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>
<thead>
<tr>
<th>Process parameter</th>
<th>Low level</th>
<th>High level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melt temperature [°C], Tₘₘₙ</td>
<td>330</td>
<td>340</td>
</tr>
<tr>
<td>Mould temperature [°C], Tₘ₈₉₉</td>
<td>90</td>
<td>110</td>
</tr>
<tr>
<td>Holding pressure [bar], pₚₘ₈₉</td>
<td>175</td>
<td>275</td>
</tr>
<tr>
<td>Injection flow rate [cm³/s], vᵢₘ₉</td>
<td>22.5</td>
<td>47.5</td>
</tr>
</tbody>
</table>

Table 1: Experimental moulding conditions

$$\Delta = c + a \cdot T_{\text{mould}} + b \cdot p_{\text{hold}} + e$$

![Main effects plot of Δ_H](image2)

Fig. 2. Main effects plot of Δ_H

![3. 1st order regression plane](image3)

Fig. 3. 1st order regression plane

Uncertainty evaluation method

- Regressions ⇒ model equation: \(\Delta = f(x)\)
- DOE analysis
- Significant process parameters \(x_i\)
- Uncertainty calculation using GUM [2]:

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

- Uncertainty contributions:
  • Regression coefficients \(c, a\) and \(b\)
  • Process parameters \(T_{\text{mould}}\) and \(p_{\text{hold}}\)
  • Measurement reproducibility (standard deviation of the model residuals \(e\) )
- \(U_u\) resulted equal for all the process conditions

<table>
<thead>
<tr>
<th>Measurand</th>
<th>(U_u) [mm]</th>
<th>(U_u/T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Y_l)</td>
<td>0.003</td>
<td>29 %</td>
</tr>
<tr>
<td>(Y_R)</td>
<td>0.003</td>
<td>29 %</td>
</tr>
<tr>
<td>(X_R)</td>
<td>0.003</td>
<td>29 %</td>
</tr>
<tr>
<td>(X_L)</td>
<td>0.003</td>
<td>29 %</td>
</tr>
</tbody>
</table>

Table 2: Uncertainty budget

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.

References

Acknowledgements
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