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Material behaviour

The influence of environmental conditions on the dimensional stability of components injected with PA6 and PA66

Isabel Clavería [a,*], Daniel Elduque [a], Jorge Santolaria [b], Carmelo Pina [a], Carlos Javierre [a], Angel Fernandez [a]

[a] Mechanical Department, University of Zaragoza EINA, Maria de Luna 3, 50018 Zaragoza, Spain
[b] Department of Design and Manufacturing Engineering, University of Zaragoza EINA, Maria de Luna 3, 50018 Zaragoza, Spain

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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.

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, 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

* Corresponding author.
E-mail addresses: isabel.claveria@unizar.es (I. Clavería), danielduque88@gmail.com (D. Elduque), jsmazo@unizar.es (J. Santolaria), carmelo.pina@BSHG.com (C. Pina), carlos.javierre@unizar.es (C. Javierre), afernan@unizar.es (A. Fernandez).

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

2.2. Component

The component selected for the study was 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 was also studied. The main geometrical features of the component are its rectangular box shape, similar to a tray, its general dimensions of 460 mm × 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 because of the position of an electronic device on it (see Fig. 1).

Table 1
General properties of PA66 and PA6.

	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 °C 49 N (50 °C/h)	245	204
HDT °C0.45 MN/m^2	242	178
ISO 75 242 °C 1.81 MN/m^2	162	77

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 100 °C for three hours, the melt temperature was 270 °C for PA6 and 280 °C for PA66, the mould temperature was 90 °C 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 50 °C 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 100 °C, 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 laboratory conditions at 20 ± 0.5 °C for 24 h 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 h at 20 ± 0.5 °C (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.