Analysis of shape deviations of technical polyamide workpieces in different defined time intervals

M Aclan\textsuperscript{1,*}, M S Popa\textsuperscript{1} and R Oezden\textsuperscript{1}

\textsuperscript{1}Technical University of Cluj-Napoca, Department of Manufacturing Technology, Romania

E-mail: metin.aclan@googlemail.com

Abstract. Engineering grade plastics gain importance across the industry and have become indispensable today. Machine operators must concern themselves among others with environmental and manufacturing influences that can affect the geometrical properties of plastic articles daily. In practice, these are declared as check gauges in the inspection drawing and are checked in accordance with quality standards. Based on experience, plastic articles made from polyamide start to grow after a certain time span. Even manufacturers of plastic granulate indicate this in their fact sheets. Here, the geometry of the plastic articles themselves plays a crucial role, especially in how far it can be altered. Additionally, in globally aligned companies with several production facilities, certain ecological influences such as temperature and humidity are different. The effect this has on plastic articles in terms of growth has been investigated in a different research paper [1]. This paper is primarily concerned with the evaluation of geometrical alteration by means of warpage formation. Thereby, an experimental part is demonstrated and constituted in comparison with two different climate simulations, of standard climate and one of extreme climate, over the course of a defined period of two months.

1. Introduction

In this paper, a comparative experiment conducted in Germany and Romania on the geometric changes of plastics is shown. The geometrical changes are shown and evaluated three-dimensionally. This means that not only the distances in relation to the length are considered, but also the surface form considerations in relation to the warpage. Since the comparison of two different climates is in the foreground, only the simulated test environments of:

- Normal climate 21°C / 50% relative humidity (Germany),
- Extreme climate 40°C / 93% rel. humidity (Romania),

were taken into consideration. This is followed by a presentation of the test object considered in this experimental part. Here, the focus is on the plastic property PA66/6. Furthermore, the test equipment CT (computer tomography) has been used for the images of the test object, as only this enables 3D viewing. Point clouds are created, which can then be evaluated with the help of 3D measurement technology software. Subsequently, the procedure for accepting the specifications to be examined is presented on a digitized plastic workpiece. This is followed by the evaluation of the individual test criteria with the aid of the false colour comparison. Then, the evaluation is explained and presented through graphic representations. Finally, the water absorption is determined [2].
2. Experiment on the geometric changes of plastics
The experiment includes the experimental setup as well as the performance of a series of measurements on a plastic article made of PA66/6. The following points demonstrate this successively. The overall objective is to find out how the plastic article changes in the two different simulated environments. In the process, tools such as 3D measurement technology will be used to obtain a valid overview of this topic.

2.1. System Analysis
The product characteristics refer to two fixed distances for the following investigation. These contain the length dimensions in X and Y direction (coordinate system). Systematic measurement errors should be prevented in a geometrical measurement's early phase [3]. Therefore, it was important to find reproducible specification for each investigation. In the following figure 1, the respective linear dimensions are graphically displayed.

![Figure 1](image_url)

**Figure 1.** Length dimensions in X (a) and Y(b) coordinates respectively.

The process parameters remain unchanged and constant for the test, as they are fixed for production in the manufacturer's material data sheet [4]. Thus, the environmental influences are the only variable parameters in the product manufacturing process.

2.2. Test duration
The temporal aspect of the measurement is based on the final state (saturation) of the distance measures in X and Y coordinates. The time factor for these measurements is kept variable, but the number of measurements is bound to a time guideline as follows:

- the first two weeks daily (excluding weekends),
- then at weekly intervals,
- measuring duration orientation to the saturation value. This means that the values have been reached according to the manufacturer's specifications or that no more water increase must be measured.

2.3. Experiment execution
The individual steps involved in carrying out the test are explained below. The test execution only refers to the German location. First, freshly sprayed parts (within 24 hours) must be removed directly from the machine and then cleaned in order to not influence the measurement results. The first measurement is carried out after 6 hours according to ISO 20457 [5]. Further measurements are carried out daily and, after 14 days, weekly. Based on the experience of the company, the saturation in the climatic environment of 40°C with 90% relative humidity is reached after approximately one week. Derived from the following real saturation values, the test duration will be oriented accordingly. Initially, a total measurement duration of approximately two months will be determined, as a constant growth is expected for the climate environment with 20°C and a relative humidity of 50%. This results in 17 measurements over a period of 63 days. The aim of the study is to determine the changes in plastic
articles in terms of growth in the different simulated environments and the respective warpage. The main parameters determined should be the previously defined distances in X and Y and the warpage. The output unit of the evaluations is documented in the unit mm. The plastic workpiece property polyamide PA66/6 is selected for the investigations. After the first measurements, the same plastic article is placed in the two different climatic conditions. One of the two climatic environments simulates the average climate in Germany. The temperatures are fixed at 20°C +/- 2°C and at a humidity of 50% +/- 10% [5]. The climate test chamber is used to simulate the second environment. Here, different temperature and humidity influences can be simulated. The air flow with a correspondingly high circulating air volume guarantees a continuously good transfer to the test samples. The required parameters are entered manually on a control panel. For the test measurements the environments with 40 °C and 93% relative humidity (Romania) as well as 23°C and 50% relative humidity are simulated. A point cloud for the 3D model measurement is to be created with the aid of computer tomography. This allows an assessment of the entire geometry in comparison to the 2D view. Thus, visual observations and measurements in 3D are possible for the first time. After the X-ray of the respective test object, a stereolithography (STL) file can be created in order to be able to measure it in the following step with the 3D measuring system software available at the company. In order to obtain reproducible measurements, automated measurement is used for a series of measurements over the two previously defined length distances (in X and Y coordinates). For reproducible measurements, regular geometries are explicitly evaluated in order to avoid systematic measurement error [6]. All that remains to be done is to load the respective scan and the resulting STL file into the measuring system software. This has, among other things, the advantage that it is more time-saving than conventional measurement, whereby the identical measurement strategy is maintained and the alignment can be neglected. The first measured value in the time between 16 and 24 hours is regarded as the reference value [5].

