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ANALYSIS OF THE INFLUENCE OF TEMPERATURE ON THE DIMENSIONAL STABILITY OF A PART MADE THROUGH 3D PRINTING

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Abstract. The objective of this work was to analyze the influence of temperature on the dimensional stability of parts made by of 3D printing. They were subjected to temperatures of 100ºC and -20ºC respectively. To start the case study, 2 samples were designed and printed with various printing parameters. After printing, the samples were subjected to 10 thermal cycles each, in order to accelerate the aging process of the material. At the end of each complete cycle, measurements and analyzes were carried out.

Keywords: Additive manufacturing, 3D Printing technology, thermal aging.

INTRODUCTION

Three-dimensional printing introduces a novel manufacturing technique that enables the creation of solid objects by progressively adding material. To accomplish this, a 3D model of the desired component is required, which can be generated through scanning or dedicated software applications like Catia, Autocad, Inventor, etc., and saved with the STL* extension.

By employing the additive manufacturing approach, it becomes possible to fabricate intricate and diverse products with distinct designs. In today's landscape, a wide array of technologies and materials are utilized, and the equipment necessary for both industrial-scale production and personal utilization is readily accessible.

The FDM process, also known as Fused Deposition Modeling or modeling by thermoplastic extrusion, operates by depositing overlapping layers of melted plastic material. A plastic wire, such as PLA or ABS, is fed through a heated nozzle in a work head, causing it to melt and be deposited onto the previous layer, followed by rapid solidification. The work head moves systematically in the XY plane to construct the current layer, while the model support platform descends and advances to form the subsequent layer.

This technology is alternatively referred to as FFF, which stands for Fused Filament Fabrication. FDM is widely employed as an additive manufacturing method for producing prototypes and functional parts. Its popularity stems from its affordability and simplicity, leading to its adoption by industries, consumers, and academic institutions. FDM is also utilized in research and development endeavors to enhance the process and explore new materials.

The procedure is based on a CAD file in STL format. The file is picked up by the 3D printer software, and the 3D model is sectioned into layers, which are then built one by one, superimposed by the machine (Nunez, Rivas 2015).

The material in the form of filament is pushed by two rollers towards the thermal head, which melts it and deposits it on the printing platform respecting the shapes and sizes defined by the CAM system (figure 1). The object is built from the bottom up, and the movements of the print head are driven by a stepper motor or servo motor (Mwema 2020).

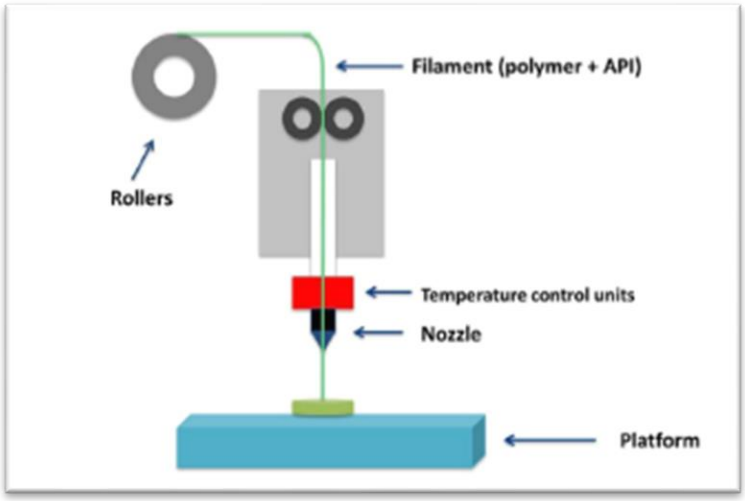

Figure 1. How FDM works

In the past few years, significant attention has been dedicated to studying the fatigue and aging characteristics of plastics due to their growing utilization in various industries such as automotive, aerospace, and manufacturing (Afrose 2016, Senatov 2016). Consequently, researchers have conducted investigations to analyze the fatigue behavior of 3D printed components and identify the printing parameters or materials that exhibit the most favorable fatigue properties (Shanmugam 2021, Safai 2019, Miller 2017, Rizea 2021). These studies aim to enhance our understanding of the fatigue performance of 3D printed parts and optimize their design and production processes.

2D MODEL OF THE SPECIMEN

To achieve the established objective, the sketch of a glass-type specimen was designed, which was later 3D printed, with certain dimensions (figure 2). Two samples with the same dimensions were printed in order to be subjected to temperature variations (-20°C – 100°C).

