Technological Parameters Effects on Mechanical Properties of Biodegradable Materials Using FDM

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Abstract*.The additive manufacturing technology has made its debut in the industrial field about 30 years ago, when prototyped parts were usually used at the 3D printing stage during fabrication, to give the end customer a truthful concept of how a part will looks when conventional manufacturing techniques were used for final part fabrication. Because of the increasing demand for non-toxic, biodegradable materials and products, human society is always searching for new materials with specific applications, which are able to fulfill the above-mentioned requirements. Consequently, it is essential to identify the qualities of these materials and their behavior when subjected to various external factors, in order to find their optimal solutions for application in various domains. Manufacturing parts from biodegradable materials by 3D printing represents a major concern of industry specialists. The 3D printing process involves several parameters whose influence on the sample functional characteristics is a topical issue. In this paper are determined influences of certain technological parameters (thickness of the layer, filling speed, and part orientation on the printing bed) on some mechanical properties (tensile strength, structure, thermal analysis by DSC, and friction coefficient). Experiments were performed on specimens made of three materials: PLA, HD PLA Green, and Impact PLA Gray. A complete factorial experimental plan was used with three input parameters on two levels. Each experiment was repeated three times following the process stability. The obtained mean values of the tensile test were used in the analysis. The analysis was performed with the MiniTab application, which allowed the parameters hierarchy by influencing each mechanical characteristic studied, model development, and optimum values setting.*

Keywords: biodegradable materials, FDM, mechanical properties

1. Introduction

3D printing technology has revolutionized in the last decades the way products are made and has become one of the reference technologies that develop applications in a wide range of areas. Additive manufacturing or 3D printing technologies can be achieved through several processes, such as extrusion of molten material; printing using an additional energy source; by powder solidifying, melting, or combining the particles; photo-polymerization, solidification of a liquid polymer; pure lamination, bonding of layers, [1, 2].

Initially the 3D printing technology was used to obtain prototypes of parts which were to be obtained by traditional manufacturing methods, aiming to ease and shorten the technological fabrication of a finite product, [3-5].

The prototyping based on polymers is depending mostly on fossil-based material such as Acrylonitrile butadiene styrene (ABS), polycarbonate (PC), nylon, and many more others, with significant long-term consequences on the health and the environment. In order to mitigate these consequences, biomaterials with comparable properties and qualities are sought as alternatives in many applications. Poly (lactic acid) (PLA) is a bioplastic, compostable, thermoplastic polyester obtained from

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renewable annual resources, such as corn or sugar beet, [6]. PLA has the potential to substitute a fossil thermoplastic and its low melting point is a major benefit, due to the fact that it needs less energy for 3D printing compared to (ABS) and polyamides. PLA has a variety of applications, including biomedical and industrial applications.

The FDM (Fused Deposition Modelling) technology is a three-dimensional printing process in which a thermoplastic filament is heated above its melting temperature and then extruded onto a printing surface using layer by layer deposition. It is applicable in several industries, such as housing, healthcare, transportation, and so one, as well as in a variety of industrial applications in the care of the benefits of customizing unique items, [7]. The benefits of prototyping by material extrusion include the promotion of inexpensive and sustainable development with reduced materials waste, eliminating tool requirements, and a significantly shorter supply chain.

2. Materials and method

The experimental researches used "dumbbell" shaped samples and the dimensions according to ISO 527 standard, [8]. The experiments were carried out after a complete factorial program of 2^3 type (8 experiments), the considered factors were: printed layer thickness, infill speed and part orientation on the printing bed. The two levels for the three input factors are shown in Table 1:

Table 1. Input parameters in the experimental plan

No. crt.	input parameter	Levels	
		1	2
1	printed layer thickness [mm]	0.1	0.2
2	infill speed [mm/min]	40	80
3	part orientation on the printing bed	flat	on-edge

The samples were printed from the PLA, HD PLA Green and Impact PLA Gray materials. The prototyping was done on the Raise3D Pro2 PLUS equipment after the FDM procedure. The nozzle diameter was 0.4mm. All samples were printed with three shell layers and a 100% filling degree. Table 2 presents the extrusion nozzle and the printing bed temperatures for the three printed materials.

Table 2. The working temperatures of the nozzle and of the printing bed for the studied materials

No. crt.	Material	Nozzle temperature [°C]	Printing bed temperature [°C]
1	PLA	220	60
2	HD PLA Green	215	65
3	Impact PLA Gray	220	65

For each experiment, three samples were printed to highlight the process stability by calculating the mean and the dispersion of the values for each set of input parameters values from the experimental plane.

The obtained samples were subjected to *uniaxial tensile test* on an Instron 3382 equipment, with a constant crosshead speed of 5mm/min according to ISO 527-3: 2003 recommendation.

Each test has generated tensile strength, σ [MPa], strain, ε [%], and modulus of elasticity, E [MPa], calculating for each media and dispersion. Using the ANOVA method was determined the input parameters influences on the tensile strength, on the strain and on the Young modulus, which allowed an influence hierarchy of these factors.

The *surface and morphological analysis* in the breaking zone and on the surface of the samples was performed using the SEM and EDAX method on a QUANTA 200 3D electron microscope.

The *friction coefficient* was determined using the UMT-2 MicroTribometer (CETR). In order to carry out this determination, a steel ball with a diameter of 1.6 mm was used, under dry conditions, at room temperature. The ball has made cyclical displacements (round trip) on the surface of the samples (from studied bioplastic materials) over a total distance of 20mm. The test parameters taken into account were: the normal force on the Z direction of the equipment Fz = 10N, the displacement speed of the linear table V = 10mm/s and the test time t = 300s.

The *DSC analysis* was performed on a differential scanning calorimeter of F3 Maia NETZSCH type.