![Figure 2. False colour comparison on the test object.](image)

2.4. Test evaluation

The following shows how to visualize and examine a 3D model in a false color comparison. First, the CAD model and the respective scans are adjusted. With the help of the colours, it can be determined whether a delay or growth has taken place. With the help of the legend, the deviations from the CAD are displayed in mm. It also becomes clear in which areas of the workpiece these can be found. In addition, local surfaces can be tagged with deviation flags and conclusions can be drawn in order to carry out investigations on:
• warpage,
• form deviation.

In the figure 2, a model is represented in the false colour comparison. The area deviations of the different simulated climates are graphically displayed for the distances in X and Y direction. The initial state (reference) is compared to the final state (saturation). For each of the front and back sides of the plastic article.

2.4.1. Climate environment (extreme climate) 40°C/ 90% relative humidity (Romania). First, the plastic workpiece is considered for the simulated climate in Romania. On the one hand, it is noticeable that the distance in X increases disproportionately to the distance in Y. Herewith follows the first important realization that due to the given geometry of the workpiece, X and Y grow disproportionately. In addition, it is noticeable that more is happening in the outer areas than in the inner areas. This becomes clear with the help of the false colour comparison. Higher growth is achieved in the outer areas. A further insight is, that on the one hand, after one day, in the simulated climate environment a clear growth prevails and that it reaches its saturation after a short time. This is visually very well represented by the change from yellowish to red. Otherwise, only slight distortions can be observed in the corners and in the foot area. Overall, the plastic article shows relatively similar tendencies. In the following figures 3 and 4, the initial and final condition of the plastic workpiece is shown in a comparison of the different colours.

![Figure 3. Initial state of the area deviation.](image)

In the following figure 4, the final state of the plastic workpiece is shown in the false colour comparison.

![Figure 4. Final state of the plastic workpiece.](image)

2.4.2. Climate environment 23°C/ 50% relative humidity (Germany). In this climatic environment, the plastic article has the same characteristics as the climatic environment with 40°C/ 90% relative humidity. However, it becomes clear that growth is much slower. This is confirmed in the false colour’s comparison. Overall, the test object shows relatively similar tendencies compared to the other climatic environment. Therefore, the findings are also documented in key points. In the following figures 5, 6, 7, the beginning, middle and final condition are shown in a false colour’s comparison.
As shown in the following figure 6, the condition of the plastic workpiece after five weeks is shown in a false colour comparison.

![Figure 6. Condition of the plastic workpiece after five weeks.](image)

As shown in the following figure 7, the final state of the plastic workpiece is shown in a false colour comparison.

![Figure 7. Final condition of the plastic article.](image)

In this climatic environment, the plastic article has the same characteristics as in the climatic environment with 40°C/90% relative humidity.

It is clear however, that growth will be much slower.

This is confirmed by a comparison of false colours.

3. **Determination of water absorption according to DIN EN ISO 62**

Based on the standard, the water absorption and the growth for the plastic workpieces are determined. To determine the water absorption, they are weighed when freshly sprayed and after being saturated with a digital precision scale. Since the water absorption is determined in different climatic environments, different results are expected in this respect. After completion of the series measurements,
the percentage of water absorption was defined by the weight for the respective materials in the various environments according to DIN EN ISO 62. This is followed by an analysis for the plastic article made of the material PA 66/6. The water absorption values determined from the series measurement are listed in Table 1 for an overview.

Table 1. Evaluation of maximum growth and weight gain in %.

| Test object | Test environments | 21°C/ 50% rel. humidity | 40°C 93% rel. humidity |
|-------------|--------------------|--------------------------|------------------------|
| Moulding part | 4,292              | 4,581                     |

4. Conclusion
This paper demonstrated that there are increasing growth differences for workpieces in different climates. The evaluation has added further insights to show the growth of the individual plastic materials in the respective environments. With the help of 3D measurement technology, new possibilities have been demonstrated in the investigation compared to the previous 2D measurement technology. With the false colour comparison, it has been possible not only to examine the distances, but also to further investigate warpage possibilities. Nevertheless, the geometrical changes determined for the investigated plastic article cannot be generalized, but tend to represent an actual situation, since the growth is still decisive for the geometry of the object. An outlook could be the scientific observation of simulations based on real tomographed objects. The trend behaviour of distortion and flow behaviour can be observed. Thus, simulation programs could be optimized accordingly.

References
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