ANNEALING INFLUENCE ON 3D PRINTED PARTS WITH AMORFOUS STRUCTURES

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Abstract: *Continuous research in the field of 3D printing, and the study of the resulted parts from the FFF (Fused Filament Deposition) manufacture, demonstrated the possibility and usefulness of applying post-processing by heat treatment on parts from different materials. In most cases, it has been shown that both parts with semi-crystalline structure (PLA) and those with amorphous structure (ABS, ASA) can be subjected to heat treatment, ensuring enhanced mechanical properties. This article presents the influence of the heat treatment applied to ASA (acrylonitrile styrene acrylate) parts, especially in the layer change zone. The parts were in the form of standardized specimens (ISO 527-2 type 1B), which were subjected to tensile tests. The results showed that, under the right annealing temperature for minimum dimensional changes, the tensile strength of the parts was increased, even in the layer change zone.*

Keywords: *additive manufacturing, fused filament fabrication, ASA, annealing*

1. Introduction

Among the well-known manufacturing technologies, both conventional such as cutting [1, 2] or cold forming [3] and unconventional processing such as incremental forming [4-6], there is the additive manufacturing process [7,8]. It is well known that additive manufacturing (AM) is increasingly used in engineering, and it falls into several categories, which can use even metallic or ceramic materials as the main working material, but which can lead to considerable costs [9]. However, a variant of additive manufacturing, with lower costs, is represented by the 3D printing process FFF (Fused Filament Fabrication) also called FDM (Fused Deposition Modeling), in which, the continuous researches on this type of manufacture make it possible to fabricate more and more mechanical enhanced parts, as close as possible to the parts obtained by other processes.

In this regard, the literature has highlighted the possibility of applying different types of post-processing by different chemical treatments (to improve surface quality) [10, 11] or heat treatments (to improve physical and mechanical properties) [9, 12, 13].

Studies to date have shown that heat treatment can be applied both to semi-crystalline materials such as PLA (polylactic acid) [14], where the results are satisfactory, and to amorphous materials such as ABS (styrene butadiene acrylonitrile) [15], where the treatment is limited by the tendency of the material to shrink, warp and to radically change its overall dimensions. Among the most used materials with amorphous structure are ABS, a material more resistant to PLA but more difficult to process due to the warping tendency of the material when printed in an open environment, PETG (Polyethylene terephthalate glycol), and ASA (Acrylonitrile styrene acrylate). As an alternative to ABS material; due to the difficulty to process, a new material called ASA has been developed, which is the improved version of ABS material, in terms of thermal resistance and UV stability [9].

A number of authors have referred to the study of the application of heat treatment to ASA or ABS parts [9, 15, 16], and the results of the researches has highlighted the fact that, although it is possible to apply heat treatment to increase the overall mechanical proprieties, overcoming much of the glass transition temperature leads to considerable changes in the final size of the parts, due to micro-stresses in the printed material [9], which leads to an additional step in the design process to compensate the size of the part.

This paper aims to study the influence of heat treatment on ASA material especially in the layer change zone (seam position), taking into account the results and conclusions found in the literature. In this regard, the temperature and duration of the heat treatment were established, being subjected to treatment for short periods of time at temperatures below 105 °C, after which, the tensile strength, specific elongation and dimensional changes of the parts were tested.

2. Experimental setup

To study the influence of heat treatment on the overall mechanical proprieties of the printed parts, the experimental plan in figure 1 was followed.

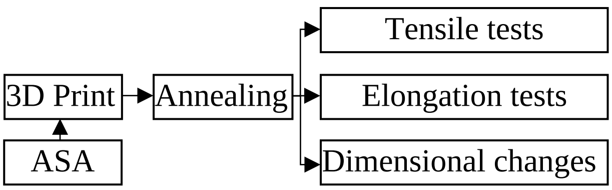


Figure 1: *Experimental plan*

The test specimens material was ASA (styrene acrylate acrylonitrile), and they were printed using a Creality CR6-SE budget 3D printer (figure 2). Given the properties of the material and its warping tendencies to temperature variations, the parts were printed in a home-made enclosure, in which the temperature had minimal fluctuations and was kept at about 40 °C, with the humidity in the enclosure being below 25%.

