THE INFLUENCE OF ENVIRONMENTAL CONDITIONS ON THE DIMENSIONAL STABILITY OF COMPONENTS INJECTED WITH PA6 AND PA66

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ABSTRACT:

The design of assembly components requires special attention to aspects related to their dimensions to ensure their functionality. The goal of this paper is to analyse the influence of case-based environmental conditions, including extreme hydrothermal conditions, on the dimensional stability of a component made from different polyamides throughout the component's working life. The results support the conclusion that components made from PA6 have a higher capacity to absorb humidity than those made from PA66 and, on the other hand, a higher capacity to lose this humidity, which implies a more significant effect on the average error in the dimensions considered (12% for PA6 in comparison to 3% for PA66). With regard to assembly dimensions, components remain within dimensional tolerances under average and extreme humidity conditions and average temperature conditions. Components injected with P66 are more stable for all of the situations analysed.

Keywords: polyamide, composite, dimensional, injected, humidity, absorption.

1 INTRODUCTION

Polyamides are among the most versatile technical polymers and can be found in a wide range of applications. From their discovery at the beginning of the previous century, several types of polyamides have been developed, including polyamide 6, polyamide 66, polyamide 11, polyamide 12, polyamide 4 and amorphous polyamides. In recent years, polyamides from natural resources have also been generated. Their properties vary with the type of polyamide and, frequently, their mechanical behaviour is improved by adding glass fibre and/or a mineral filler. The most commonly used polyamides are polyamide 6 (PA 6) and polyamide 66 (PA 66).

Polyamides are hygroscopic polymers, that is to say, they absorb moisture from the environment. This feature is especially representative of PA 6 and PA 66 and has remarkable consequences for their behaviour and dimensions [1]. The amount of moisture absorbed by PA 6 or PA 66 can reach up to 8% [2-5]. Due to this high value, gravimetric methods must be used to characterize these materials according to UNE-EN ISO standard 62 [6]. Tests based on this standard are conducted on small samples.

The relationship between the amount of moisture absorbed from the environment and the material properties have been studied by numerous authors. Mechanical properties are affected [4, 7], as are damage mechanisms [8], fatigue behaviour [9], viscosity [10] and glass temperature variations [11]. In fact, mechanical properties such as the Young's modulus and tensile strength are often supplied as functions of the amount of moisture in the material. For some materials, these mechanical properties can vary up to 63% (Young's modulus) or 34% (tensile strength).

Other features affected by moisture absorption are dimensions and changes in shape due to this variation of dimensions for components made from polyamides, as described by

Thomanson et al. [2] and Carrascal et al. [5], although this feature is also influenced by the manufacturing process and its conditions [12].

The amount of moisture absorbed depends on the environmental conditions to which the material has been exposed [13]. Injection moulding is the process through which components are manufactured from PA. Before processing, PA raw material is dried at a temperature determined by the type of polyamide to avoid creating scrap due to both aesthetic defects such as bursts and flow marks and mechanical defects such as interior bubbles. After injection moulding, the processed PA components are completely dry, but they absorb or release moisture according to the environmental conditions to which they are exposed.

When a component that will be made from PA is designed, the variation in its properties due to environmental conditions throughout its life under working conditions, and between its manufacture and the beginning of its working period, must be taken into account. The variations in its properties should not affect its functionality in spite of the significant variations in mechanical properties and dimensions due to moisture absorption. One of the main contributions of this paper is to analyse the behaviour of components under different environmental conditions.

Few studies that analyse the relationship between moisture absorption and dimensional changes have been performed. A study conducted by Bergeret et al. [7] consists of a systematic investigation into the dimensional changes of a glass-fibre reinforced polyamide composite during conditioning in coolant fluid, and concluded that materials intended for long-term use should be tested in realistic in-service environments, which is the goal of this paper. Thomanson et al. subjected samples to fixed lab conditions [2, 14], which do not reproduce those experienced by the real component during its working life. Carrascal et al. [5] studied thickness variations of samples in different environmental conditions, but did not examine dimensional variations along the other axis of the samples, which become relevant for analysing the behaviour and functionality of nylon components.

The current study is an analysis of the influence of environmental conditions on dimensional stage of an industrial component made from two different types of polyamides, PA6 and PA66. The evolution of the moisture absorption and change in dimensions is reported by sequentially subjecting the samples to different environmental conditions during its working life. Three representative dimensions of the component are taken as references, along with the flatness of the main surface. These parameters are critical from the point of view of both the component functionality and the process of assembling them. The importance of the dimensional variations during assembly has been studied by Vichere et al. [15]. Variations in these dimensions are studied in the different environmental conditions to which the components are normally exposed [7]. The component selected for the research is the base plate of an induction cooktop manufactured by BSH, a company that has collaborated in this study. A preliminary study is also conducted to analyse the evolution of the moisture absorption and stabilization times of the two polyamides from the injection moulding phase, when it is subjected to different environmental conditions.