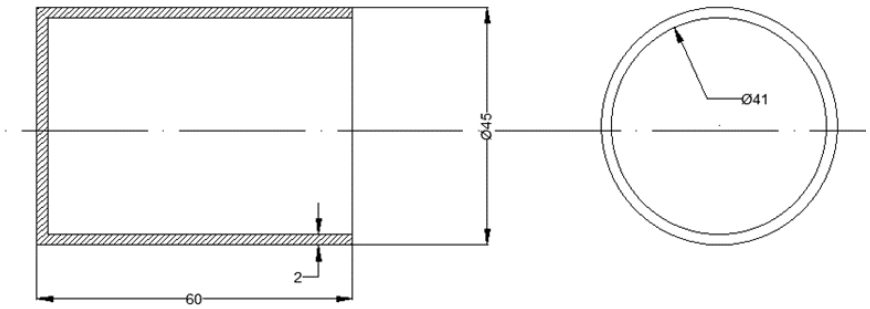

Figure 2 The dimensions of the specimen

The specimen has a height of 60 mm, inner diameter of Ø 41mm, outer diameter of Ø 45 mm, wall thickness of 2 mm, which makes it ideal for this study, not requiring a large amount of material for its printing.

The specimen is economical from the point of view of material consumption, but also of the time consumption required for printing.

INPUT PARAMETERS

Input parameters for specimen 1:
• Material: Z-ULTRAT blue;
• Type of filling (figure 3).
• Layer thickness: 0.14 mm;
• Filling density 10%.

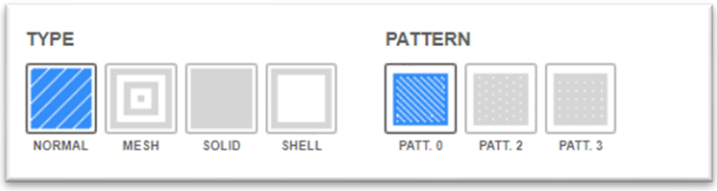

Figure 3. The type of filling used

Input parameters for sample 2:
• Material: Z-ULTRAT;
• The type of filling identical to that of the first sample;
• Layer thickness: 0.29 mm;
• Filling density: 90%.

The Z-ULTRAT material is found in the form of filament and is designed to have durability and good quality of the surfaces obtained. It is used for functional prototypes, parts, other objects.
Z-ULTRAT material is more durable than standard ABS, resisting high temperatures and shocks.

THE PROCESS OF PRINTING THE SPECIMENS

Printing the specimens consists of successively adding layers of material on the printing plate, with the help of the print head, until the swatch is complete, a process that is repeated 2 times, since two specimens were printed.

The Zortax M200 3D printer was used for printing. The actual printing process begins by inserting the SD card into the printer slot and selecting the desired file, zcode.

After loading the models into the printer's memory, the machine will automatically heat its printing platform, so that the samples are not deformed. This process takes a few minutes and the percentage the platform is heated is displayed on the LCD screen.

Once the machine has warmed up, the printing process begins, from bottom to top. The print head first builds a base, which connects the print platform to the sample. This is to help obtain a conformal surface of the sample and to facilitate the removal of the part from the printing platform.

After building the base, the print head starts printing the sample. In the process of printing the two samples, it was decided to print without support elements.

The printing time differs for the two samples depending on the data set initially.

Thus, for the first sample (figure 3) the printing time is 3 hours and 24 minutes and for the second sample (figure 4) the printing time is 1 hour and 51 minutes.

Figure 3. Specimen 1

Figure 4. Specimen 2

After the printing process is completed, the part can be removed immediately because the cooling was done gradually as it was built. A tool similar to a spatula, but with a sharper end edge, is used to remove the part from the platform.

To detach the sample from the platform, firm movements are performed, which do not damage the part. After detaching from the platform, the base is removed.

PREPARATION OF THE SPECIMENS

To carry out the experiment, the specimes will be subjected to temperatures of -20°C and 100°C, respectively, in order to analyze the influence of the thermal parameters on the dimensional stability of the specimens.

To make the determinations, it was necessary to process the samples, because they had a rough surface and a dimensional instability after printing and the measurements could not be made accurately.

The samples were processed on the outer cylindrical surface with the help of a lathe.

After processing, the pieces were measured according to the measurement scheme shown in figure 5.