3. Results and discussions
3.1. Tensile strength determination

The average values obtained for the tensile tests, according to the experimental plan for PLA, HD PLA Green and Impact PLA Gray are presented in Table 3, with the highlight of the experiment with the best values for each material separately.

Table 3. Experimental results of the tensile tests

Exp. no.	Material	Input parameters			σ_{max}	E	ε
		layer thickness [mm]	filling speed [mm/min]	part orientation	MPa	MPa	%
1	PLA	0.1	40	flat	37.89±1.50	1050.71±68.87	4.48±0.16
2		0.1	40	on-edge	47.55±4.74	1369.32±146.05	4.56±0.18
3		0.1	80	flat	42.41±0.85	1363.31±13.53	4.23±0.03
4		**0.1**	**80**	**on-edge**	**51.01±2.02**	**1375.55±51.53**	**5.91±0.65**
5		0.2	40	flat	32.22±3.61	919.60±139.41	6.26±1.12
6		0.2	40	on-edge	47.32±3,81	1252.37±141.58	6.94±2.95
7		0.2	80	flat	34.10±2.66	996.63±44.44	5.92±0.63
8		0.2	80	on-edge	50.11±0.90	1333.77±2.75	5.89±0.25
1	HD PLA Green	0.1	40	flat	32.75±0.28	1225.83±66.65	5.37±0.63
2		0.1	40	on-edge	44.02±0.66	1452.83±34.40	4.56±0.30
3		0.1	80	flat	36.04±0.52	1256.48±35.89	3.76±0.06
4		0.1	80	on-edge	44.27±0.01	1300.27±48.08	4.21±0.23
5		0.2	40	flat	37.43±0.52	1191.61±50.45	4.11±0.09
6		**0.2**	**40**	**on-edge**	**46.22±2.79**	**1377.82±114.26**	**5.09±0.85**
7		0.2	80	flat	39.68±0.45	1317.16±63.16	3.99±0.27
8		0.2	80	on-edge	44.06±0.33	1409.49±27.62	5.77±1.28
1	Impact PLA Gray	0.1	40	flat	23.03±1.29	856.79±14.63	4.62±1.01
2		0.1	40	on-edge	31.93±1.56	1084.98±38.74	4.56±0.79
3		0.1	80	flat	23.88±0.11	910.36±18.83	5.34±0.06
4		0.1	80	on-edge	33.20±0.55	1058.99±53.45	3.91±0.07
5		0.2	40	flat	25.16±0.58	845.16±47.53	5.49±1.32
6		**0.2**	**40**	**on-edge**	**33.88±1.60**	**1071.25±41.01**	**5.50±0.67**
7		0.2	80	flat	25.63±0.34	876.95±34.87	5.45±1.23
8		0.2	80	on-edge	32.79±0.10	1025.78±80.79	6.34±0.45

The characteristic curves similitude of each experiment revealed (example exp. no. 4, PLA) the relatively homogeneous behaviour of the samples, Figure 1, which shows that the printing process was stable and reproducible, the mechanical properties of the material varying in acceptable limits (e.g. σ_{max}= 51.01±2.02 (MPa) ε_{max}=5.91±0.65 (%).
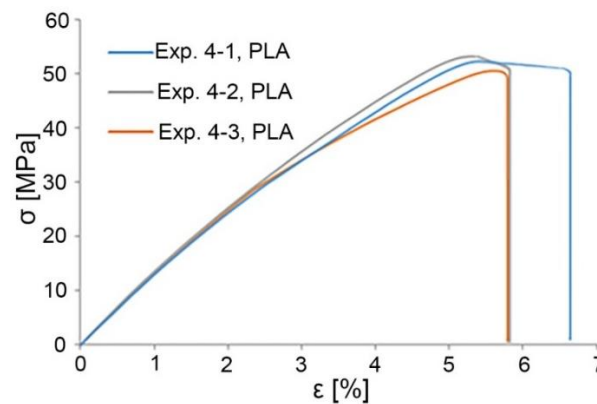

Figure 1. Strain - strength curve for PLA material,
experiment no. 4

In the case of HD PLA Green material, there is the same similarity of the characteristic curves for each experiment (example exp. no. 6), which demonstrates the existence of a relatively homogeneous behaviour of the samples, Figure 2. In this situation, besides the stability and reproducibility of the process, the mechanical properties of the material, for the most favourable experiment, are σ_{max}= 46.22±2.79(MPa) and ε_{max}= 5.09±0.85 (%).
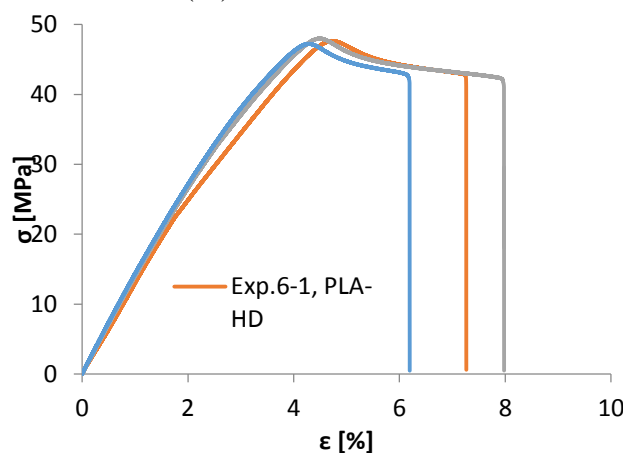