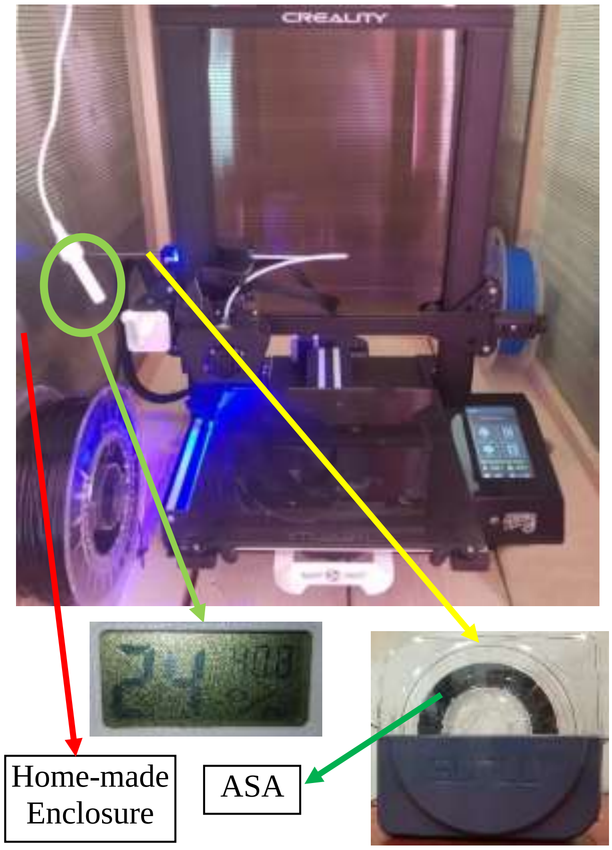
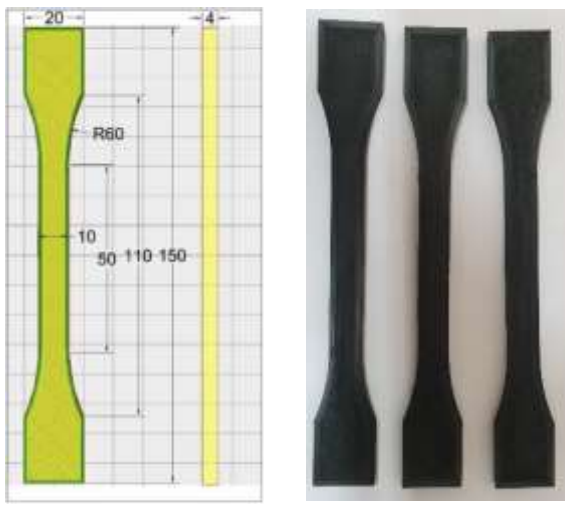


Figure 2: *3D printing setup*

To ensure superior quality of the resulting parts, the filament role was subjected to drying for 5 hours at 50 °C in a SUNLU dryer.

The specimens were fabricated with the dimensions according to ISO 527-2 type 1B (figure 3), and the printing parameters such as layer height and printing speed are presented in table 1.



a. dimensions b. physical parts

Figure 3: *Test specimen ISO 527-2 type 1B*

Table 1: Print settings

Parameter	Values	Parameter	Values
Layer height	0.2 [mm]	Print speed	50 [mm/s]
Nozzle	0.4 [mm]	Wall speed	25 [mm/s]
Infill	100%	Travel speed	150 [mm/s]
Infill type	Line	Retraction distance	6.5 [mm]
Wall thickness	1.6 [mm]	Cooling	OFF
Printing temperature	235 [°C]	Print jerk	8 [mm/s]
Build plate temperature	80 [°C]	Print acceleration	500 [mm/s^2]

The subject of this study is the influence of heat treatment on ABS parts, especially in the layer change area. In this sense, when the G code was generated in the Ultimaker Cura 4.11 slicer, the layer change position of the nozzle was chosen so that layer change is in the test area but not in its middle (figure 4), with the purpose to produce necking and fracturing of the part in a non-conventionally way.

