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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. 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 measurands

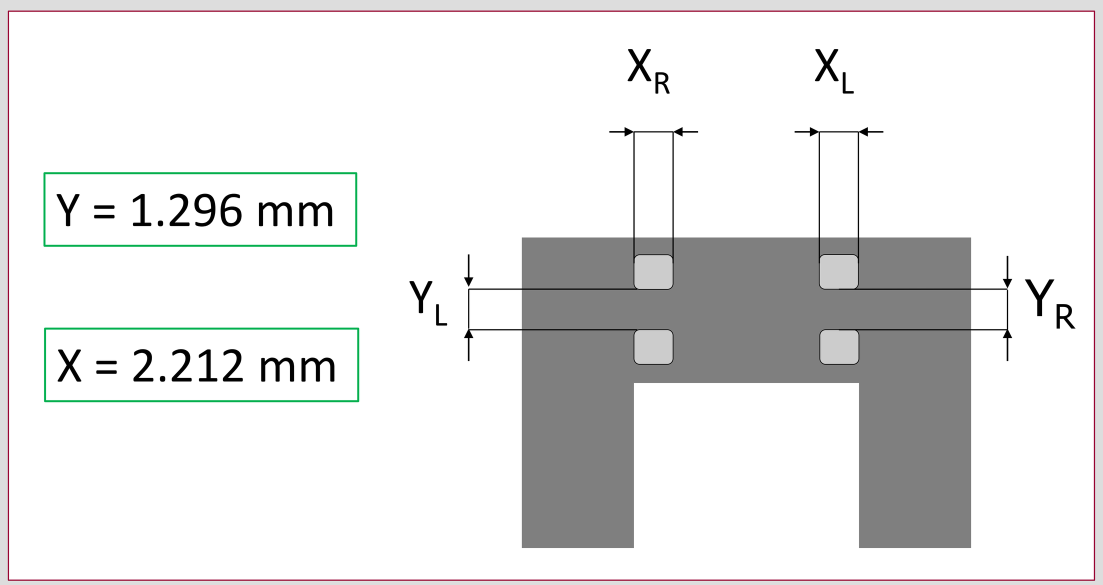

Fig. 1. Geometry of the component and nominal dimensions

Experimental setup

- Injection moulding machine: Engel EVC 80/50
- Design of experiment (DOE)
  - Full factorial 2^4 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:

$$\Delta = D_{polymer} - D_{mould}$$

Process parameter	Low level	High level
Melt temperature [°C], T_{melt}	330	340
Mould temperature [°C], T_{mould}	90	110
Holding pressure [bar], p_{hold}	175	275
Injection flow rate [cm³/s], v_{inj}	22.5	47.5

Table 1: Experimental moulding conditions

Uncertainty evaluation method

Experimental results

↓

DOE analysis

↓

Significant process parameters $\mathbf{x_i}$

↓

Regression ⇒ model equation: $\mathbf{\Delta = f(x_i)}$

↓

Uncertainty calculation using GUM [2]:

