CONSIDERATIONS REGARDING THE CHOICE OF THE MATERIAL AND THE PRINTING PARAMETERS FOR EFFICIENT PROTOTYPES IN THE INDUSTRY OF PLASTICS

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The paper deals with the comparison between two materials (ABS- Acrylonitrile Butadiene Styrene and PLA-Polylactic Acid) printed with different configurations of parameters (infill, and internal structure). This study is focused on the analysis of mechanical and elastic properties of five specimens for the same configuration with all the combinations of parameters. For carrying out this paper the specimens were printed using the fused filament fabrication, and they were tested using the digital image correlation and an extensometer. The results were centralized, and the most important findings were highlighted on the final part of the paper, including the maximum values for mechanical and elastic properties.

Keywords: Fused Filament Fabrication, Poisson's ratio, Digital Image Correlation, Young modulus, Additive Manufacturing

1. Introduction

Nowadays there are a lot of materials used for filament fabrication for 3D printers. These materials are often made from biodegradable sources, and they are cheap and easy to print. These factors led to a decrease in costs for the plastics industry. The paper deals with the determination of Young modulus and Poisson's ratio for different configurations of printing parameters such as infill and internal structure. The specimens were designed using CATIA V5 R21 software with size specifications according to ASTM D638 Standard. The specimens were made using a 3D printer based on Fused Filament Fabrication. For their testing the authors used a INSTRON servo-hydraulic machine and two cameras to analyze the specimen elongation, this technique being called Digital Image Correlation. To calculate the elastic equivalent modulus, it was used WolframAlpha to determine the slope of the obtained stress-strain curve.

2. The specimens preparation

The specimens were made using the dimensions according to ASTM D638 standard as shown in Figure 1. It was used CATIA V5 R21 software.

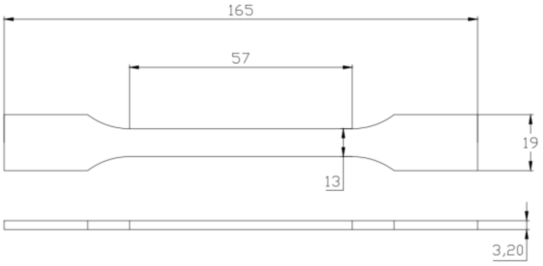

Fig. 1. Specimen dimensions

The next step was to determinate the printing parameters for the specimens. For this study there were used two materials (ABS and PLA), two types of internal structures (triangular and trihexagonal) with two infill percentages (30% and 80%). These two types of materials were used because they are very cheap and widely used for prototypes in plastics industry. The trihexagonal structure is made of hexagons and triangles interconnected to each other, and this configuration offers a bi-directional strength (along longitudinal and transversal axis) using a minimal quantity of material. The triangle structure is made of parallel lines in three directions forming triangles all over the structure. This configuration offers good shear stress. There were used two percentages of infill to make the comparison between printing times and the quantity of materials needed to print the specimen. In general, the 30% is used to test the printer and to evaluate the quality of the printed surfaces because it requires less time, and 80% is used for prototypes with a functional role. Other important parameters for this study are the diameter of the filament used was 1.75 mm, the printer resolution was 60 μm, printing speed 60 mm/s, diameter of the printing head was 0.4 mm, the printing temperature for PLA was 210°C and 260°C for ABS and the temperature of the printing bed was 60°C for PLA and 80°C for ABS. The differences between the internal structure and infill are shown in Figure 2. [1]

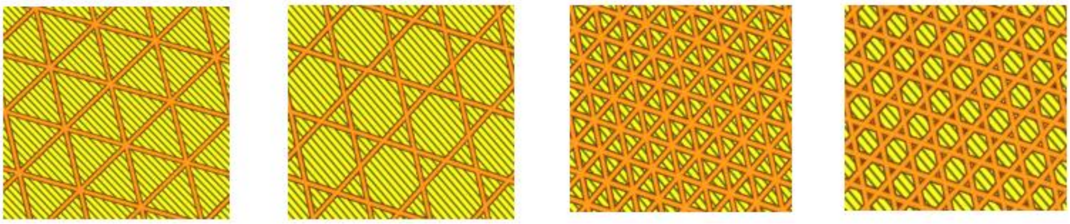

Fig. 2. Differences between the internal structure

3. Experimental analysis

For the experimental analysis it was used the INSTRON 8872 testing machine, which is a compact servo-hydraulic testing machine for a wide variety of specimens. The maximum force of this device is 25 kN. The specimens were fixed between the two grips as one can see in Figure 3.