2 EXPERIMENTS

2.1 MATERIALS

Two polyamide materials are used for the tests, PA6 KELON B H CE/40 BLACK:3302 and PA 66 KELON A H CE/40 BLACK:3330. Both are supplied by LATI. Table 1 summarizes the most significant properties of these materials.

	PA 6.6	PA 6.6
DENSITY (g/cm^3)	1.49	1.54
Tensile strength at break (MPa) (5 mm/min)	75	65
Young's modulus (MPa) (1 mm/min)	8500	6200
VICAT ºC 49 N (50°C/h)	245	204
HDT ºC0.45 MN/m² ISO 75 242 °C	242	178
1.81 MN/m²	162	77

Table 1: General properties of PA66 and PA6

2.2 COMPONENT

The component selected for the study is a base support plate, "base 2-elin," that is inserted into the mechanical structure of an induction cooktop manufactured by BSH Group. Currently, the component is manufactured from PA 66, but the behaviour of PA 6 is also studied. The main geometrical features of the component are its rectangular box shape, similar to a tray, its general dimensions of 460 mm x 415 mm x 28 mm, and its nominal thickness of 2.5 mm. From the dimensional point of view, the most critical dimensions are those that locate the screw holes on the assembly frame and the general flatness of the component due to the position of an electronic device on it (see Fig. 1).

2.3 METHODS

The components used for the trials were injected using a Billion 750 ton injection moulding machine with process conditions within the process window. The material was dried at 100ºC for three hours, the melt temperature was 270ºC for PA6 and 280ºC for PA66, the mould temperature was 90ºC and the injection time was 4 s. Seven components were made using each material. All of the components were injected on the same day, using the same mould and the same injection machine. After the components were moulded, they were weighed and prepared for the different environmental conditions. They were measured later.

A first humidity test was conducted to establish the amount of moisture absorbed from the environment and the time required to stabilize the component.

A sample of each material was tested under five different temperature and humidity conditions with different exposure times. The evolution of the sample weight and the time until humidity stabilization were analysed. The situations analysed in this first test were the following: Setup 1 refers to the component just after having been injected, with no moisture absorbed from the environment. Setup 2 refers to the conditions reached after a long period of stabilization in an environment with normal humidity and temperature fluctuations. Setup 3 refers to the conditions reached after the components were submerged in distilled water in a way that allowed the fluid access to all of the surfaces of the component for two days to ensure 100% humidity. Setup 4 refers to the conditions reached after the components were heated in an oven at a constant temperature of 50ºC for five days; under these conditions, the components released moisture and reached a constant value. In a second heating phase, setup 5, the oven temperature was increased to 100ºC, and the components continued releasing moisture.

2.3.1. STUDY CASES

A second set of tests was conducted to measure the critical dimensions of the components under different humidity and temperature conditions that reproduce the real working conditions of the components during their lives. The following study cases aim to reproduce the most significant situations:

Study case 1) The components were stabilized under lab conditions at 20±0.5 ºC for 24 hours with an environmental humidity of 65%. This represents average standard humidity and temperature conditions.

Study case 2) The components were saturated with moisture (100%) by being submerged in distilled water for 24 hours at 20±0.5 ºC (see Fig. 2). This represents an extremely humid situation at a medium temperature. The components were measured as soon as they were removed from the water.

Study case 3) To represent medium/high temperature conditions, unstabilized components were subjected to a temperature of 50ºC for 48 hours in an oven of type XU75 supplied by Climats (see Fig. 3). The components were taken directly from the oven and measured at a real surface temperature of 33ºC. This scenario represents high temperature conditions situation similar to those found where these components are stored. This is the most critical situation in the assembly chain with respect to the temperature.

Study case 4) The components were subjected to high temperatures in an oven. They were heated at 100ºC for 48 hours and, then, stabilized under lab conditions of 20 ±0.5 ºC and 72% humidity for 24 hours. When a component performs its function, it reaches temperatures close to 80ºC, even 100ºC in some areas, and cools to a standard temperature later. This case aims to reproduce these temperature variations.

2.3.2 HUMIDITY MEASUREMENT

The amount of moisture absorbed by the injected components was measured by weighing the components after they were subjected to different environmental conditions. When a component absorbs moisture from the environment, its weight increases, and the amount of moisture absorbed is directly proportional to the increase in weight, as described by equation (1).

$$W_f=(h/100)W_i, \tag{1}$$

where W_f is the weight after moisture absorption, W_i is the weight before moisture absorption, and h is the percent humidity.

The components were weighed using the same scale, an STZ-1000 with a resolution of 1000 g ± 0.01 g.

