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# Accurate characterisation of post moulding shrinkage of polymer parts

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**Abstract**
The work deals with experimental determination of the shrinkage of polymer parts after injection moulding. A fixture for length measurements on 8 parts at the same time was designed and manufactured in Invar, mounted with 8 electronic gauges, and provided with 3 temperature sensors. The fixture was used to record the length at a well-defined position on each part continuously, starting from approximately 10 minutes after moulding and covering a time period of 7 days. Two series of shrinkage curves were analysed and length values after stabilisation extracted and compared for all 16 parts. Values were compensated with respect to the effect from temperature variations during the measurements. Prediction of the length after stabilisation was carried out by fitting data at different stages of shrinkage. Uncertainty estimations were carried out and a procedure for the accurate characterisation of post moulding shrinkage of polymer parts was developed. Expanded uncertainties (k=2) of 3 µm were obtained.

Keywords: Shrinkage, length probe, uncertainty

## 1. Introduction

The use and importance of polymer parts in industry are increasing, and polymer parts are now used for critical elements, e.g., in the health care industry, high quality toys industry, etc. Polymer parts are mass manufactured by injection moulding, for instance, the LEGO Group produces over 50 billion elements a year.

Injection moulding is a complex process where the polymer reaches stabilisation after a certain number of hours, also in dimensional terms. Measurement after stabilisation requires a long waiting time and measurements before stabilisation have to tackle shrinkage and warp phenomena. Shrinkage refers to the reduction of the polymer part dimensions after injection moulding while warp is a non-uniform shrinkage where the dimension reduction for each point of a surface is different.

This paper studies the shrinkage of polymer parts before stabilisation time, considering the main uncertainty contributors. A new experimental set-up capable of measuring dimensions on polymer parts has been developed.

## 2. Experimental set-up

A set-up for measurement after injection moulding on polymer parts has been developed, figure 1. This set-up allows the simultaneous length measurement of 8 parts at a specific point. The set-up is made of invar with a coefficient of thermal expansion (CTE) equal to 1.5 $10^{-6}$ $K^{-1}$, for thermal stability. The feature measured is the length of a 2x4 ABS LEGO™ brick, approximately 32 mm.

Lengths on the 8 bricks are measured with 8 contact probes (P1-P8) continuously over the test duration. Length signals are collected with a frequency of 1 sample every 5 seconds and a resolution of 0.5 µm. Temperature is acquired by three temperature sensors (2 for set-up temperature and 1 for the ambient) having an uncertainty of 0.02°C according to the calibration certificate.

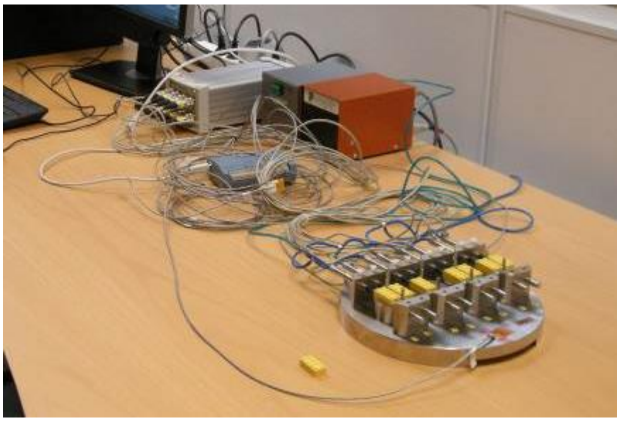

**Figure 1.** Set-up for shrinkage measurements

## 3. Experimental results

### 3.1. Calibration and stability

For the purpose of set-up calibration, 25 measurements were taken on a reference block made of invar. During the tests, the temperature range was 0.1°C. Stability of the system over time was studied by keeping the probes statically in contact with steel gauge blocks and measuring the length variation and measuring the length variation over 7 days in a laboratory with a temperature range of 0.25°C. The standard deviations for probe 1 to 8 in both tests are shown in table 1.

**Table 1.** Results from probe calibration and stability tests. Values in µm.

| Std.dev. | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 |
|---|---|---|---|---|---|---|---|---|
| Calibration | 0.25 | 0.20 | 0.28 | 0.22 | 0.17 | 0.14 | 0.17 | 0.23 |
| Stability | 0.26 | 0.15 | 0.14 | 0.20 | 0.13 | 0.21 | 0.08 | 0.05 |

### 3.2. Shrinkage measurements

A total of 16 length measurements were taken, in 2 measurement campaigns with 8 samples each. The 8 samples were obtained from 4 cavities of the same mould and 2 shots per cavity. Measurements started 10 minutes after the samples were moulded, the injection moulding parameters being the same for all parts. This investigation was performed in a metrology lab within a temperature range of 1°C. The P1 length variation over 7 day can be seen in figure 2. A rapid drop occurs over the initial hours, after which the length signal oscillates about a general reduction. After day 5, the length is stabilised.