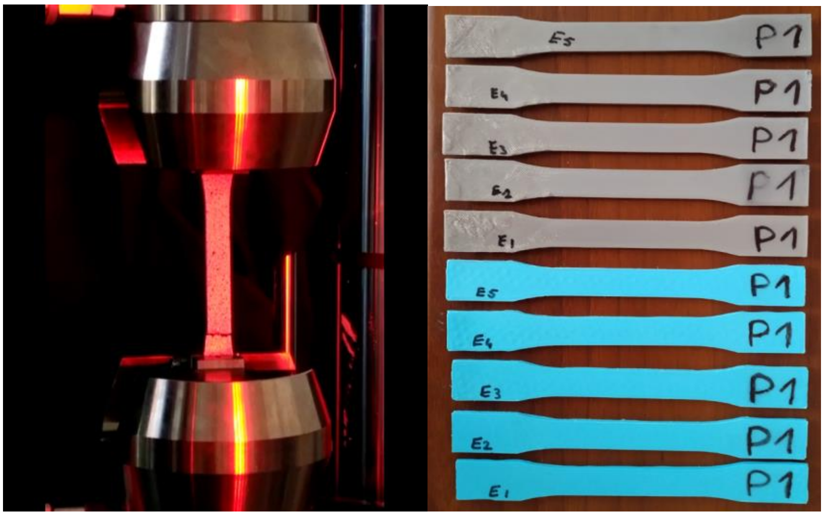

Fig. 3. The specimens in INSTRON machine and before testing

To determine Poisson’s ratio for those specimens it was used the Digital Imagine Correlation. This method consists in the analysis of the dimensions and the shape of the objects through images from two cameras. The images are processed using a software which will assign a Cartesian coordinate system for each pixel from the images. Comparing these images the software can show the elongation in real time, and all the values (the force and elongation) are collected. For the software to calculate the elongation the specimens must be painted in white with black dots. The cameras must be calibrated before using the machine, as one can see in Figure 4.

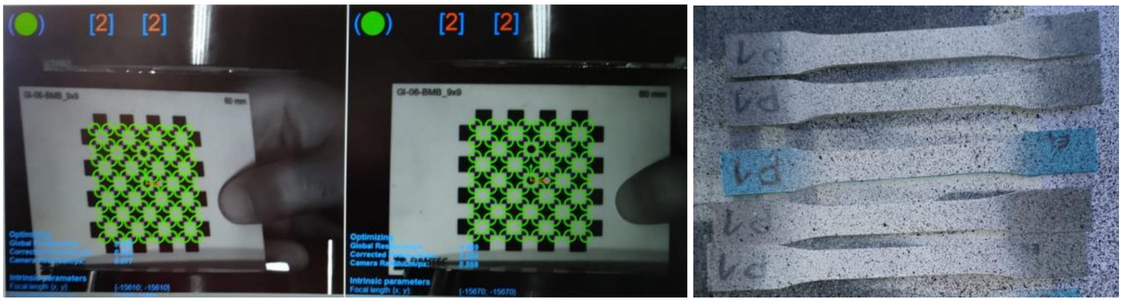

Fig. 4. The calibration procedure for the machine and the painted specimens

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4. Comparison of the results

For this study the most important features to compare at first were the material used, density (infill), the internal structure, time spent on printing, quantity of the material used and the maximum force (breaking force of the specimen). Those results can be seen in table 1.