Figure 2. Strain - strength curve for HD PLA Green
material, experiment no. 6

With the same specifications mentioned for the first two materials, in the case of Impact PLA Gray (Figure 3), example experiment number 6, the means values of σ_{max}=33.88±1.60 (MPa) - tensile strength and ε_{max}=5.50±0.67 (%) - strain were obtained. The behaviour of this material differs from the first two, by the fact that during the tensile test, the shell layers of the specimen, gave up first, on both sides, and in the next phase the raster of the specimen. The explanation may be one of low layers' adhesion during printing.
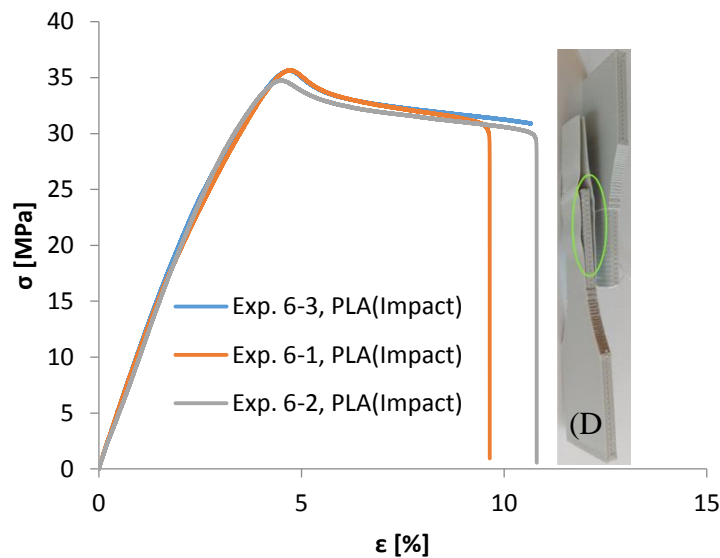
Figure 3. Strain - strength curve for Impact PLA Gray
material, experiment no. 6

The highest modulus of elasticity was registered by HD PLA Green material (1377.82±114.26MPa), followed by PLA (1375.55±51.53 MPa) and Impact PLA Gray, having a low elasticity module, 1071.25±41.01MPa. In terms of tensile strength, PLA material has the best behaviour (51.01±2.02 MPa) followed by HD PLA Green (46.22±2.79 MPa) and, at a great distance, the Impact PLA Gray (33.88±1.60 MPa).

The largest strain is presented by PLA (5.91±0.65%) followed by Impact PLA Gray (5.5±0.67%) and HD PLA Green (5.09±0.85%).

Analysing the results dispersion of the three tested samples, of each material, it can be concluded that Impact PLA Gray has the lowest dispersion, followed by PLA and HD PLA Green.

For Impact PLA Gray, it was observed a detachment of the shell layers from the raster area before the rupture occurrence (Figure 3 – "D" detail). The other samples of the PLA and HD PLA Green materials did not show delamination between the shell layers and the infill layers at the time of rupture.

3.2. The influence of input parameters on some physicomechanical properties of used materials

The experimental data were entered into a sheet of the MiniTab program in the sight of their processing.

It should be mentioned that *Fisher-Value* is used to test whether the terms in the model are significant. If all the factors in the model are fixed, then the formula for Fisher-Value it is the ratio between the adjusted mean square and the mean square error (the variance around the fitted regression line). Also, another term that needs to be explained is the *probability of Fisher value*, noted - *p-value*. The p-value is used in hypothesis tests and helps to decide whether to reject or fail to reject a null hypothesis. The p-value is the probability of obtaining a test statistic that is at least as extreme as the actual calculated value if the null hypothesis is true. A commonly used cut-off value for the p-value is 0.05. For example, if the calculated p-value of a test statistic is less than 0.05, the null hypothesis is rejected.

The influence of input parameters on tensile strength

In Table 4 are presented the influence variance analysis results of the considered input parameters on the tensile strength in the case of the PLA, HD PLA Green and Impact PLA Gray material.

In the case of PLA material, a significant influence on the tensile strength it has the part orientation on the printing bed (for p=0.002, value less than 0.03, admitted in statistics, the factor is statistically

significant, and the Fisher value is 54.17). The other two factors did not have a significant influence (p=0.087 for layer thickness, respectively p=0.132 for infill speed, values greater than 0.03).

Table 4. Results of the variance analysis on the tensile strength.

Input Parameters	PLA		HD PLA Green		Impact PLA Gray	
	Fisher-Value	Probability of Fisher value, p-value	Fisher-Value	Probability of Fisher value, p-value	Fisher-Value	Probability of Fisher value, p-value
Part orientation	54.17	0.002	39.04	0.003	255.52	0.001
Infill speed, [mm/min]	3.56	0.132	0.48	0.526	0.49	0.521
Layer thickness, [mm]	5.07	0.087	3.89	0.120	6.46	0.064

Figure 4 shows the influence of the parameters on the tensile strength in the case of PLA material. The mean value of the model is 42.83MPa. The figure shows that the second level of the part orientation ("on edge") confers maximum resistance.

Tensile strength is better for higher speed (80mm/s) and for smaller layer thickness (0.1mm).

In the case of HD PLA Green samples, it was observed that the part placement, on the printing bed, has the greatest influence (for the probability p=0.003, the Fisher-value is 39.04). The other two factors did not have a significant influence (p=0.12 for layer thickness, respectively p=0.526 for infill speed).

Figure 5 shows the influence of the three input parameters on the tensile strength of HD PLA Green material. The mean value of the model is 40.559MPa, lower than for the PLA material.

As in the case of the PLA, printing the sample by placing it "on edge", ensures the best tensile test strength. In contrast to the PLA, it is noted that the tensile strength is ensured at a layer thickness of 0.2.

A significant influence on the tensile strength in the case of Impact PLA Gray specimens, it has the part orientation on the printing bed (for p=0.001 the Fisher value is 255.52). The other two factors did not have a significant influence (p=0.521 for layer thickness, respectively p=0.064 for infill speed).

Figure 6 shows the influence of the three input parameters on the tensile strength for HD PLA Green material. The mean value of the model is 28.69MPa, lower than for the first two analysed materials.