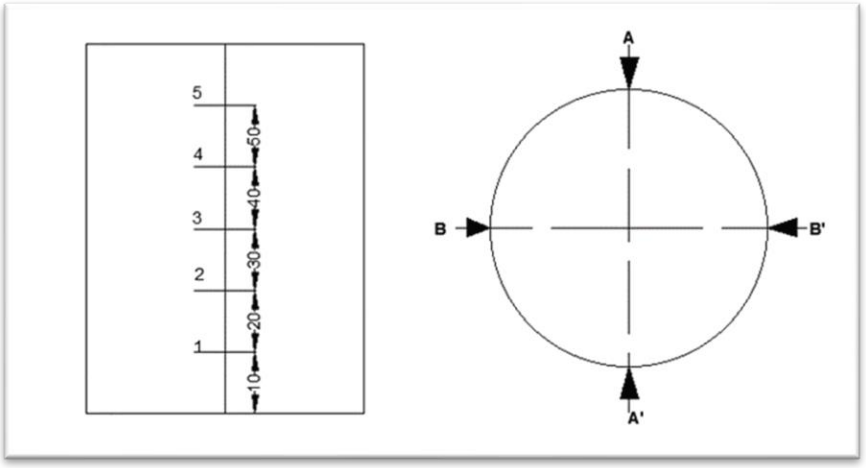

Figure 5. Measurement scheme

The determinations were made at a controlled temperature of 22°C with of a caliper with a measuring range between 0-150 mm. Before performing the measurements, the caliper was calibrated using the standard calipers.

The initial dimensions of the samples were influenced by the turning operation performed to remove the surplus of rough material from the outer surface of the samples where the determinations were made (table 2).

Table 2. Initial dimensions of the specimens

Specimen 1			Specimen 2		
Point	Surface A-A’	Surface B-B’	Point	Surface A-A’	Surface B-B’
1	44,35	44,37	1	44,32	44,30
2	44,32	44,31	2	44,30	44,27
3	44,32	44,31	3	44,32	44,12
4	44,30	44,44	4	44,00	44,15
5	44,23	44,33	5	44,20	44,09

The measurements were carried out according to the measurement scheme, on the outer surface of the specimens at 5 points located at a distance of 10 mm from each other. The measured diameters were noted so that they could be identified with A-A' and B-B' respectively (figure 7, figure 8).

Figure 7. Surface A-A’

Figure 8. Surface B-B’

After the specimens have been prepared for the experiment, they will be placed in the Binder ED53 Oven (figure 9) at a temperature of 100°C for approximately 5 hours. Before being introduced, they were kept at a controlled temperature of 22°C.

The oven is a thermostatic enclosure whose role is to maintain the constant temperature of the laboratory samples.

Figure 9. Inserting the specimens into the oven

After finishing the first cycle at the temperature of 100°C, they are extracted from the oven and allowed to reach the temperature of 22°C, in order to perform the measurements. The temperature and humidity in the laboratory was determined using a thermohygrometer.

RESULTS

The samples were subjected to thermal cycles. Thus, they were cooled to a temperature of -20°C, maintained to equalize the temperature in the mass of the specimen, removed from the enclosure and measured at ambient temperature, then heated to a temperature of 100°C, after which they were removed from the enclosure and measured at ambient temperature, thus carrying out a thermal treatment cycle, according to figure 10.

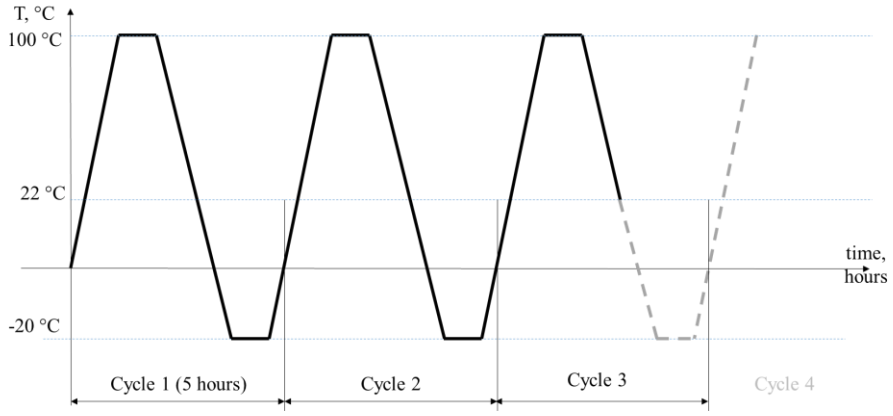

Figure 10. Treatment cycle

In table 1, the measurements recorded for first thermal cycle of the specimen 1 are presented, for all of the 5 points of measurement.