Table 1. Preliminary comparison

As can be seen in the table, the printing time and quantity of material used was almost the same for all the specimens, so those two criteria can’t show the best configuration of the specimens. The breaking forces for the PLA specimens are with around 15% higher than ABS. For this study the authors determined the conventional stress-strain curve for all the configurations, meaning that it was used the whole cross-section area for each specimen. This area doesn’t have an exact value because of the internal pattern and the infill percentage. So that means the values for the elastic modulus that there were first calculated with Wolfram Alpha are not the real ones. In order to have the real values it was used a compensation formula. The values are centralized in table 2.[2]

Material	Infill and internal structure	Printing time	Quantity of material used	Breaking force of the specimen
ABS	30% triangles	74 min	8.2 g	882.6 N
	30% tri-hexagonal	74 min	8.2 g	848.4 N
	80% triangles	87 min	10.2 g	958.4 N
	80% tri-hexagonal	86 min	10.2 g	988.6 N
PLA	30% triangles	74 min	8.2 g	1038.2 N
	30% tri-hexagonal	74 min	8.2 g	1057 N
	80% triangles	86 min	10.2 g	1271.4 N
	80% tri-hexagonal	85 min	10.2 g	1252.6 N

Table 2. Second Comparison

Material	Infill and internal structure	Poisson’s ration	Maximum stress [MPa]	Elastic modulus [MPa]	Elastic modulus (real) [MPa]
ABS	30% triangles	0.29	15	1089	762.3
	30% tri-hexagonal	0.31	14	1003	702.1

	80% triangles	0.22	17	1260	1008
	80% tri-hexagonal	0.34	17	1291	1032.8
PLA	30% triangles	0.31	18	1266	886.2
	30% tri-hexagonal	0.34	18	1280	896
	80% triangles	0.30	23	1767	1413.6
	80% tri-hexagonal	0.29	22	1675	1340