2.3.3 ANALYSIS OF THE DIMENSIONS

The critical dimensions of the components were analysed from the perspective of their assembly and functionality. To locate the component, the tool used for industrial quality control was used. Fig. 4 shows the locating tool with a component. To record measurements, a Zeiss PMC 876 coordinate measuring machine with a Vast XT probe and Calypso measurement software was used.

The base reference system was placed in the locating tool to automate measurements from this baseline once the tool was located in the measuring machine. Fig. 5 shows this base reference system. The component was always supported on the tool in the same way, first on the XY plane, then on the XZ plane and, finally, on the YZ plane, to ensure that the component's location was repeatable.

2.3.4. THE DIMENSIONS CONSIDERED

The distance between the two axes of the screw holes is considered the critical assembly dimension to control. The dimensions to be controlled are distances between fixing points of the component and the flatness of the inner surface of the part, (see Fig. 5).

Planes for each of the fixing points are measured independently, and also the plane defined by all of them. To measure the positions of the circles corresponding to the fixing points, the circles made by the holes are projected onto the plane defined by all of the fixing points because the final component assembly is in a single plane. Finally, the flatness of the inner surface is also measured.

The dimensions considered are shown in Fig. 5.

- **D1**: The Cartesian distance from fixing point 4 to fixing point 5. To determine the behaviour of this distance, the line joining fixing points 1 and 4 is taken as a reference in such a way that D1 is normal to it. D1 is calculated from the distance between the centres of the circles projected onto the plane common to all of the fixing points. D1's nominal value is 394.6±0.5 mm.

- **D2**: The Cartesian distance from fixing point 1 to fixing point 4. To determine the behaviour of this distance, the line joining fixing points 2 and 3 is taken as a reference in such a way that D2is normal to it. D2 is calculated from the distance between the centres of the circles projected onto the plane common to all of the fixing points. D2's nominal value is 315±0.4 mm.

- **D3**: The Cartesian distance from fixing point 2 to fixing point 3. To determine the behaviour of this distance, the line joining fixing points 1 and 4 is taken as a reference in such a way that D3 is normal to it. D3 is calculated from the distance between the centres of the circles projected onto the plane common to all of the fixing points. D3's nominal value is 302.3±0.4 mm.

- **PLN**: The geometric tolerance of the flatness of the inner plane. This dimension represents the error in measuring the plane, which represents the flatness of the plane measured for each component of the sample. There is no nominal value for this plane. Instead, it represents the separation between two parallel planes containing the measured points adjusted by using the least squares method that are on the inner plane that is normal to it. The locations of fifty-seven favourable points were measured. In selecting these points, injection points, ejector points, edges and moulding defects were avoided.

3 RESULTS

3.1. THE PRELIMINARY TEST

The humidity results shown in Fig. 6 confirm that the amount of moisture absorbed in the different situations was significant, with increments of 1.25% of the component's weight for PA6 and 0.95% for PA66. Regarding loss of weight when the components were dried, the values observed are -0.7% for PA66 and -1.1% for PA6. The magnitudes of these values confirm that the gravitational methods for measuring the moisture absorbed described in this paper are adequate.

Another interesting result of this test is the amount of time needed for stabilizing the sample components. It was observed that, after the samples were saturated (setup 3) and stabilized for 48 hours, their weights remained almost constant. Regarding the temperature, it was observed that, after the component was heated to 50ºC and stabilized for 48 hours, the weight remained constant. When temperature was increased to 100ºC, 24 hours sufficed to keep the weight constant.

3.2 MOISTURE ABSORPTION

Fig. 7 and Fig. 8 show the weights of the seven samples of each material for each case.

Table 2 shows the variation in the weight percentage with respect to case 1.

It can be seen that PA6 absorbed a higher percentage of moisture than PA66. PA6 absorbed approximately 1.1% and PA66 absorbed approximately 0.83%. Another interesting conclusion is that the moisture content of PA6 varied more easily than that of PA66 when the humidity and temperature conditions varied. In the same temperature and humidity range, the humidity variations are 50% higher for PA6 components than for PA66 components.

PA6			
Case study 1	Case study 2	Case study 3	Case study 4
100.00%	100.99%	100.11%	99.45%
100.00%	101.10%	100.22%	99.56%
100.00%	101.22%	100.22%	99.56%
100.00%	101.22%	100.22%	99.56%
100.00%	101.10%	100.22%	99.56%
100.00%	101.10%	100.22%	99.56%
100.00%	101.10%	100.11%	99.45%
PA66			
Case study 1	Case study 2	Case study 3	Case study 4
100.00%	101.13%	100.72%	100.24%
100.00%	100.95%	100.48%	100.00%
100.00%	101.07%	100.60%	100.12%
100.00%	100.71%	100.24%	99.76%
100.00%	100.83%	100.36%	99.88%
100.00%	100.83%	100.24%	99.76%
100.00%	100.83%	100.24%	99.76%

Table 2: weight percentage variation for PA6 and PA66 components

3.3 ANALYSIS OF THE DIMENSIONS

Figs. 9, 10, and 11 show the values of reference dimensions D1, D2, and D3 in comparison with the allowable values. The allowable values of these dimensions are also shown in order to analyse if dimension variations due to moisture absorption are relevant for the proper performance of the component. Measurements were performed on seven samples that were stabilized under lab conditions, when saturated with moisture, and after being placed in the oven at 50ºC and 100ºC.