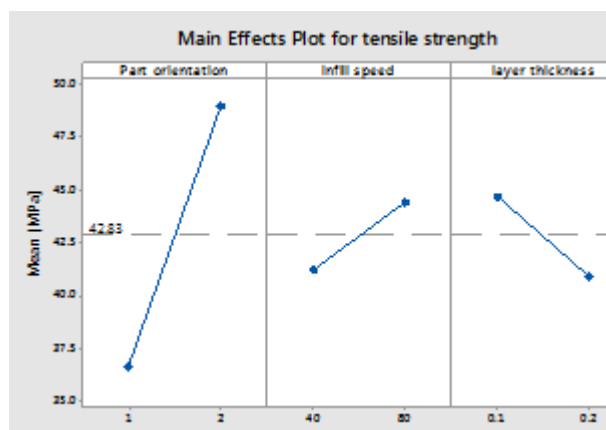The input parameters influence graph on the tensile strength is comparable to that of the HD PLA Green.

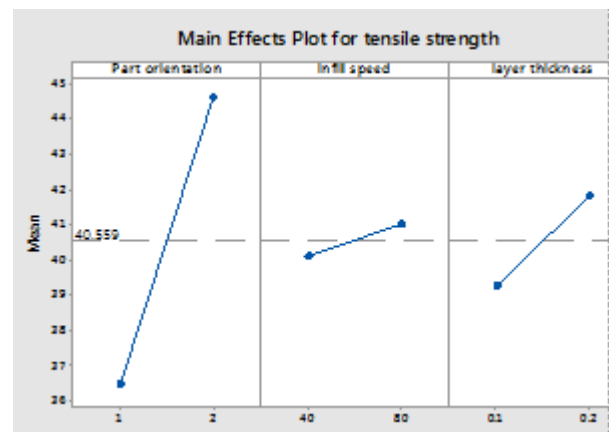**Figure 4.** The factors influence on the PLA tensile strength

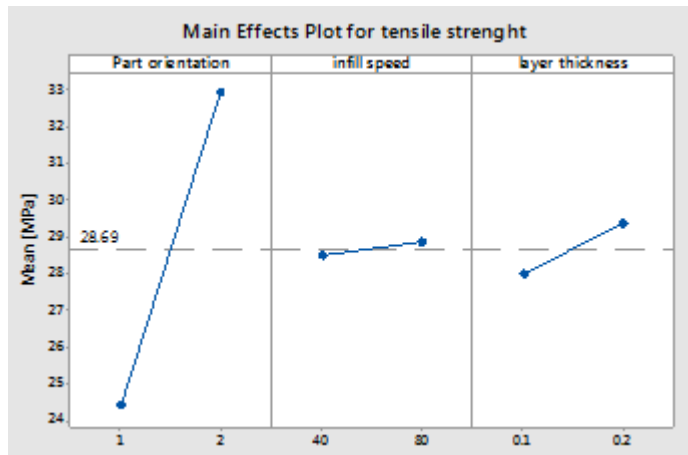**Figure 5.** The factors influence on the HD PLA Green tensile strength

Figure 6. The factors influence on the HD PLA Green tensile strength

The influence of input parameters on elasticity modulus

In order to highlight the influence of the three input parameters on the elasticity modulus the case of the samples made from the three materials, it was preceded similarly to the tensile strength. In Table 5 are presented the influence variance analysis results.

The strongest influence on the elasticity modulus, in the PLA samples case, it has the part orientation ($p=0.025<0.03$ and Fisher Value is 12.20). The other two parameters taken into account have no statistical influence ($p=0.171>0.03$ for the infill speed and $p=0.084>0.003$ for the layer thickness).

In the case of HD PLA Green material, no parameter has a statistical influence (all p values are greater than 0.03).

Table 5. Results of the variance analysis on the elasticity modulus

Input parameters	PLA		HD PLA Green		Impact PLA Gray	
	Fisher-Value	Probability of Fisher value, p-value	Fisher-value	Probability of Fisher value, p-value	Fisher-value	Probability of Fisher value, p-value
Part orientation	12.20	0.025	7.42	0.053	85.94	0.001
Infill speed, [mm/min]	2.77	0.171	0.03	0.870	0.03	0.872
Layer thickness, [mm]	5.25	0.084	0.09	0.779	1.29	0.320

For Impact PLA Gray material, as in case of PLA material, the only parameter with statistical influence is the part orientation on the printing bed ($p=0.001<0.003$ and the Fisher value is 85.94), the other parameters have no influence from a statistical point of view on the elasticity modulus ($p = 0.87> 0.03$ for the infill speed respectively $p = 0.32> 0.03$ for the layer thickness).

The influence of input parameters on the strain

The influence variance analysis results of the input parameters on the strain (Table 6) revealed that none of the three input parameters does exert significant influence, from a statistical point of view, on this qualitative parameter. All values of p are greater than 0.03.

Table 6. Results of the variance analysis on the strain

Input parameters	PLA		HD PLA Green		Impact PLA Gray	
	Fisher-Value	Probability of Fisher value, p-value	Fisher-Value	Probability of Fisher value, p-value	Fisher-Value	Probability of Fisher value, p-value
Part orientation	1.12	0.349	1.12	0.349	0.12	0.746
Infill speed, [mm/min]	0.38	0.570	0.38	0.570	0.26	0.636
Layer thickness, [mm]	0.22	0.664	0.22	0.664	6.55	0.063

3.3. Friction coefficient determination

The friction coefficient (COF) was determined by translational movements between the steel ball and the samples made of biodegradable material (PLA, HD PLA Green and Impact PLA Gray). Following are presented the graphs of the COF variation in time for the samples tested at 10N pressing force and a test speed of 10mm/s. During the tests, the friction regime it was rolling with slip one.