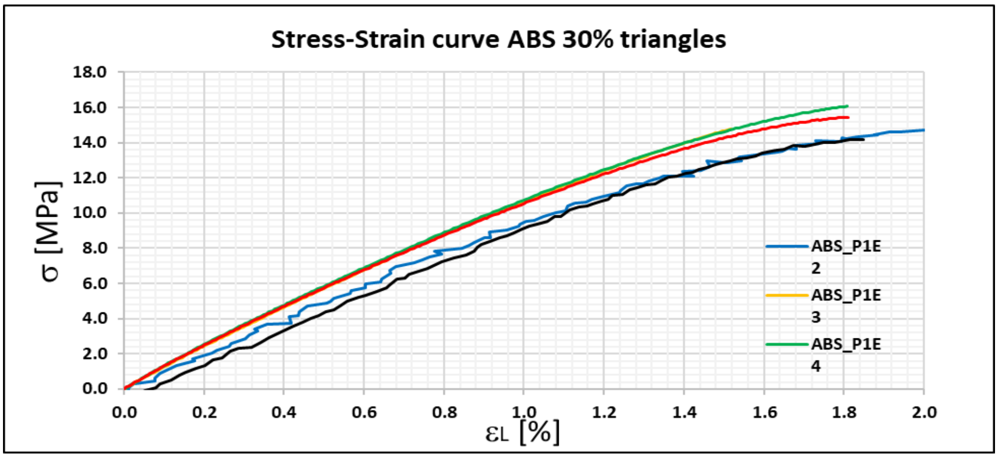

Fig. 5. Stress-strain curve for ABS 30% triangles

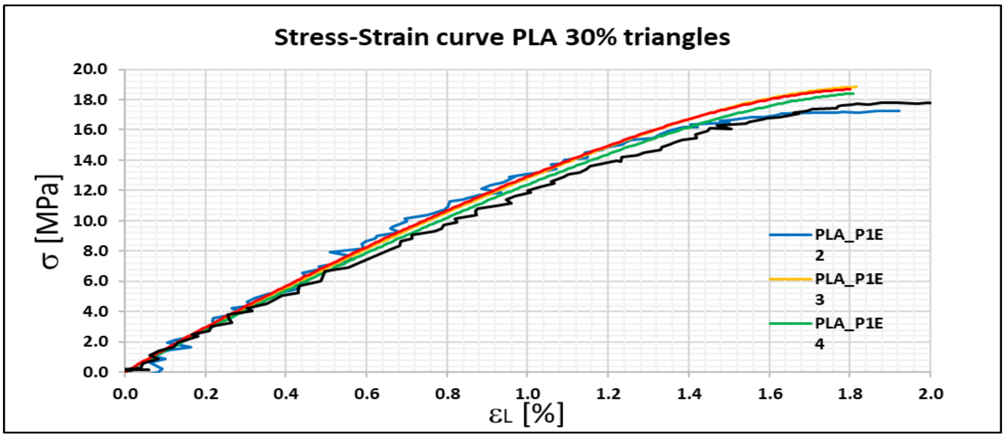

Fig. 6. Stress-strain curve for PLA 30% triangles

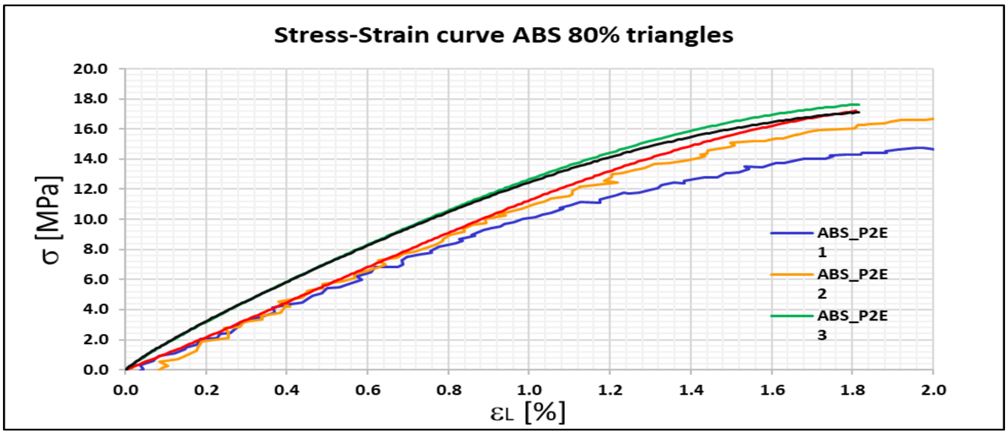

Fig. 7. Stress-strain curve for ABS 80% triangles

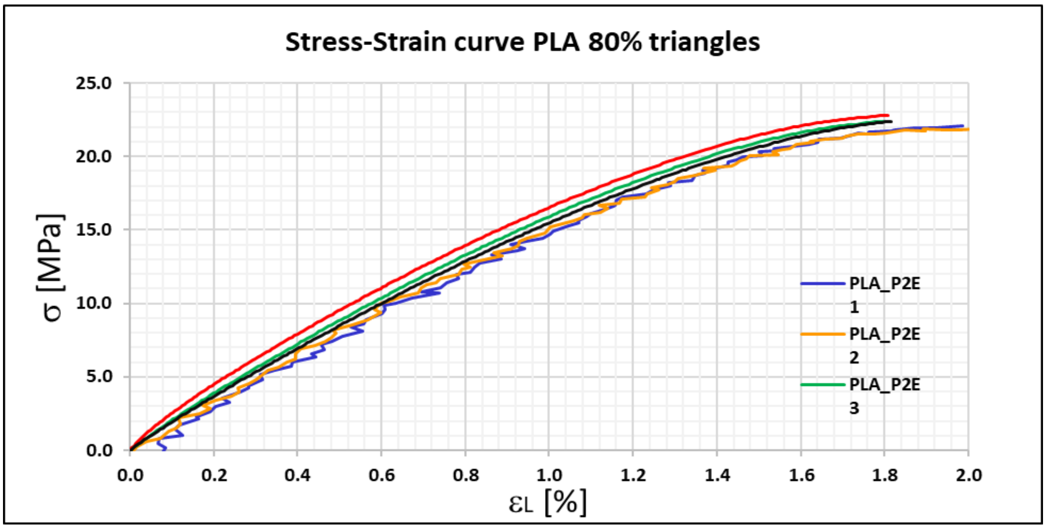

Fig. 8. Stress-strain curve for PLA 80% triangles

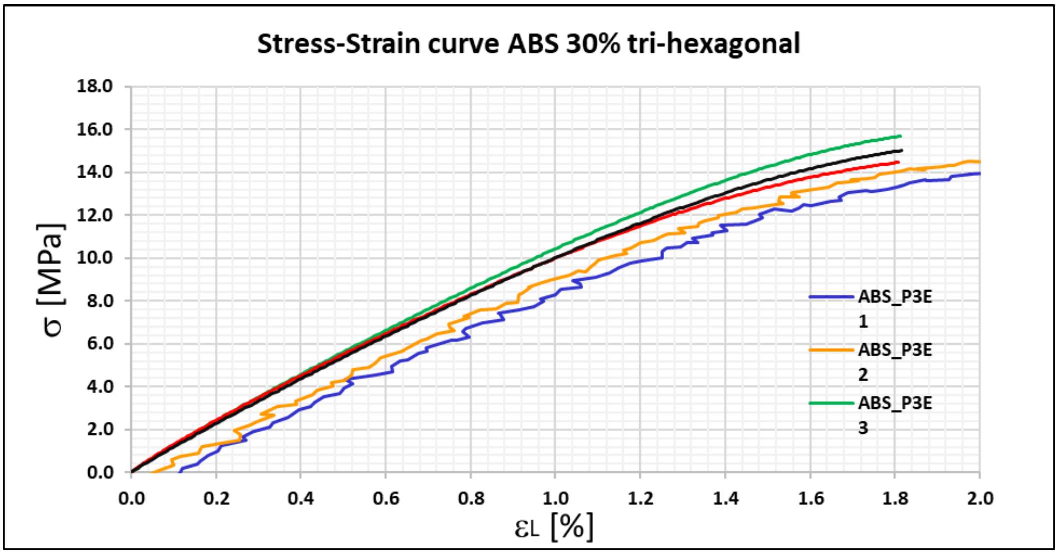

Fig. 9. Stress-strain curve for ABS 30% tri-hexagonal

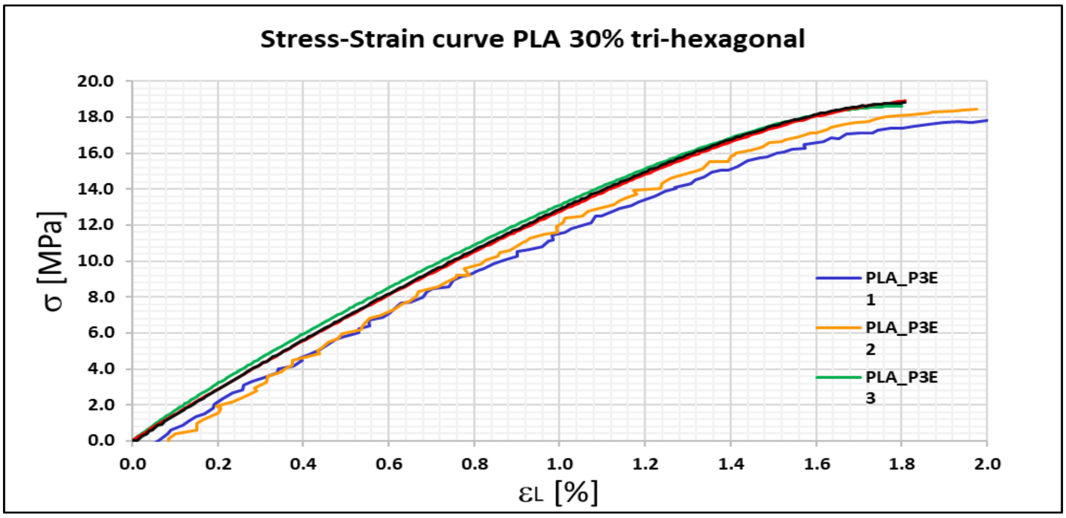