Dimension D1 remained within the tolerance for the two materials tested under lab conditions, when saturated with moisture and at a temperature of 50ºC. The values of D1 for the two materials were very similar; see Fig. 9.

The effect of the dilatation of the components heated to 50ºC and measured without allowing temperature stabilization did not predominate over the decrease in dimensions due to the loss of moisture.

The effect of high temperatures on components made from PA6 was significant. When these components were heated to 100ºC, dimension D1 decreased by more than 1 mm, putting it outside of the tolerated range, which would imply a poor performance of the components.

The behaviour of D2 was similar to that of D1, as shown in Fig. 10, but the following refinements can be made:

- The effect of the humidity was greater for PA6 than for PA66.
- The effect of heating a component to 50ºC was greater for both PA6 and PA66.

Fig. 11 shows that the behaviour of dimension D3 was similar to that of D2. PA66 was more stable, even though the values obtained under lab conditions and 100% humidity are outside the tolerated range.

Fig. 12 shows that the component's flatness remained under 2 mm under lab conditions, when saturated with moisture and at a temperature of 50ºC. The variations in this dimension were very similar for the two materials. The flatness value was greater than 2 mm when components made from both materials were subjected to high temperatures. These values were much more dispersed for PA6 components subjected to high temperatures than for PA66 components in the same situation. The results for the different PA6 samples were more uniform than those for the PA66 samples.

The number of PA6 samples exhibiting a significant worsening of the flatness value was very high. For PA66, this worsening only occurred for one sample. It is advisable to test a larger number of samples to analyse this behaviour.

3 CONCLUSIONS

This paper presents a method of analysis for experimentally evaluating the influence of the hydrothermal environments on the dimensions of components injected with PA6 and PA66 used in the supporting mechanical structure of plates in induction cookers, together with the results of that analysis. After the moisture-absorbing behaviour of both materials were characterized, different study cases were developed to the environmental conditions to which these components will be subjected during their working lives. These cases simulate expected and extreme manufacturing, storage and working conditions. The analysis is applicable to structural elements for which the mechanical and dimensional sensitivity to the environmental humidity and processing temperature must be considered in the design stage for both functional and assembly reasons. It is concluded that injected PA6 has a higher capacity to absorb moisture than PA66 (1.2% compared to 0.8%) and a higher capacity to release it. The capacity to absorb moisture from the environment implies a more significant effect on the average error in the dimensions considered (12% for PA6 compared to 3% for PA66), which is more than doubled for four of the seven samples analysed. The general geometric trend observed indicates that PA6 exhibits flatness errors that are four times as great as those established by the tolerances of the design because this effect is more significant for this material. The assembly dimensions remain within the dimensional tolerances under average and extreme humidity conditions and average temperature conditions, with similar variations for all of the samples tested. However, under extreme temperature conditions, the effect is much more significant than for any other situation analysed. In addition, this effect is much more important for PA6 because it results in a decrease of more than 1 mm in the nominal value of the assembly dimension after stabilization. Components injected with P66 are more stable in all of the situations analysed. This paper has direct industrial applications to assembly structural components made from a material affected by humidity and temperature in ways similar to polyamides 6 and 66. Components of this type can be found in any industrial field. The likely users are component designers who should consider the thermal and dimensional stability of the components throughout their working lives.

Acknowledgements

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FIGURE CAPTIONS

Fig. 1 A component assembled on the frame with the electronic device

Fig. 2. Components submerged in distilled water

Fig. 3: The oven used to simulate high temperature conditions

Fig. 4: The coordinate measurement machine used to register measurements

Fig. 5. The base reference system for finding the position (a) at which the component (b) is located to make measurements: The Z axis is normal to the plane defined by the four supports, the X axis is the straight line between the intersections of this plane with the upper support cylinders, and the origin is on the upper left support.

Fig. 6 The preliminary humidity test

Fig. 7. The evolution of the weight of components made from PA6

Fig. 8. The evolution of the weight of components made from PA66

Fig. 9 The average D1 dimension of the PA6 (up) and PA66 (down) components

Fig. 10. The average D2 dimension of the PA6 (up) and PA66 (down) components

Fig. 11. The average D3 dimension of the PA6 (up) and PA66 (down) components

Fig. 12. The flatness of the PA6 (up) and PA66 (down) components

Zaragoza, October 30th 2015

Dear sir,

It is an honor for me to present the paper titled “THE INFLUENCE OF ENVIRONMENTAL CONDITIONS ON THE DIMENSIONAL STABILITY OF COMPONENTS INJECTED WITH PA6 AND PA66” for review and consideration for publication in Polymer Testing.