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

Results

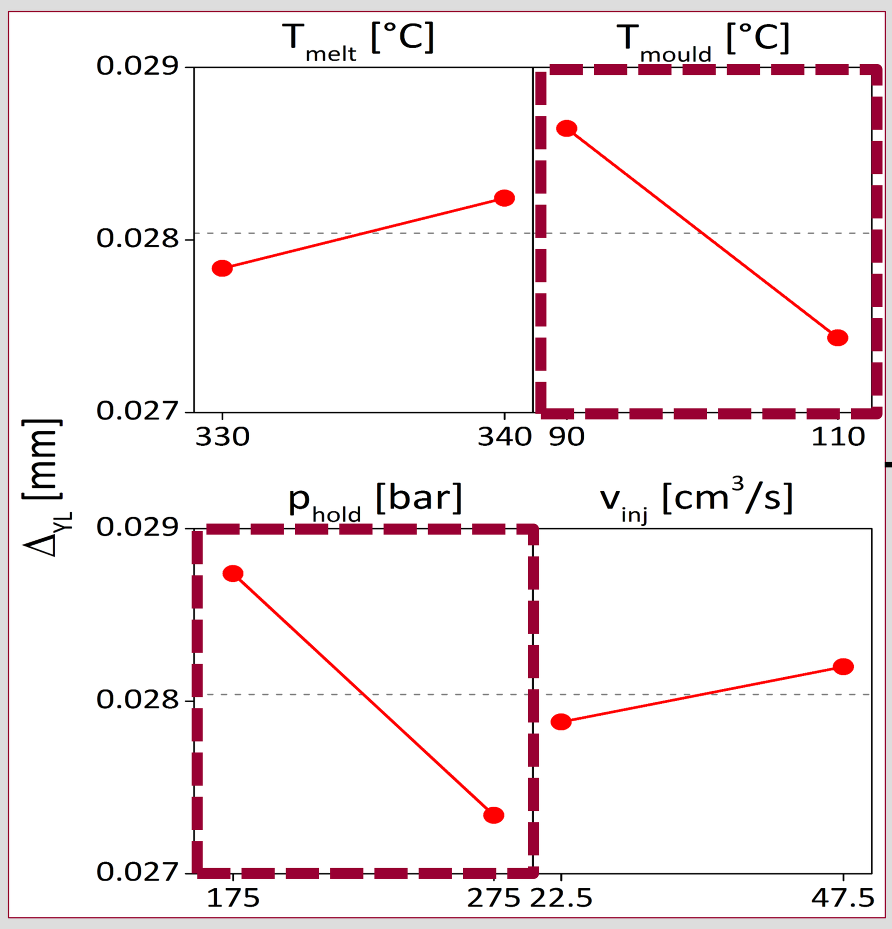

Fig 2. Main effects plot of Δ_{YL}

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

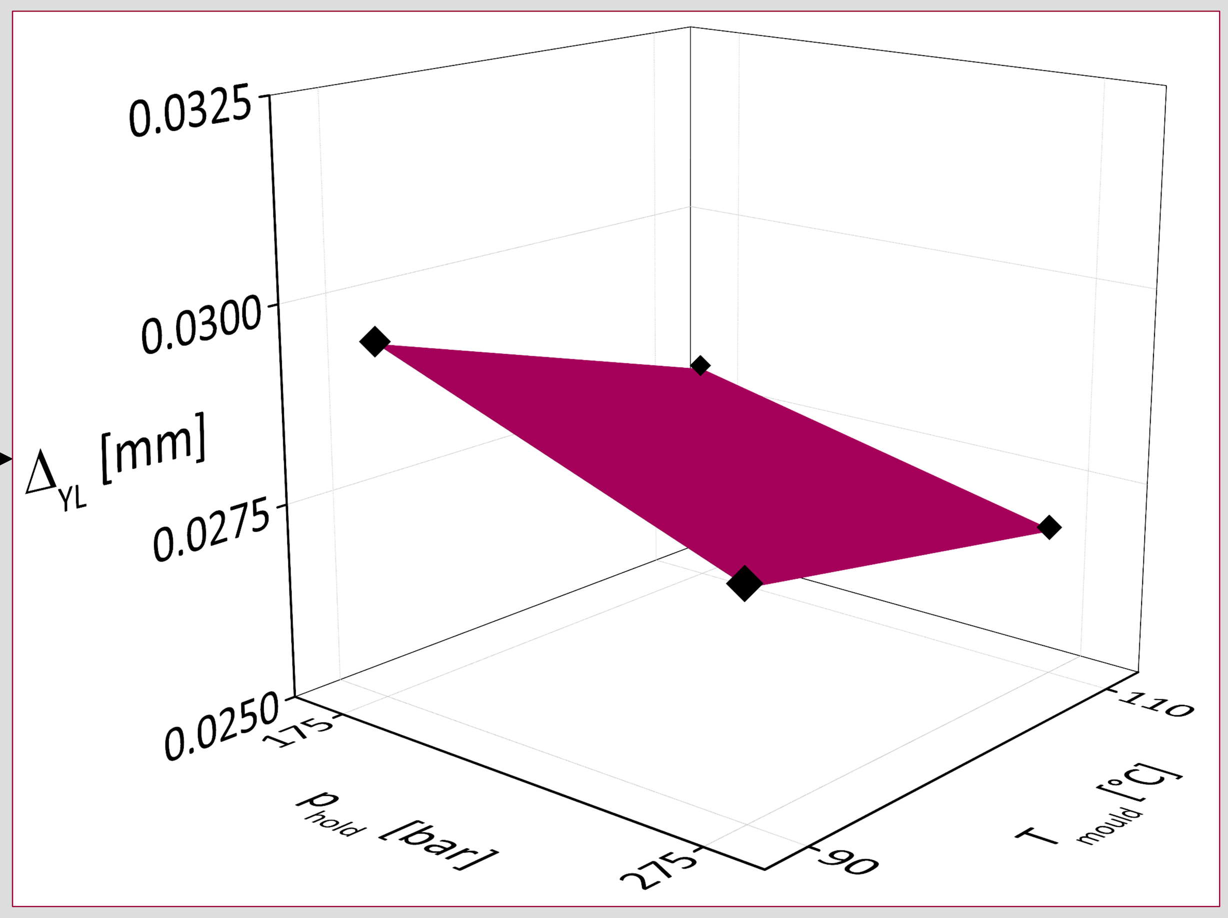

Fig 3. 1st order regression plane

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

Measurand	U_Δ [mm]	U_Δ/T
Y_L	0.003	29 %
Y_R	0.003	29 %
X_L	0.003	29 %
X_R	0.003	29 %

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

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Acknowledgements

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