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Post moulding thermal characterization of polymer components

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Abstract
Industries seek to anticipate product dimensional measurements to quickly control the process and ensure production conformity. The anticipation of the dimensional measurement is often prevented due to dimensional instabilities of the produced parts. In the case of injection moulded polymer components, one of the main instabilities is represented by expansion due to temperature changes. This work proposes a methodology consisting in the prediction of the dimensions at reference temperature conditions using information from measurements performed within few minutes from the moulding process. An industrial component consisting of a thin wall tubular part made of POM (polyoxymethylene) has been selected for the investigation. The measuring equipment included an inductive probe, two thermocouples for concurrent measurements of length and temperature. The dimension at reference temperature conditions is estimated using the information from the transitory cooling period subsequent to the moulding process and through the definition of an apparent coefficient of thermal expansion. Further development of the methodology must be introduced to tackle other dimensional instabilities, such as hygroscopic swelling, stress relaxation and recrystallization.

Production, Metrology, Polymer, Predictive model

1. Introduction

Dimensional measurements for quality and process control are a necessary step in the manufacturing process chain to reduce costs due to defective production [1]. However the costs necessary for the installation of metrology facilities limit its benefits. In this optic the common practice of performing dimensional measurements in costly metrology laboratories is nowadays substituted with measurements performed directly in production environment with the further advantage of prompt intervention of the operator to adjust the process. Previous studies from the authors have introduced the concept of Dynamic Length Metrology (DLM) for obtaining accurate dimensional measurements from the transitory period subsequent the production process [2]. For polymer components produced by injection moulding the effects of temperature and moisture absorption have been investigated with experiments to mimic the conditions after production [3-4]. This work continues the study on the post moulding thermal deformations considering measurements performed just after the production process.

2. Experimental work

The selected item for the investigation is a polymer component made of polyoxymethylene (POM) with a tubular shape. The dimension under investigation is its length with nominal value of 59 mm, intended as the distance between the two extremity planes. The component is manufactured by injection moulding.

2.1. Measurement equipment

The measuring unit (Figure 1) consists of a column type frame made with Invar (36%Ni) elements to limit thermal deformations. The frame holds an inductive probe (TESA GT22, maximum permissible error MPE of 0.07 + 0.4·L, L in mm) equipped with a flat end tip. The temperature of the measuring object is monitored (simultaneously to the length) on two locations equidistant to the extremities of the component using two thermocouples type K (MPE of 0.2 °C) attached to the tube with sticky pads. The fixture allows the univocal alignment of the workpiece with regards to the probe axis.

Ambient conditions are close to reference condition with temperature of 20±1 °C and relative humidity of 45±5 %.

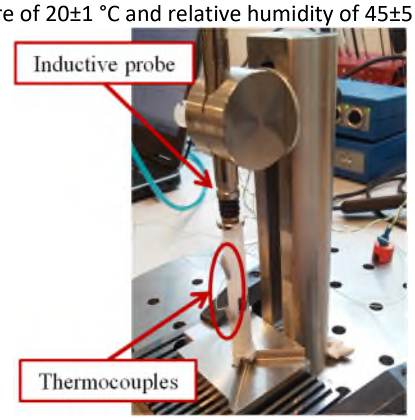

Figure 1. Test equipment for concurrent measurements of length and temperature.

2.2. Procedure

A POM tube is collected directly from the injection moulding machine and placed in the measuring fixture after approximately 5 minutes from the ejection. Length and temperature variations are measured simultaneously with a rate of 0.2 Hz for a sufficient time to reach ambient conditions, approximately 10 minutes. A cooling curve (length vs temperature) is therefore obtained. The procedure is repeated for 7 different tubes, selected from random cavities of the mould and produced in a time span of 4 days.

3. Data analysis

The average value of the two temperatures measured on the polymer tube is considered in the data processing as an estimation of the mean temperature of the part.

Length variations are compared to the concurrent temperature variation, producing a cooling curve similar to the one depicted in Figure 2. Temperature perturbations due to the change in the boundary conditions after the positioning of the tube on the fixture and non-linearity due to fast temperature changes are limited by discarding the first two minutes of measurement, corresponding to the segment of the cooling curve at higher temperature. The remaining part of the cooling curve is characterized by temperature changes of about 3 °C. A linear regression based on equation (1) is performed to determine the length of the tube at 20 °C (L_{20}) and a coefficient of thermal expansion which is named apparent (CTE_a) since it is not calculated using standardized procedure [5]. The concept of apparent CTE has to be introduced since it is referred to the particular geometry of the component and defined with a transient measuring condition.