This presentation has been promoted after buying and reading some original research papers in this Journal or others belonging to Elsevier. The paper presented has been revised by Elsevier Language Editing Services to ensure language quality, and some improvements suggested by the reviewer have been included. A file including authors’ answers to reviewer comments is also attached to the submission.

The main author and affiliation is:
Dr. Ind. Eng. Isabel Claveria*
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The type of the paper is: “Research Paper”. I declare this paper is unpublished work and is not considered elsewhere for publication. Preferred editor is Roger Brown.

The main contribution to the field is the relevant information taken from the analysis conducted, that takes into account mechanical and dimensional sensitivity at design stage due to functional and assembly reasons, both at an environmental relative moisture and at processing temperature of the material used for structural elements.

The novelty of the paper is related to the experimental methodology used for the analysis. The environmental conditions tested reproduce the real working conditions of assembly structural components. On the other hand, tests are not conducted on laboratory samples, but the samples are the components themselves, so the observed behavior is easily extrapolated to real functionality of this kind of components.

The paper has direct industrial applications on any assembly structural component made of a material affected by humidity absorption and temperature such as polyamides 6 and 66. This kind of component can be found in any industrial field. Likely users are component designers that should take into consideration thermal and dimensional stability of the component along its working life.

Yours faithfully,
Dr. Ind. Eng. Isabel Clavería
Mechanical Engineering Department
University of Zaragoza

COMMENTS TO REVIEWER

I attach some additional information about reviewer comment.

1) Page 3, last paragraph.

Another feature affected by absorbed moisture is the physical behaviour, the main manifestation of which is a change in the dimensional stage of a component made from polyamides, as described by Thomanson et al. [2] and Carrascal et al. [5], although the dimensional stage is also influenced by the manufacturing process and its conditions [12].

Authors answer:

In effect, authors mean simply dimensions and derived changes in shape due to this change in dimensions. This paragraph has been rewritten in order to clarify the meaning as follows:

"Other features affected by moisture absorption are dimensions and changes in shape due to this variation of dimensions for components made from polyamides, as described by Thomanson et al. [2] and Carrascal et al. [5], although this feature is also influenced by the manufacturing process and its conditions [12]."

2) Page 12, first text paragraph

Figs. 9, 10, and 11 show the values of reference dimensions D1, D2, and D3 in comparison with the allowable values. The allowable values of these dimensions are also shown. Measurements were performed on seven samples that were stabilized under lab conditions, when saturated with moisture, and after being placed in the oven at 50ºC and 100ºC.

Authors answer:

Including allowable values of analyzed dimensions on figures 9, 10 and 11 is relevant because not only the variation of dimensions is analyzed, but also if performance of the components is affected by the variation or not. From the results can be concluded that dimension variations between upper and lower limit values are not relevant for the component performance, but other dimensions variation out of these limits, such as those shown on figures 9 and 10 for dimensions under oven conditions at 100ºC, and on figure 11 for dimensions under lab conditions or humidity 100% conditions, are relevant because they prevent the component from a proper performance. The paragraph has been rewritten in the paper as follows:

"Figs. 9, 10, and 11 show the values of reference dimensions D1, D2, and D3 in comparison with the allowable values. The allowable values of these dimensions are also shown in order to analyse if dimension variations due to moisture absorption are relevant for the proper performance of the component. Measurements were performed on seven samples that were stabilized under lab conditions, when saturated with moisture, and after being placed in the oven at 50ºC and 100ºC."

Last paragraph on page 12 has been also rewritten as follows:

"The effect of high temperatures on components made from PA6 was significant. When these components were heated to 100ºC, dimension D1 decreased by more than 1 mm, putting it outside of the tolerated range, which would imply a poor performance of the components."


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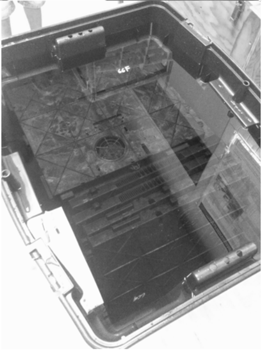