Table 3. Thermal cycle 1 for specimen 1

Diameter values after heating to 100°C and cooling to ambient temperature [mm]			Diameter values after cooling to -20°C and warming to ambient temperature [mm]		
Points	Diameter A-A'	Diameter B-B'	Points	Diameter A-A'	Diameter B-B'
1	43,89	43,89	1	43,88	43,88
2	43,63	43,73	2	43,73	43,77
3	43,64	43,76	3	43,57	43,74
4	43,70	43,61	4	43,53	43,83
5	43,51	43,55	5	43,62	43,70

Also, in table 2, the measurements recorded for first thermal cycle of the specimen 2 are presented, for all of the 5 points of measurement.

Table 4. Thermal cycle 1 for specimen 2

Diameter values after heating to 100°C and cooling to ambient temperature [mm]			Diameter values after cooling to -20°C and warming to ambient temperature [mm]		
Points	Diameter A-A'	Diameter B-B'	Points	Diameter A-A'	Diameter B-B'
1	43,75	43,95	1	43,75	43,75
2	43,75	43,56	2	43,71	43,69
3	43,69	43,46	3	43,80	43,75
4	43,50	43,24	4	43,62	43,52
5	43,43	43,16	5	43,50	43,38

After that, the specimens were subjected to another 9 thermal cycles, measuring the diameter in all 5 points on the direction A-A', table 5, finding a change in the diameters, see figure 11.

Table 5. Specimen 1, surface A-A'

Number of cycles	Diameter values [mm]				
	Point 1	Point 2	Point 3	Point 4	Point 5
1	-0,0106	-0,01331	-0,01692	-0,01738	-0,01379
2	-0,01285	-0,01692	-0,0185	-0,01761	-0,01922
3	-0,01759	-0,01963	-0,02256	-0,0228	-0,02329
4	-0,01533	-0,0185	-0,02031	-0,01941	-0,02125
5	-0,01939	-0,02076	-0,02076	-0,02641	-0,02216
6	-0,01736	-0,02189	-0,02572	-0,0246	-0,02284
7	-0,0212	-0,02392	-0,02301	-0,02438	-0,0251
8	-0,02074	-0,02459	-0,02685	-0,02641	-0,02939
9	-0,01105	-0,02617	-0,02753	-0,02664	-0,03188
10	-0,02345	-0,02708	-0,02775	-0,02889	-0,03233

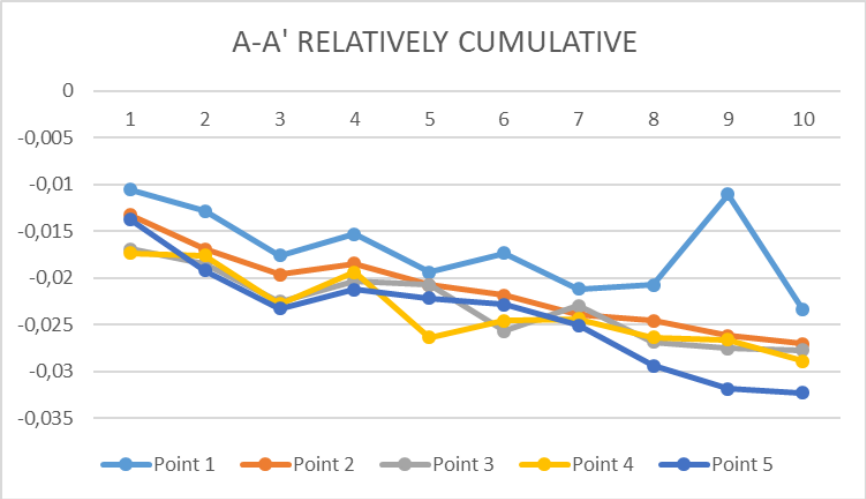

Figure 11. A-A' relatively cumulative

After that, the specimens were subjected to another 9 thermal cycles, measuring the diameter in all 5 points on the direction B-B', table 6, finding a change in the diameters, see figure 12.

Table 6. Specimen 1, surface B-B'

Number of cycles	Diameter values [mm]				
	Point 1	Point 2	Point 3	Point 4	Point 5
1	-0,01104	-0,01352	-0,01286	-0,01373	-0,01421
2	-0,01397	-0,01983	-0,01986	-0,01935	-0,02166
3	-0,01442	-0,01961	-0,02167	-0,0252	-0,02527
4	-0,01533	-0,02366	-0,02302	-0,02588	-0,02594
5	-0,01871	-0,02344	-0,02573	-0,0333	-0,03113
6	-0,01578	-0,02817	-0,02708	-0,03083	-0,02978
7	-0,01826	-0,0284	-0,02889	-0,0333	-0,03271
8	-0,01826	-0,0284	-0,02821	-0,03555	-0,03587
9	-0,02051	-0,02862	-0,03047	-0,036	-0,03271
10	-0,02141	-0,03043	-0,03092	-0,0369	-0,03361