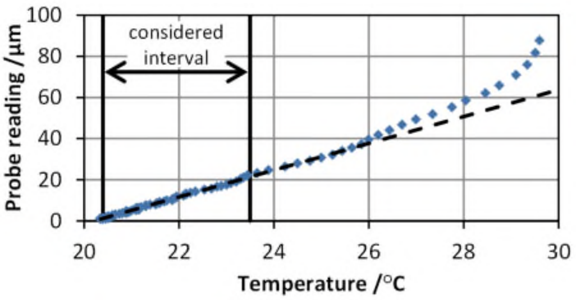

Figure 2. Post-moulding cooling curve (length vs temperature) of the tube under test. The linear regression model (dashed line) is obtained considering only the data points within the highlighted interval.

$$L(T) = L_{20} \cdot \left[1 + CTE_a \cdot (T - 20)\right] \qquad \text{eq. (1)}$$

where: $L(T)$ is the measured length of the tube during cooling
L_{20} is the length at reference temperature state (20 °C)
CTE_a is the apparent coefficient of thermal expansion
T is the measured average temperature on the part

4. Discussion

The considered tubes show similar values of CTE_a, which are compatible with the nominal CTE for POM, equal to 110 ppm/°C, found in literature [6]. The apparent CTE presents a slight influence from the production day (Figure 3), probably due to different production or measuring conditions.

The estimated expanded uncertainty of the CTE_a, U_{CTEa} (depicted as error bars in Figure 3) follows equation (2) and considers contributions from the regression u_{reg}, as standard error of the calculated coefficient, from the uncertainty of the measured length variation u_L and from the uncertainty on the defined mean temperature u_T. The sensitivity factor ΔT and ΔL are defined as the overall length and temperature variation range. the coverage factor k is fixed equal to 2. The value of U_{CTEa} corresponds to approximately 10 % of the value of CTE_a.

As the experimental work has been performed at an ambient temperature close to the reference condition, the uncertainty on the calculation of L_{20} is barely affected by the uncertainty contribution due to U_{CTEa}. Supposing a difference between ambient and reference temperature of 5 °C, this contribution can be as high as 3 µm.

$$U_{CTE_a} = k \cdot \sqrt{{u_{reg}}^2 + {u_L}^2 \cdot \Delta T^2 + {u_T}^2 \cdot \Delta L^2} \qquad \text{eq. (2)}$$

The estimation of L_{20} cannot be directly compared with reference measurements performed under stable conditions since the dimensions of the POM tubes undergo other types of post-moulding instabilities which are not considered in this work, such as hygroscopic swelling and recrystallization.

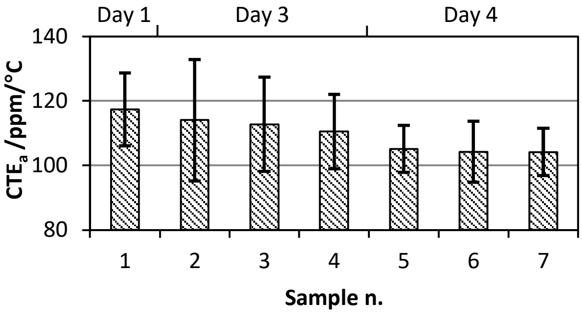

Figure 3. Apparent CTE of the POM tubes calculated from the regression of the cooling curve. The error bars represent the estimated expanded uncertainty. The upper horizontal scale represents the production day.

5. Conclusion

An experimental set-up and procedure has been developed for process control of a POM industrial component made by injection moulding. Simultaneous measurements of length and temperature are performed during the cooling phase to obtain an estimation of the coefficient of thermal expansion and the length at reference temperature. Uncertainty coming from the CTE is reduced to 10% of the nominal value with the consequent length uncertainty reduction. The measuring methodology extracts material information directly from the measurement, making it suitable in the case of fluctuations on the material behaviour, i.e. due to colour/filler changes.

The procedure described must be implemented in a more complex measuring system, where also other dimensional instabilities typical of injection moulded polymers are considered.

Acknowledgements
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