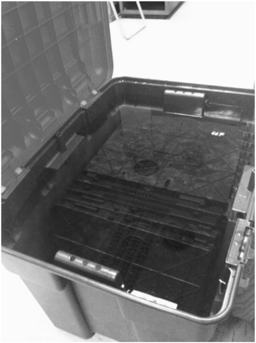

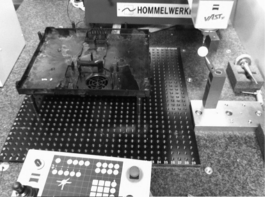
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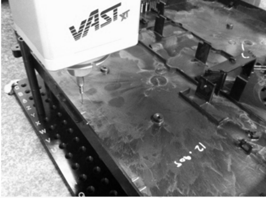
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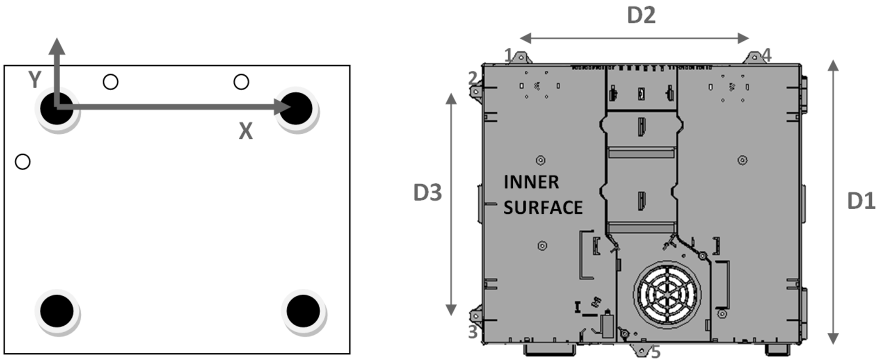

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SURFACE
D1
3
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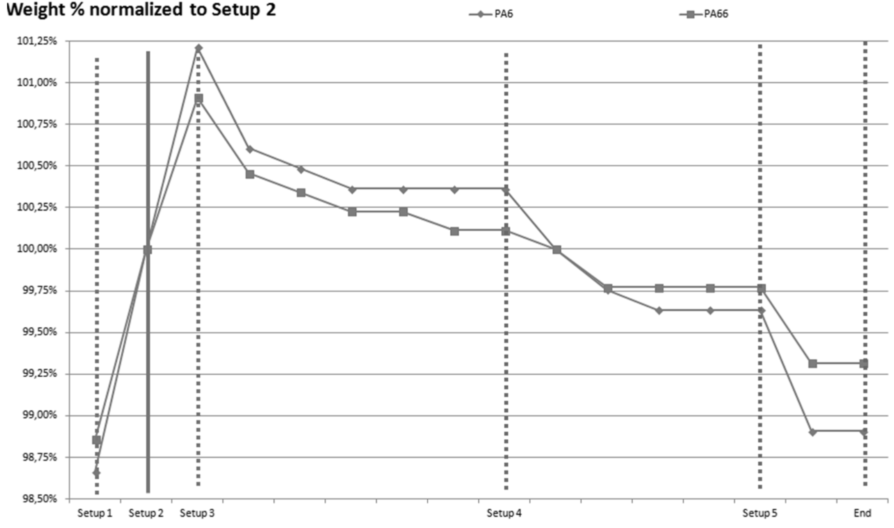
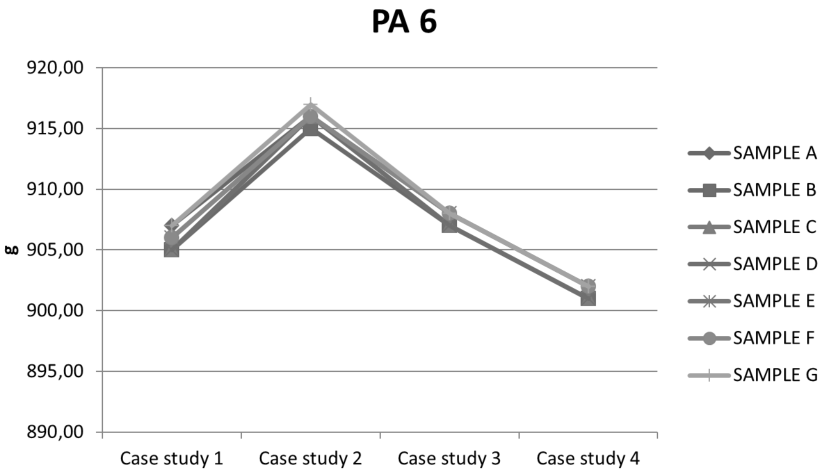
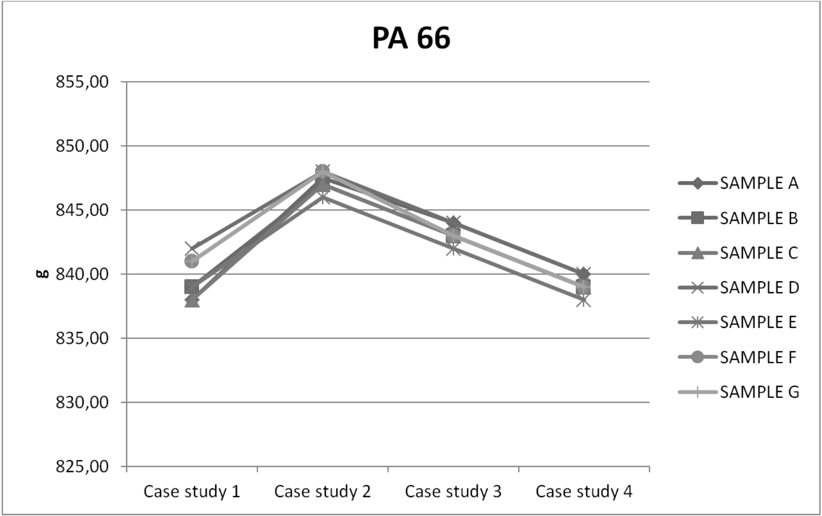
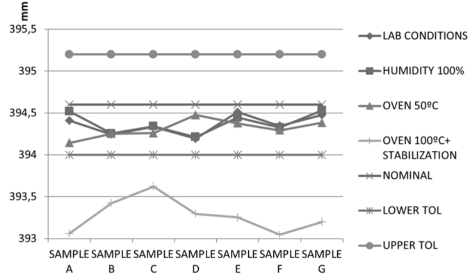
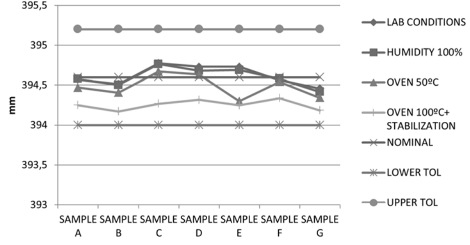