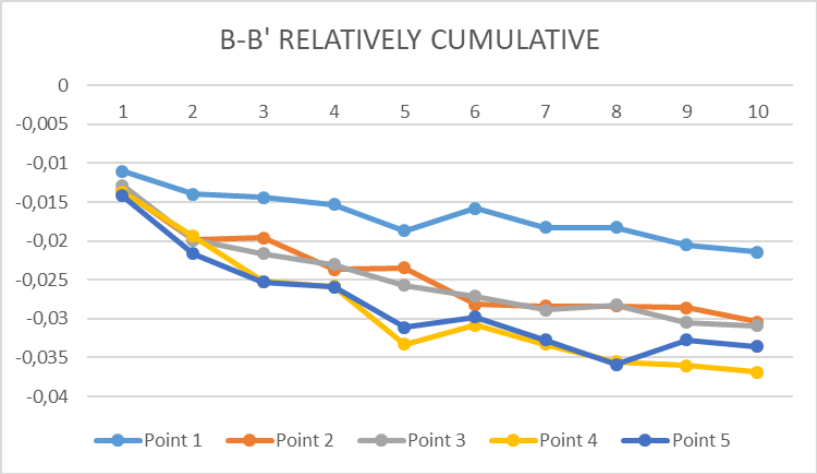

Figure 12. B-B' relatively cumulative

At the end of the 10 thermal cycles, after the specimens were subjected to temperatures of -20oC and 100oC respectively, a slight change in the outer diameter of the specimens that were subjected to the experiment is observed. The measurements were made according to the measurement scheme after each cycle.

CONCLUSION

Following the research study carried out on the two specimens that were subjected to thermal variations in order to accelerate the aging process of the material, it was demonstrated that after 10 thermal cycles (-20°C respectively 100°C) the dimensions changed significantly.

The material used is Z-ULTRAT. It is a thermoplastic material, which has in its composition ABS in percentage of 90-100% and PC in percentage of 0-3%.

After the first thermal cycle, both specimens changed their diameter in all 5 points established at a distance of 10 mm along the entire height. Before being placed in the oven at 100°C, they were measured at an ambient temperature of 22°C. After the 5 hours, there was a change in the diameter of the first sample by approximately 0.75 mm on the surface AA' and 0.63 mm on the surface BB'. The values are presented in table 5, table 6.

DISCUSSION

The processing and interpretation of the resulting experimental data were done starting from the initial measurements, comparing them with those resulting from the 10 thermal cycles.

In order to simplify the interpretation of the obtained data, some adjustments were made. All the data from the previous subchapter were entered in an excel file. For the graphic representation, figure 13, the data were grouped according to the surface and the points where the measurements were made.

For each individual point, the relative value was calculated with the following relationship:

$$\frac{d_o - d_i}{d_o} \quad (1)$$

where:

d_o, represents the diameter obtained at the measured point;

d_i, represents the initial diameter of the specimen at the measured point.

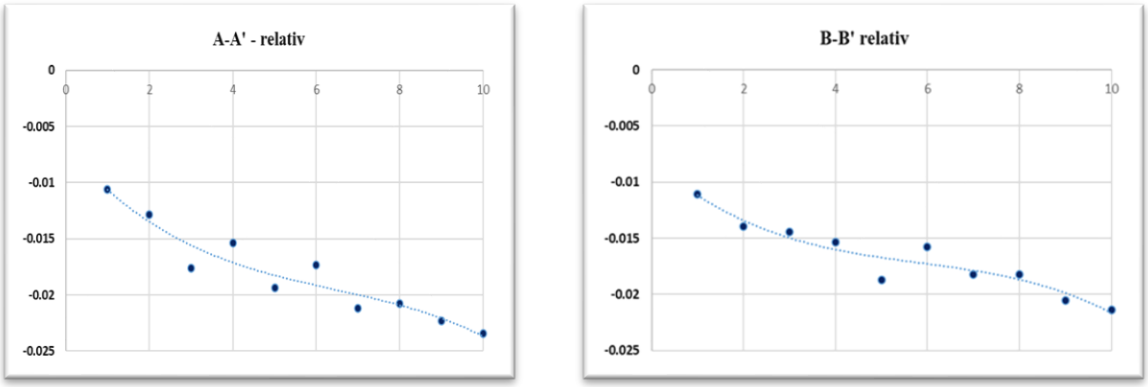

Figure 13. Graphic interpretations for specimen 1

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