Figure 7 shows the variation graphs obtained during the friction coefficient determination, for the samples from the experiments that showed the most favorable results during the tensile tests: PLA – experiment no. 4 (represented in the figure with 1 - red), HD PLA Green – experiment no. 6 (2 - green) and Impact PLA Gray – experiment no. 6 (3 - black). For the PLA samples (1st variation) the COF decreases, in the first 20s, to approximately 0.11, a value that remains approximately the same until the end of the test. In the case of HD PLA Green (2nd variation), a decrease of COF is observed during the first 20s, after which the average value of COF is stabilized throughout the test. For the Impact PLA Gray material (3rd variation) the COF increases from 0.65 is observed throughout the test up to a value of approximately 0.1 registered at 300s. For the PLA samples (variation 1) the coefficient of friction decreases, in the first 20s, to about 0.11, a value that remains approximately the same until the end of the test. The highest average value of the friction coefficient, of 0.11, was recorded for the PLA sample, followed by the Impact PLA Gray sample (0.1) and the HD PLA Green sample (0.04).
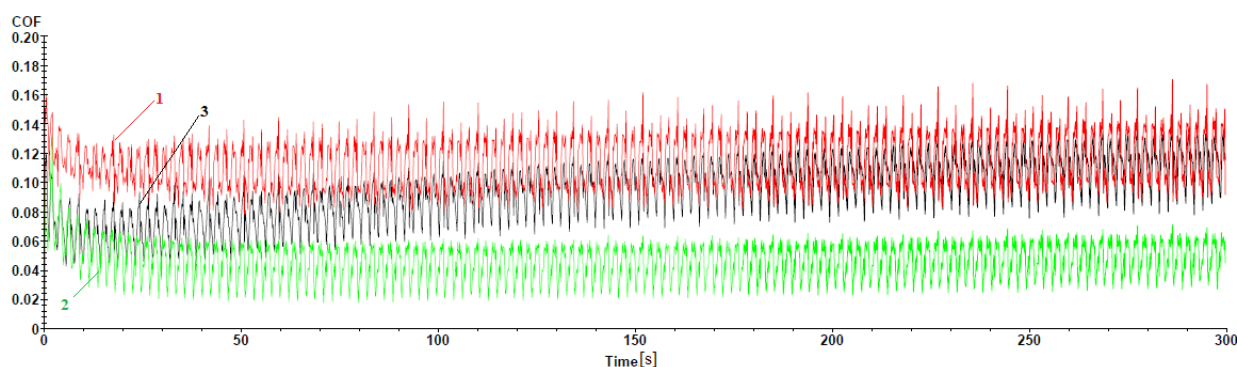

Figure 7. COF variation with test time for samples from PLA (1-red), HD PLA Green (2-green) and Impact PLA Gray (3-black)

3.4. SEM surface and structural analysis

For the surface analysis, have been elected, samples from the experiments where the highest value of the tensile strength was found. The SEM analysis was performed for the surface area of the samples and for the area where the complete rupture occurred.

Figure 8 shows micrographic maps of the PLA sample. It can be observed a no uniform profile of the deposited wires, at the layer construction, these are not adjacent. Also, it can see an almost perfect deposit at a 90° degree angle, between the deposited wires on each layer. Due to the pressure of the nozzle, during the printing process, the wire from the upper layer is deformed, more than in the free space created between the wires, Figure 8(a). In the breaking area of the sample, Figure 8(b), there are elongated wires due to deformation occurred during the tensile test.
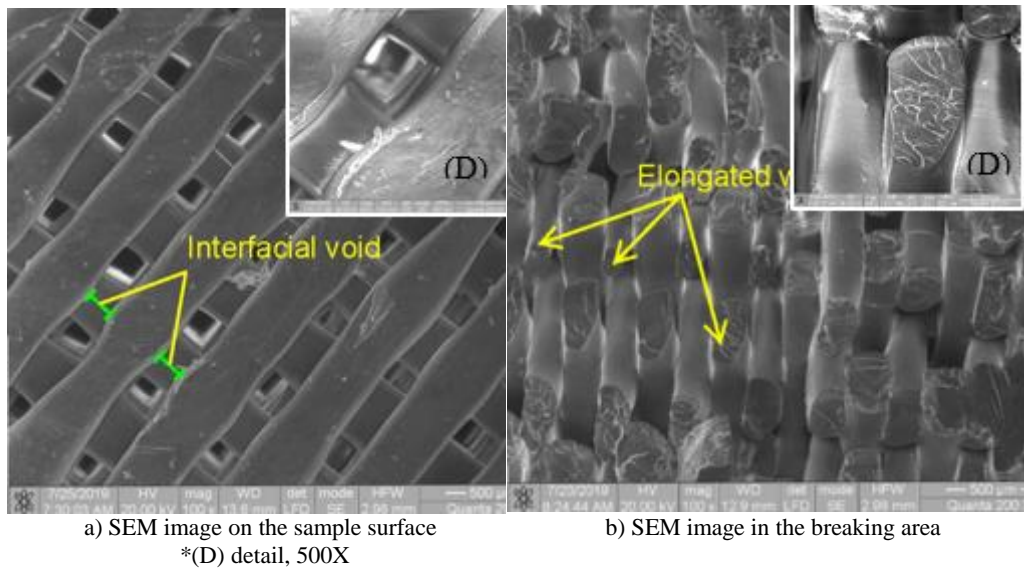
a) SEM image on the sample surface   b) SEM image in the breaking area
*(D) detail, 500X

Figure 8. SEM images of the PLA sample

The surface images of the HD PLA Green and Impact PLA Gray samples indicate a homogeneous surface with specific printing lines at 45°/-45°, and interfacial bonds, Figure 9(a) and Figure 10(a).