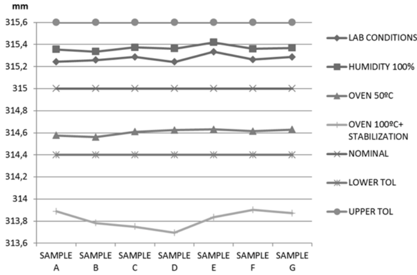
Weight % normalized to Setup 2
PA6
PA66
101,25%
101,00%
100,75%
100,50%
100,25%
100,00%
99,75%
99,50%
99,25%
99,00%
98,75%
98,50%
Setup 1
Setup 2
Setup 3
Setup 4
Setup 5
End

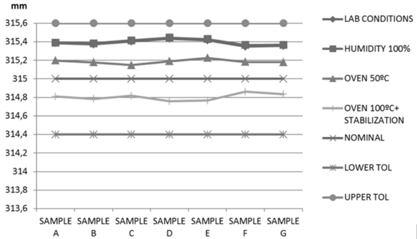

PA 6
920,00
915,00
910,00
905,00
900,00
895,00
890,00
g
Case study 1
Case study 2
Case study 3
Case study 4
SAMPLE A
SAMPLE B
SAMPLE C
SAMPLE D
SAMPLE E
SAMPLE F
SAMPLE G

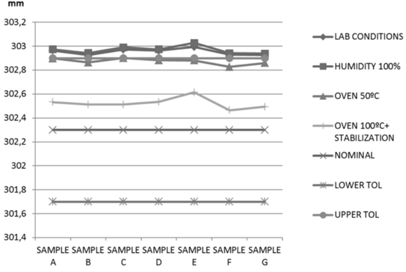

PA 66
855,00
850,00
845,00
840,00
835,00
830,00
825,00
g
Case study 1
Case study 2
Case study 3
Case study 4
SAMPLE A
SAMPLE B
SAMPLE C
SAMPLE D
SAMPLE E
SAMPLE F
SAMPLE G

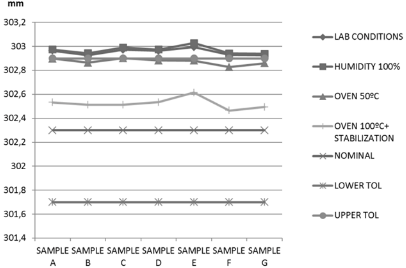

mm
395,5
395
394,5
394
393,5
393
SAMPLE A
SAMPLE B
SAMPLE C
SAMPLE D
SAMPLE E
SAMPLE F
SAMPLE G
LAB CONDITIONS
HUMIDITY 100%
OVEN 50ºC
OVEN 100ºC+ STABILIZATION
NOMINAL
LOWER TOL
UPPER TOL