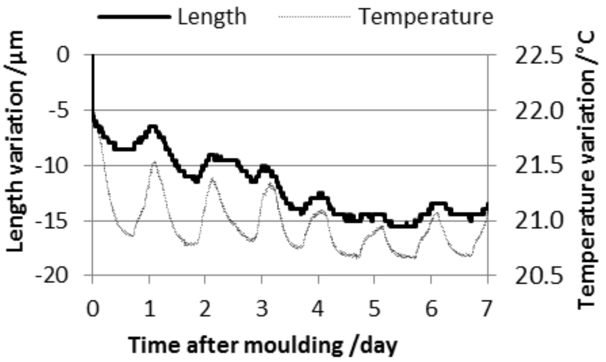


**Figure 2.** Example of shrinkage curve for probe P1 and temperature on the set-up over 7 days.

### 3.3. Temperature compensation

It appears from the signals that length variation is synchronised with temperature, so compensation for this factor was performed. Compensation was done using the set-up temperature and a CTE value of 95±15 $10^{-6}$ $K^{-1}$, Figure 3. After compensation, the oscillation of the length signal has been reduced. Thermal drift of the probes (0.15 µm $K^{-1}$) has also been compensated.

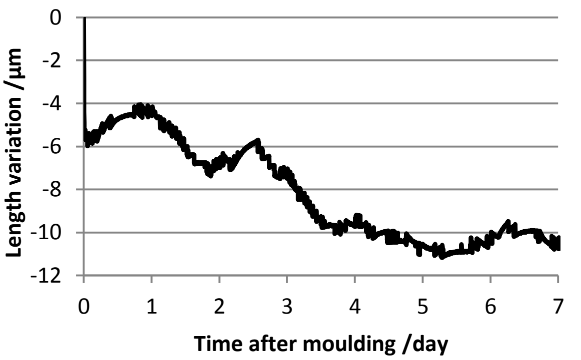


**Figure 3.** Shrinkage curve after temperature compensation. Probe P1.

Expanded uncertainty for temperature compensation has been calculated according to equation 1, considering the uncertainty associated with the temperature sensor and a rectangular distribution for the CTE of ABS.

$$U_{tempc} = k\sqrt{(L\, u(\Delta T)\alpha)^2 + (L\, \Delta T u(\alpha))^2} \qquad \text{Eq.1}$$

The resulting expanded uncertainty (k=2) for general temperature compensation is 0.56 µm.

### 4. Curve fitting – prediction models

After day 5, signals appear stabilised. A logarithmic fitting was applied to different data sets in order to predict length values after stabilisation, which were calculated as averages over day 5-7. In order to determine how early after moulding it is possible to predict the length after stabilization, fitting was carried out taking the data 10, 30 and 50 minutes after moulding and for acquisition times of 30, 60, 90, 120, 150 and 180 minutes.

The uncertainty of the shrinkage prediction was calculated according to equation 2.

$$U = k\sqrt{u_r^2 + u_m^2 + u_e^2 + u_p^2 + u_{tempc}^2 + u_{fit}^2} \qquad \text{Eq. 2}$$

Where: $u_r$ is the reference block calibration uncertainty, $u_m$ is the uncertainty from the probes calculated from the calibration and stability tests, $u_e$ *is* the uncertainty due to the variation of the thermal expansion coefficient of the measured parts related to temperatures changes during the test, $u_p$ is the uncertainty of the measurement process calculated as standard deviation of the 16 measurements for days 5-7 prediction, $u_{tempc}$ is the uncertainty associated with the temperature compensation, $u_{fit}$ is calculated as the maximum standard deviation of the fitting model for the 16 measurements. The expanded uncertainty U was calculated with *k*=2. Table 2 shows the average expanded uncertainty for all probes using different fitting parameters.

**Table 2** Expanded uncertainty for 16 shrinkage curves as a function of start time after moulding and acquisition time. Values in µm.

| Expanded uncertainty | | Acquisition time (min) | | | | | |
|---|---|---|---|---|---|---|---|
| | | **30** | **60** | **90** | **120** | **150** | **180** |
| **Start time (min)** | **10** | 8.4 | 3.5 | 3.1 | 3.5 | 4.4 | 5.0 |
| | **30** | 6.2 | 7.1 | 7.3 | 7.6 | 7.9 | 8.2 |
| | **50** | 7.8 | 7.3 | 8.1 | 8.4 | 8.6 | 8.9 |

Results show an expanded uncertainty of 3.1 µm for the best of the cases. This table can be used to set the starting and acquisition time under these circumstances. Generally, starting to measure as soon as possible and acquisition times of 60-120 minutes gives the best lowest uncertainty.

### 5. Conclusions

A set-up for accurate measurement of shrinkage was developed and used to characterise parts after injection moulding. A prediction model of the shrinkage using different sets of data was implemented in order allow part dimensions inspection as early as possible. An uncertainty including terms of reproducibility from different cavities and different shots and probes of approximately 3 µm was achieved.

**Acknowledgments**

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