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The influence of humidity on accuracy length measurement on polymer parts

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Abstract

The work deals with an experimental study of the influence of humidity on accurate length measurements on ABS parts. Polymer parts absorb water from the ambient until they reach hygroscopic equilibrium. Water content causes an expansion of the polymer part. The relationship between the water content and this expansion has been barely studied, especially from a metrology point of view including its contribution to the measurement uncertainty. The experimental set-up includes a humidity chamber, an invar fixture with 8 inductive probes and a scale. The humidity chamber was used to create the experiment ambient conditions. The invar fixture with the inductive probes, with a resolution of 0.1 µm, allows length measurement on 8 ABS parts at the same time. The scale was used to collect the water content variation during the experiment with a resolution of 0.1 mg. The length and weight of the ABS parts were measured at 5 levels of relative humidity from 50 %RH to 90 %RH, and constant temperature, 20 ±0.2˚C. Water content equilibrium with the ambient was achieved at each level by acclimatization of the parts for 24 hours. An average length variation over the humidity range of 15 µm was found. A condition specific coefficient of moisture expansion of 69±4 µm/(Δ of weight in mg) was estimated.

Keywords: Humidity, Dimensional Measurements, Measurement Uncertainty, Polymers, Production Environment

1. Introduction

Polymer parts are vastly used in industry and the polymer global production is increasing every year. Critical functional parts of instruments and devices are also being manufactured made of polymers e.g. medical industry. The metrological inspection of the polymer parts production has become a key task.

The relatively less stability of polymers compared to metals (higher coefficient of thermal expansion (CTE), lower Young modulus, etc.) makes the part dimension measurement more challenging for the same accuracy level. Although polymers have been not extensively studied from a metrological point of view, the effect of temperature and force are controlled to a certain uncertainty level. Traditionally, humidity has not been considered as a significant uncertainty contributor. Polymer parts absorb water from the ambient until it reaches hygroscopic equilibrium [1]. This alters the part dimensions.

This paper studies the effect of humidity on a polymer part length and on the measurement uncertainty. The moisture expansion coefficient was calculated based on length measurements on moulded elements.

2. Experimental set-up and conditions

An experimental set-up for length measurements on polymer parts at different humidity conditions have been used, fig.1. The set-up consists of a fixture with 8 inductive probes (P1-P8) [2], a humidity chamber, temperature sensors and a scale. The fixture is made of invar with a coefficient of thermal expansion (CTE) equal to 1.5 10^{-6} K^{-1} and provide support and alignment for the inductive probes and the polymer parts. The inductive probes have a resolution of 0.1 µm. The measurand is the length of an ABS moulded element, 31.8 mm. The fixture has been calibrated by measuring a steel gauge block 25 times at 20˚C. A standard deviation below 0.28 µm was found for measurement of the 8 lengths. The humidity chamber can keep a constant temperature at 20˚C and change the humidity level from 50 to 90 %RH. The temperature of the fixture and the ambient is acquired by 3 temperature sensors PT-100) with an uncertainty of 0.02˚C. A scale with a resolution of 0.1 mg completes the set-up.

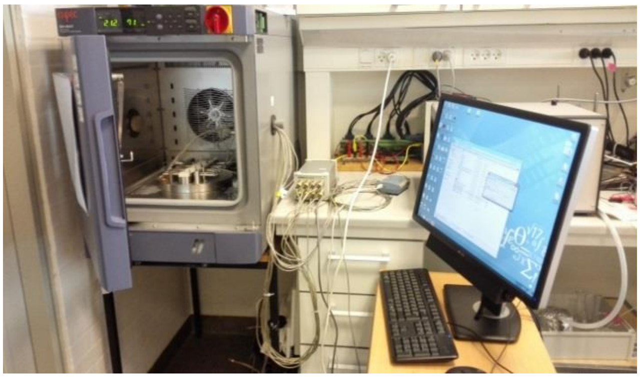

Figure 1. Set-up for length measurements in the climatic chamber.

The polymer parts have been measured in a controlled environment of constant temperature at 20°C and 5 humidity steps: 50, 60, 70, 80 and 90 %RH. Prior to measurements, parts were acclimatised to these conditions for 24 hours. Preliminary investigations showed an acclimatization time of 24 hours. The acclimatization is considered as the hygroscopic equilibrium point, where the weight of the parts is stable.

3. Experimental results

The ambient humidity, part weight variation and water content are used to study the behaviour of the parts.

3.1. Length variation VS humidity

The expansion of length in ppm with the humidity is shown for each part, fig.2. A maximum variation of 550 ppm has been found.