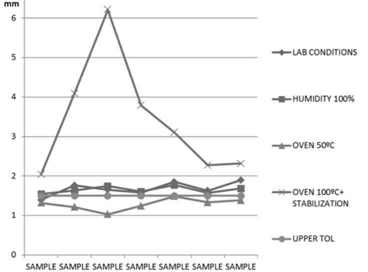

mm
395,5
395
394,5
394
393,5
393
SAMPLE A
SAMPLE B
SAMPLE C
SAMPLE D
SAMPLE E
SAMPLE F
SAMPLE G
LAB CONDITIONS
HUMIDITY 100%
OVEN 50ºC
OVEN 100ºC+ STABILIZATION
NOMINAL
LOWER TOL
UPPER TOL

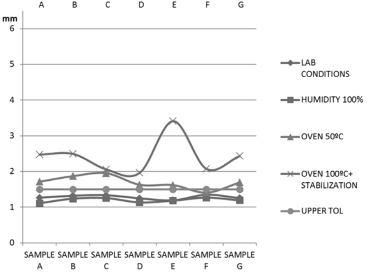

mm
315,6
315,4
315,2
315
314,8
314,6
314,4
314,2
314
313,8
313,6
SAMPLE A
SAMPLE B
SAMPLE C
SAMPLE D
SAMPLE E
SAMPLE F
SAMPLE G
LAB CONDITIONS
HUMIDITY 100%
OVEN 50ºC
OVEN 100ºC+ STABILIZATION
NOMINAL
LOWER TOL
UPPER TOL


mm
315,6
315,4
315,2
315
314,8
314,6
314,4
314,2
314
313,8
313,6
SAMPLE A
SAMPLE B
SAMPLE C
SAMPLE D
SAMPLE E
SAMPLE F
SAMPLE G
LAB CONDITIONS
HUMIDITY 100%
OVEN 50ºC
OVEN 100ºC+ STABILIZATION
NOMINAL
LOWER TOL
UPPER TOL


mm
303,2
303
302,8
302,6
302,4
302,2
302
301,8
301,6
301,4
SAMPLE A
SAMPLE B
SAMPLE C
SAMPLE D
SAMPLE E
SAMPLE F
SAMPLE G
LAB CONDITIONS
HUMIDITY 100%
OVEN 50ºC
OVEN 100ºC+ STABILIZATION
NOMINAL
LOWER TOL
UPPER TOL


mm
303,2
303
302,8
302,6
302,4
302,2
302
301,8
301,6
301,4
SAMPLE A
SAMPLE B
SAMPLE C
SAMPLE D
SAMPLE E
SAMPLE F
SAMPLE G
LAB CONDITIONS
HUMIDITY 100%
OVEN 50ºC
OVEN 100ºC+ STABILIZATION
NOMINAL
LOWER TOL
UPPER TOL


mm
6
5
4
3
2
1
0
SAMPLE A
SAMPLE B
SAMPLE C
SAMPLE D
SAMPLE E
SAMPLE F
SAMPLE G
LAB CONDITIONS
HUMIDITY 100%
OVEN 50ºC
OVEN 100ºC+ STABILIZATION
UPPER TOL


mm
6
5
4
3
2
1
0
SAMPLE A
SAMPLE B
SAMPLE C
SAMPLE D
SAMPLE E
SAMPLE F
SAMPLE G
LAB CONDITIONS
HUMIDITY 100%
OVEN 50ºC
OVEN 100ºC+ STABILIZATION
UPPER TOL

PA6			
Case study 1	Case study 2	Case study 3	Case study 4
100.00%	100.99%	100.11%	99.45%
100.00%	101.10%	100.22%	99.56%
100.00%	101.22%	100.22%	99.56%
100.00%	101.22%	100.22%	99.56%
100.00%	101.10%	100.22%	99.56%
100.00%	101.10%	100.22%	99.56%
100.00%	101.10%	100.11%	99.45%
PA66			
Case study 1	Case study 2	Case study 3	Case study 4
100.00%	101.13%	100.72%	100.24%
100.00%	100.95%	100.48%	100.00%
100.00%	101.07%	100.60%	100.12%
100.00%	100.71%	100.24%	99.76%
100.00%	100.83%	100.36%	99.88%
100.00%	100.83%	100.24%	99.76%
100.00%	100.83%	100.24%	99.76%

Table 2: weight percentage variation for PA6 and PA66 components

	PA 6.6	PA 6.6
DENSITY (g/cm^3)	1.49	1.54
Tensile strength at break (MPa) (5 mm/min)	75	65
Young's modulus (MPa) (1 mm/min)	8500	6200
VICAT ºC 49 N (50°C/h)	245	204
HDT ºC0.45 MN/m² ISO 75 242 °C	242	178
1.81 MN/m²	162	77

Table 1: General properties of PA66 and PA6

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To whom it may concern

The paper "INFLUENCE OF THE ENVIRONMENTAL CONDITIONS ON THE DIMENSIONAL STABILITY OF A COMPONENT INJECTED WITH PA6 AND PA66" by ANGEL FERNANDEZ was edited by Elsevier Language Editing Services.

Kind regards,

Biji Mathilakath
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