Fig. 10. Stress-strain curve for PLA 30% tri-hexagonal

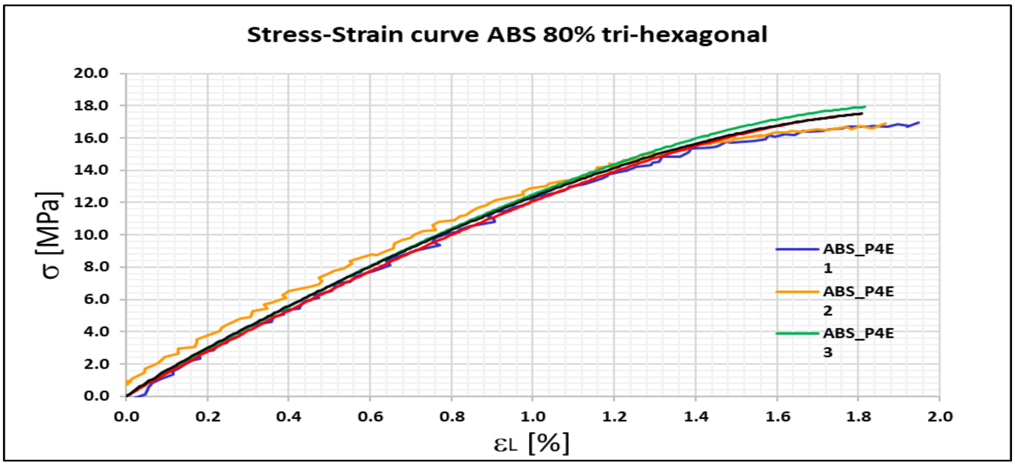

Fig. 11. Stress-strain curve for ABS 80% tri-hexagonal

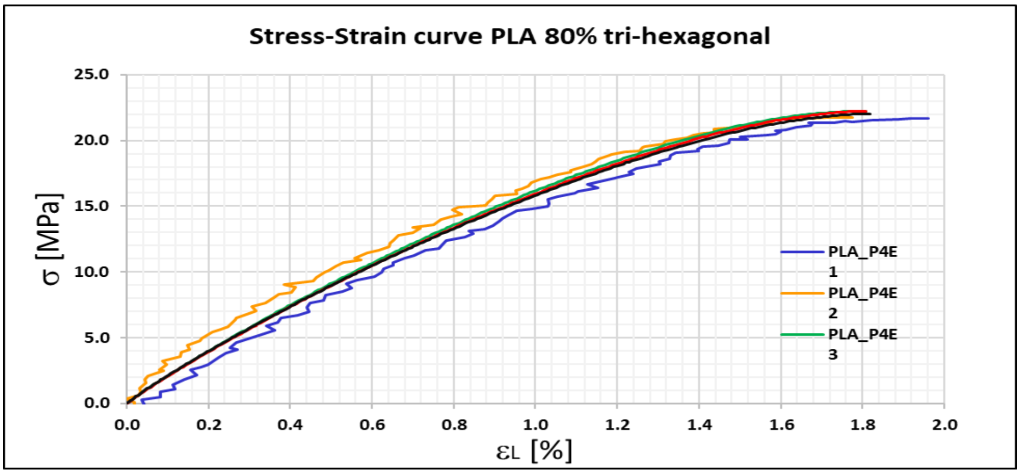

Fig. 12. Stress-strain curve for PLA 80% tri-hexagonal

5. Conclusions

The two materials, PLA and ABS, had a similar behavior during the tests, but as we can see in Table 2, PLA has a higher elasticity modulus than ABS, and all the specimens made from PLA withstand higher breaking forces than ABS, so this material is defiantly stronger. For these specimens the differences in those with the same infill and different internal structure are not very prominent both breaking at the same stress value. The maximum stress was supported by PLA specimen with 80% triangles. The same specimen with the same configuration had the highest value for the Young modulus. In conclusion, we can affirm that the best configuration from the tested specimens was 80% triangles.[3]

6. References

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