From the SEM micrographic maps of the prototyped samples from HD PLA Green and Impact PLA Gray (Figure 9(b) and Figure 10(b)) it can be seen that the shell layer of the sample is characterized by large diamond-shaped/rhomboid voids. Their appearance indicates a rapid solidification of the extruded material, due to the intense heat exchange with the environment, which prevented the molten filament to fill the free space of the model. Also, the layers positioned near the printing bed and previously printed are better melted, bonded and pressed to the upper layers. In the filling area of the samples, the differences are significant, regarding the size of the voids/holes, there is a decrease of them. This decrease is due to the low viscosity of the layers already deposited, resulting in an almost completely solid structure. Both the presence of the voids and the difference in their size, for the surface layer and the filling area, should not significantly affect the mechanical properties.
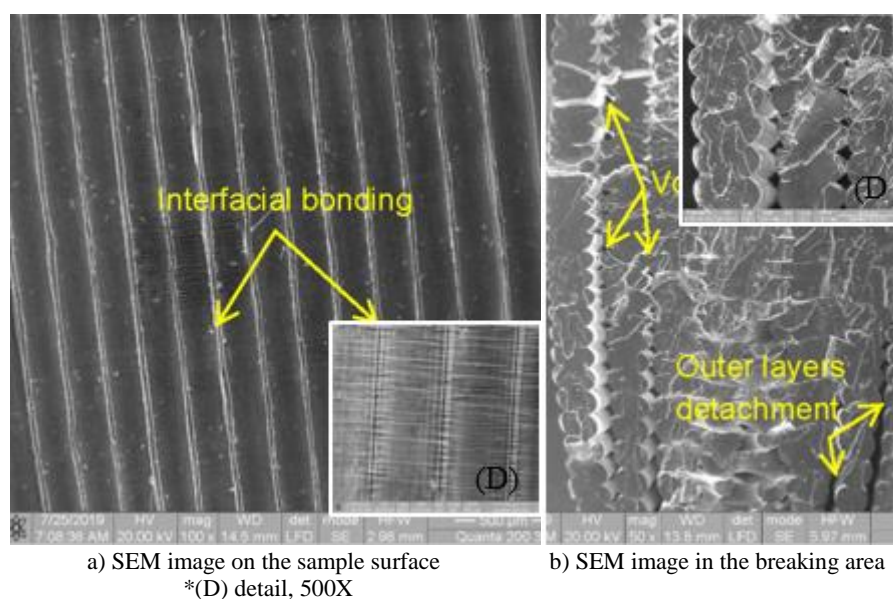

a) SEM image on the sample surface   b) SEM image in the breaking area
*(D) detail, 500X

Figure 9. SEM images of the HD PLA Green

SEM image on the sample surface | b) SEM image in the breaking area
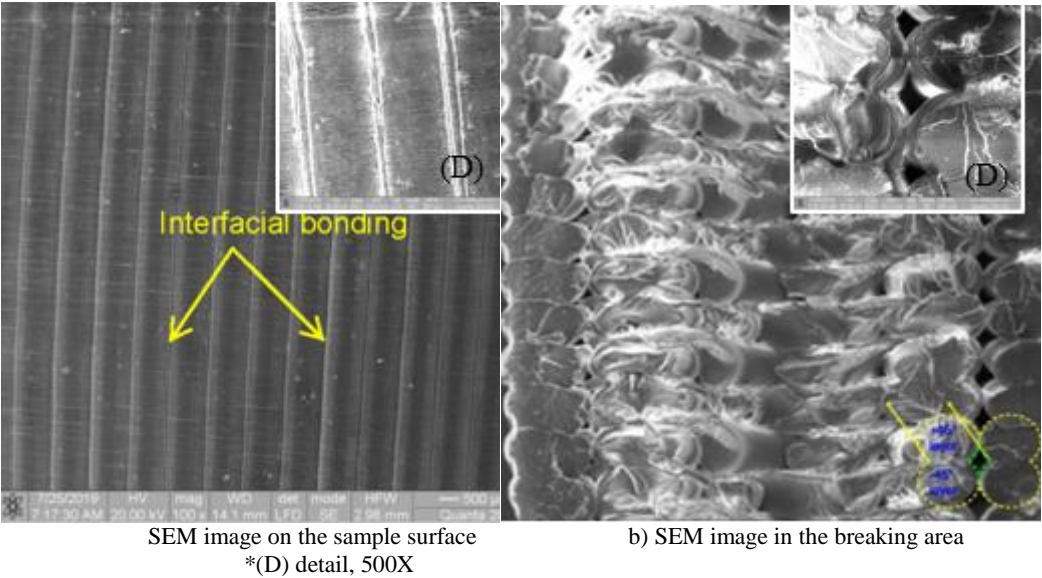*(D) detail, 500X
Figure 10. SEM images of the Impact PLA Gray