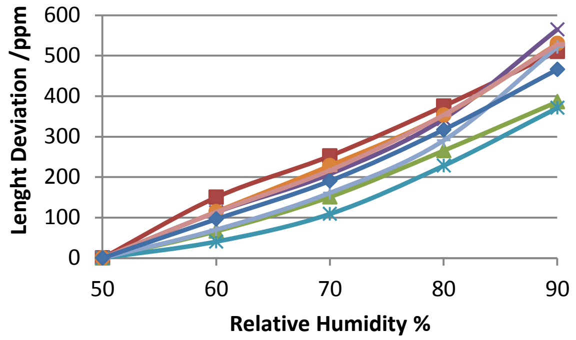

Figure 2. Length variation VS humidity for the 8 parts.

3.2. Weight VS Humidity

The weight was also measured at each humidity step 10 times, table 1. The standard deviation for each part and step is below 0.1 mg. The average weight of the parts at 50 %RH is 2.1932 g and the maximum deviation between parts is 6.6 mg. The correlation between the humidity in the chamber and the weight variation of the parts is higher than 99%.

Table 1. Relative weight variation for each brick.

Weight variation [mg]								
Humidity	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
50 (%RH)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60 (%RH)	0.9	1.1	1.0	1.0	1.0	1.0	1.2	1.2
70 (%RH)	2.0	2.2	2.2	2.1	2.1	2.1	2.2	2.2
80 (%RH)	3.2	3.5	3.4	3.5	3.5	3.5	3.6	3.6
90 (%RH)	4.7	4.9	4.9	4.9	5.0	4.8	5.1	5.0

3.3. Length variation VS water content /%

The moisture or water content of the parts is also calculated [3] since this parameter is usually used to measure the moisture on a part.

$$\text{Water content} = \frac{m_i - m_0}{m_0}\ (\%)$$

Where: m_i is the mass of the part a humidity step and m_o is the weight of the part at 50 %RH. The expansion of length with the variation of the water content for each part is shown, fig.3. A similar relationship for the water content and length compared to the relative humidity has been found.

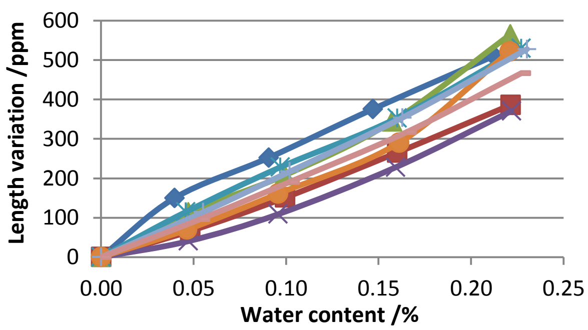

Figure 3. Length variation VS humidity for the 8 parts.

3.4. Apparent Coefficient of Moisture Expansion

The apparent Coefficient of Moisture Expansion (CME*) has been calculated:

$$\text{CME}^* = \frac{\Delta L}{Moisture\ (\%RH, \Delta weight, \Delta wc)}$$

Where: ΔL is the length variation and moisture is the humidity factor measured in %RH, variation of the part weight or water content.

The uncertainty has been also calculated:

$$\text{U}(\text{CME}^*) = 2\sqrt{\left(\frac{d(CME)}{\partial(\Delta L)}\right)^2 + \left(\frac{d(CME)}{\partial(\Delta w)}\right)^2 + (u(rep))^2}$$

Where according to the CME* equation the uncertainty associated with the length and weight measurement is calculated. A contributor for the repeatability of this term is estimated as the standard deviation of the mean for the 8 parts. The results for CME and its uncertainty are shown in table 2. As an example, measurements at 90%RH (or 5 mg weight variation) are corrected to 50%RH by 15.2 µm with 0.5 µm uncertainty associated to the CME.

Table 2. Calculated CME for different moisture factors.

Parameter	**Value**	**U**	**Units**	**Rel. Error**
Rel. Humidity	0.38	0.03	10^{-6} m/%RH	7.8%
Weight	3.1	0.1	10^{-6} m/mg	3.1%
Water content	69	4	10^{-6} m/%wc	5.5%

5. Conclusions

A new methodology to study the metrological influence of ambient humidity on polymer parts has been presented. The length of the polymer parts can be studied through the relative humidity in the ambient, the weight variation or the water content variation of the part. A maximum length expansion of 18 µm has been found from 50%RH to 90%RH. Humidity has a significant influence on accurate measurement of polymer parts. The use of the weight parameter along with the length of measurement provides an uncertainty ±0.1 10^{-6}m/mg and 3.1% or relative error. This approach also allows taking the measurements without waiting long times for stabilization in a laboratory or production environment. The variation of weight between parts is in the same order with the variation of weight due to humidity. Thus, each part needs to be always weighted at a specific reference humidity level. The influence of humidity in the measurement accuracy can be greatly reduced up to ±0.5 µm by applying an apparent Coefficient of Moisture Expansion depending on the geometry.

Acknowledgments

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