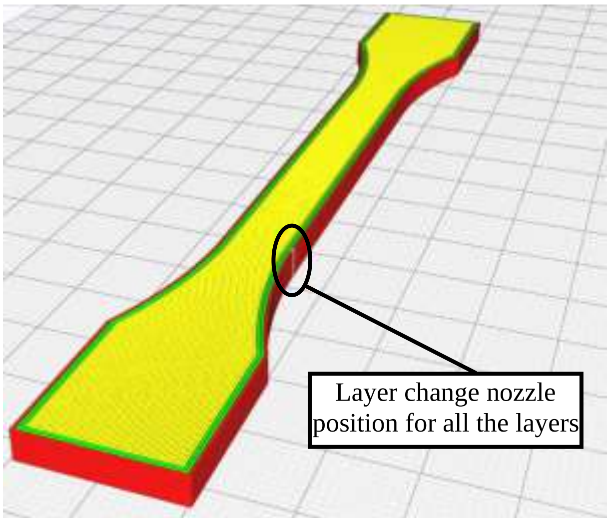


Figure 4: *Layer change positioning*

Given the information found in the literature, the heat treatment was performed according to table 2, using a laboratory oven Carbolite type ELF 11/14 (figure 5).

Table 2: Annealing time and temperature

Nr.	Temperature [°C]	Time [min]			
1	90	5	10	15	60
2	100	5	10	15	60
3	150	5	60		
4	180	5	60		

a. Carbolite oven b. test specimens

Figure 5: *Laboratory oven*

After the heat treatment, the parts were measured with a high-precision caliper, then tested for traction and elongation using laboratory equipment (figure 6).

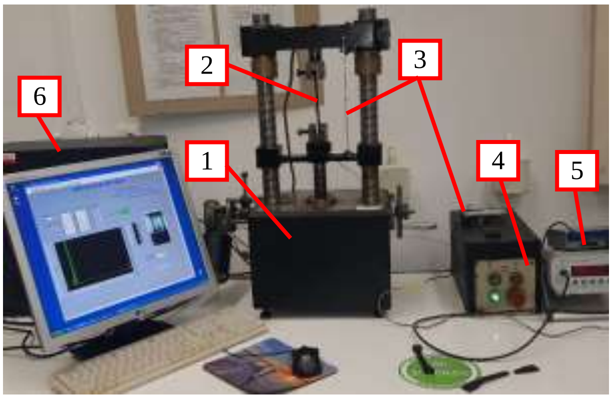


Figure 6: *Testing setup*
1. Tensile testing device; 2. Test specimen; 3. Elongation device; 4. Controller; 5. Amplyfier; 6. PC – data analysis

The tensile and elongation tests setup was as follows: the test specimen 2 was mounted in the tensile testing device 1 capable of recording the specific elongation using the sensor 3. The device 1 is operated using the controller 4, and with the help of the amplifier 5, the signals are recorded on PC 6, on which the analysis of the obtained data was done.

3. Results and discussions

The results obtained after the application of heat treatment confirmed the information found in the literature [8]. Applying heat treatment above 100 °C, the pieces showed very large dimensional fluctuations, in all directions, especially in the overall length of the part, up to

13% at 150 °C and 18.5% at 180° C (figure 7). At the same time, the duration of the treatment significantly influenced the final size of the parts.

Figure 7: *Dimensional variation of annealed ABS test specimens*

Given these aspects, the tensile strength and elongation were measured for the parts that had insignificant variations, the annealing being done in the range of 90-100 °C, for the treatment periods in the range of 5-15 min. The results obtained are in the form of those shown in figure 8, where the values are recorded as pulses / electrical signals.