3.5. EDX chemical analysis

The electron microscopy images and element analysis (chemical characterization) of the studied specimens are presented in Figure 11, for the experiments with the best results in terms of tensile strength.
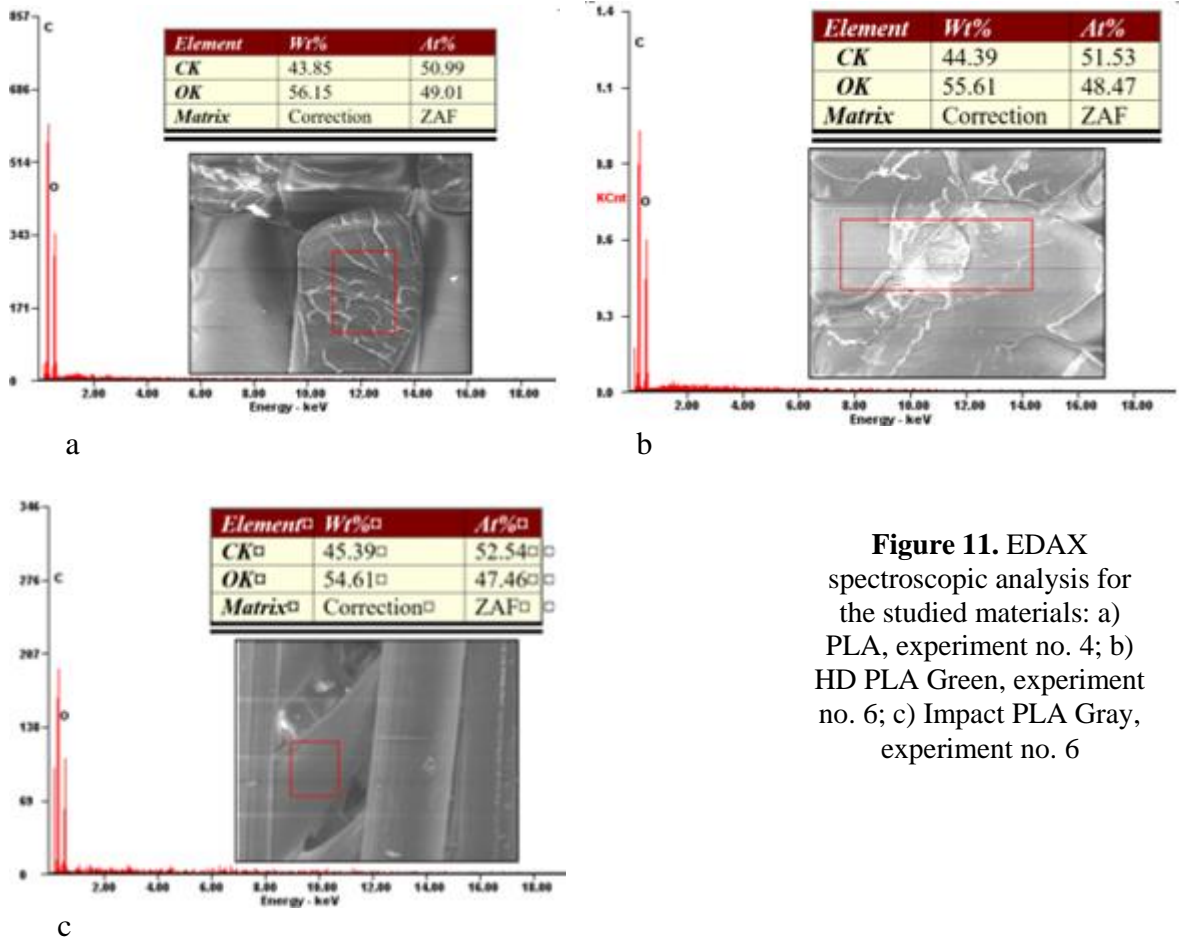

Element	Wt%	At%
CK	43.85	50.99
OK	56.15	49.01
Matrix	Correction	ZAF

a

Element	Wt%	At%
CK	44.39	51.53
OK	55.61	48.47
Matrix	Correction	ZAF

b

Element	Wt%	At%
CK	45.39	52.54
OK	54.61	47.46
Matrix	Correction	ZAF

c

Figure 11. EDAX spectroscopic analysis for the studied materials: a) PLA, experiment no. 4; b) HD PLA Green, experiment no. 6; c) Impact PLA Gray, experiment no. 6

In the above image are outlined the results obtained for the mass and atomic percentage of the chemical elements contained by the printed sample in case of the three materials: PLA, HD PLA Green and Impact PLA Gray. It can be observed that the mass ratio of O and C in the case of printed and EDX subjected samples is about 45% carbon and about 55% oxygen.

3.6. DSC analysis

In order to perform the differential scanning calorimetry, the samples were heated with 10K/min to a temperature of 220°C (493.15K), the tests were completed before the beginning of the materials decomposition. To make as visible as possible the differences between the heating behaviour of the base material (wire) and the printed sample, the DSC curves of the two forms of the material were superimposed.

Figure 12 shows the DSC curves for PLA wire (a) and for the prototyped sample from PLA material (b). Thus, it can be seen in the beginning part of curve number one (PLA wire), a small endothermic peak, the enthalpy relaxation peak with the T_g (glass transition) midpoint at 341K. In the temperature range (380-445)K begins the process of PLA wire melting, which is evidenced by an endothermic peak, with a maximum value at 427K. For curve (b) (PLA printed sample) three peaks were highlighted: endothermic peak corresponding to the glass transition, at the same temperature of 341K, as well as in the case of PLA wire; exothermic peak at 400K, (380-415)K area, where occurs the printed PLA material cold crystallization; endothermic peak, at temperatures of 431K, similar to that found in the case of PLA wire melting point. The states behaviour in which the two forms of PLA have through are different. In the case of the printed sample from the PLA, an exothermic peak appeared which characterizes the cold crystallization of the material. Thus, the material passes from amorphous material to semi crystalline material.
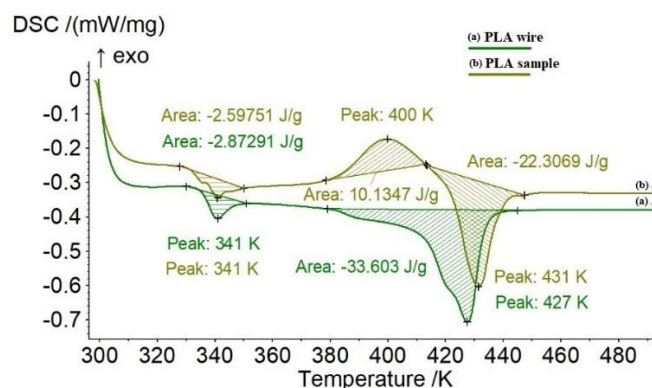

Figure 12. Highlighting the main thermal behaviour of the
PLA material:a) wire form; b) printed sample

For the HD PLA Green material DSC analysis (Figure 13) in the wire form (a) and as printed sample (b), two almost identical curves were revealed, with small temperature differences (3K) for the characteristic peaks of the state transformations incurred by the two forms of the material during the test. The glassy transition of HD PLA Green material occurs at a temperature of 339K in the case of wire and 342K in the case of a printed sample. At temperatures of 367K and respectively at 370K, the exothermic peaks corresponding to the cold crystallization appears for the two samples analysed. In the temperature range (437-472)K occurs the melting.
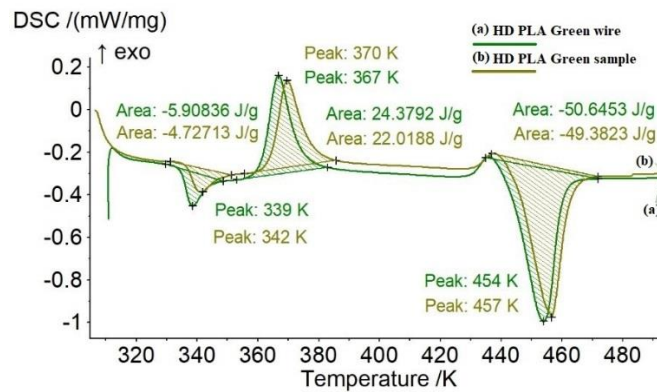
Figure 13. Highlighting the main thermal behaviour of the HD PLA
Green material:a) wire form; b) printed sample

The Impact PLA Gray material thermal behaviour, in the wire and printed sample forms, shows very small variations, figure 14, the order of only a few Kelvin.

Thus, at the temperature of 338K, Figure 14(a) and 340K, Figure 14(b), takes place the glassy transition of the material (endothermic peaks). The material crystallization, evidenced by the exothermic peak, occurs at 370K temperatures and 371K respectively. According to the analysis performed the melting point of the wire from Impact PLA Gray material is at 454K, and the melting point of the printed sample from the same material is at 456K.
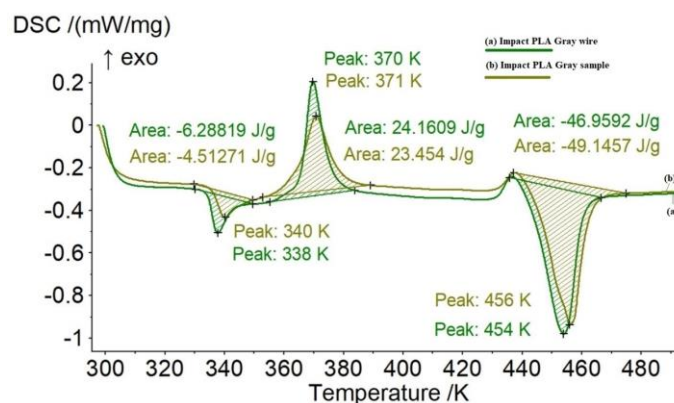

Figure 14. Highlighting the main thermal behaviour
of the Impact PLA Gray material:a) wire form; b) printed sample

4. Conclusions

The tensile strength of the analysed materials in this paper records the best average value for the printed PLA material, (51.01±2.02)MPa. The HD PLA Green and Impact PLA Gray materials revealing values of (46.22±2.79)MPa and (33.88±1.60)MPa respectively. The average value of tensile strength for the printed PLA material is comparable with those of other printed thermoplastic materials such as Carbon Nano structure ABS (39.7MPa), ABS (40.5MPa), ASA (Acrylonitrile Styrene Acrylate) (44MPa), and PETG (Polyethylene Terephthalate Glycol) (48.8MPa), [9].

Regarding the friction coefficient for the three studied materials, it was observed that the greater value was registered in the PLA material case (0.11), followed by the Impact PLA Gray sample (0.1) and the sample of HD PLA Green (0.04).

The FDM printing melts material layers successively deposited, resulting mechanical adhesion between them. As can be seen from the SEM images, the surfaces of the deposited layers are only partially adherent to the previous layers.

Structural and surface analysis of samples from PLA, HD PLA Green and Impact PLA Gray materials indicates a less compact structure, with large voids in the shell layers and smaller voids in the inner layers.

The input parameters variance analysis (part orientation, infill speed, layer thickness) on the three physical-mechanical properties (tensile strength, elasticity modulus and strain) revealed the following: in the case of the first two parameters (PLA and HD PLA Green), only the part orientation on the printing bed exerts a statistically influence; "on edge" oriented parts offer the best results on both tensile strength and elasticity modulus; The PLA has the highest average tensile strength value and the lowest is for Impact PLA Gray; no input parameter exerts statistical influence on the strain.

Therefore, the parts obtained by 3D printing using FDM have anisotropic behaviour. Comparing two of the most widely used thermoplastic materials globally, PLA and ABS, for the obtaining of extruded parts, it was found that PLA thermoplastic is the easiest to use / print. Other advantages other than PLA are: biodegradability (under appropriate conditions), greater strength and rigidity than ABS, [10].

The advantages of the FDM printing compared to those of the injection moulding, in the case of all the studied materials, are given by the minimum consumption of material, the easiness of making a prototype, the equipment low cost, so on. From the specialized literature, it was possible to highlight that the results of the mechanical properties in the case of the PLA printed parts are comparable to those obtained by injection into the mould. For example, the average value of the tensile strength obtained for the printed specimens in this study is 51MPa. The average value of a PLA injected sample from is 59MPa, [6].

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