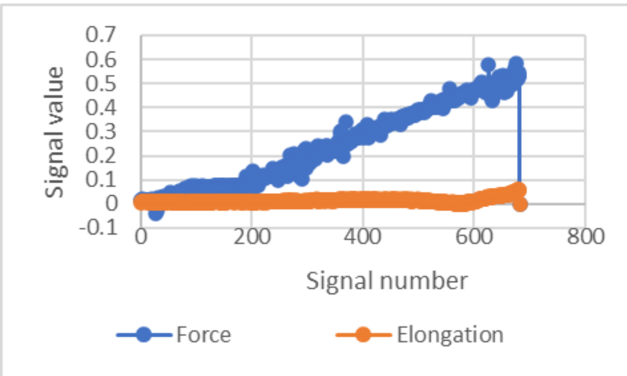


Figure 8: *Obtained results*

Following the analysis of the data resulting for each test, the values in table 3 were obtained, represented by the variation graphs in figures 9 and 10.

Table 3: Obtained results

Nr.	Temperature [°C]	Time [min]	Force [N]	Elongation
1	0	0	350.00	0.059
2	90	5	349.95	0.235
3	90	10	362.54	0.284
4	90	15	378.12	0.911
5	100	5	343.68	0.118
6	100	10	374.99	0.235
7	100	15	415.63	0.824

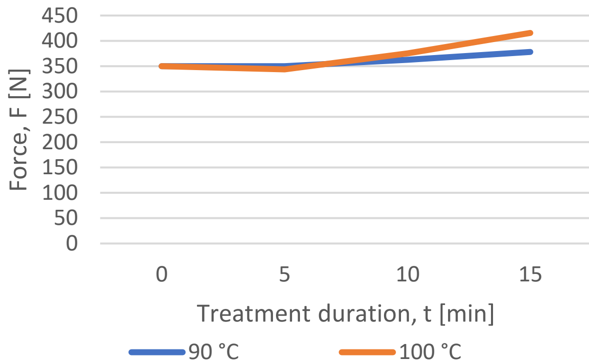


Figure 9: *Tensile force variation*

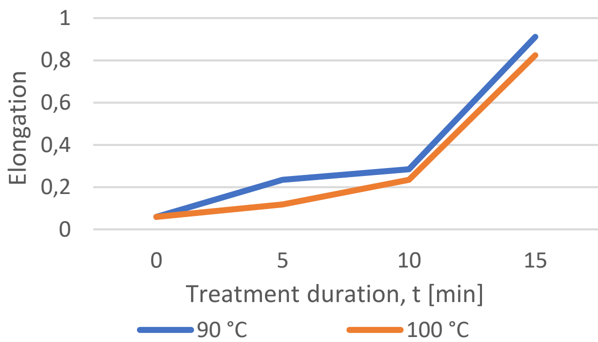


Figure 10: *Elongation variation*

As can be seen, a 5-minute treatment does not have a major impact on tensile strength, but shows an increase in elongation. Within 5-15 minutes, the tensile strength has a relatively linear variation, with 8% for treatments at 90 °C, and 21% for treatments at 100 °C. The elongation shows a relatively small increase in the range of 5-10 minutes of 20.6% for treatment at 90 °C and 99.1% for treatment at 100 °C, followed by a sudden increase in the range of 10-15 minutes of approximately 220%. for 90 °C and 250% for 100 °C.

All the results presented so far are universally valid for both the complete part and the layer change area. In all parts subjected to tensile testing, the fracture started from the outer wall in the layer change area (figure 11 a and b).

a. Fracture location for all test specimens

b. Fracture start point

Figure 11: *Fracture location*

Given this aspect, it can be considered that the heat treatment of 3D printed parts with amorphous structure influences directly the tensile strength with a fairly high percentage also in the layer change area.

4. Conclusions

The studies confirm some conclusions found in the literature regarding the dimensional changes of the parts, with amorphous structure (ASA, ABS, etc.), by applying heat treatment. However, a number of conclusions can be drawn specific to the subject of this article:

- the annealing duration, even at temperatures below the glass transition temperature, significantly influences the final dimensions of the parts;

- Heat treatment increases the specific elongation, especially as the duration of treatment increases;

- The application of heat treatment significantly increases the tensile strength in the layer change zone, in this case by up to 20%.

Acknowledgments

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