STUDY ON THE INFLUENCE OF SOME DESIGN AND TECHNOLOGICAL PARAMETERS ON THE MECHANICAL BEHAVIOR OF THE PARTS OBTAINED BY FDM

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Abstract: *Additive manufacturing has undergone an accelerated development both in terms of technologies and equipment as well as in the fields of use due to the undeniable advantage of rapidly making, without other tools and devices or manufacturing preparation, molded products. complex geometries or assemblies with fixed or movable parts. However, these technologies do not guarantee the assurance of all the requirements in terms of shape and size accuracy, surface quality, mechanical strength, etc., in accordance with the functional role of the respective product. The purpose of this study is to determine the influence of the process parameters, the layer thickness, the degree of filling and the angle of placement of the specimen on the printer tray on the mechanical characteristics.*

Keywords: *FDM, ABS, tensile test, process parameters, mechanical characteristics*

1. INTRODUCTION

The study of the influence of the process parameters on the characteristics of the parts made by the technology of additive manufacturing presents a real interest for the optimization of the process in order to obtain good quality parts that meet the functional role for which they were designed correlated with the efficiency of the process from the point of view of consumption. material and time to produce products.

The analysis of thin walled structures with circular section has a strong background in work of Abramowicz and Jones [6], Hsu and Jones [7], and Reid [8], while the structures with a rectangular cross-section were investigated by Abramowicz and Jones [9] and Wierzbicki and Abramowicz [10]. The latest developments in the field of manufacturing processes allow the use of additive manufacturing technologies for custom safety devices. Additive manufacturing includes sets of technologies used to produce complex parts [12] in limited series. The parts can be used for design and functional analysis and in some cases as structural components. The performances of the finished parts are however dependent on the technology employed for the manufacturing process [13–14]. In the specialized literature, there are few experimental data regarding the variation of the mechanical characteristics of the parts obtained by this technology according to the process parameters.

For this study, a large number of experimental determinations were performed, which were analyzed with modern laboratory techniques and finally the correlation between the measured results was established.

2. EXPERIMENTAL PART

Additive manufacturing is a process of making solid partss by adding material, layer by layer. The basic principle consists in heating a plastic filament to near the melting point and extruding it through a nozzle, followed by deposition through successive layers [5]. As the layer solidifies, the movement of the nozzle is coordinated according to the geometry of the parts to obtain that layer, after which a new layer begins to deposit which solidifies in contact with the previous layer and adheres to it. The material deposition continues until the parts is fully realized, fig. 1. The material used in this study is ABS, table 1.

Table 1: Mechanical properties of Z-ABS

Mechanical properties	Values	Test Method
Tensile Strength	30,46 MPa	ISO 527:1998
Elongation at break	11,08 %	ISO 527:1998
Elongation at max Tensile Stress	4.52%	ISO 527:1998
Flexibility (Flexural Modulus)	1.08 GPa	ISO 178:2011

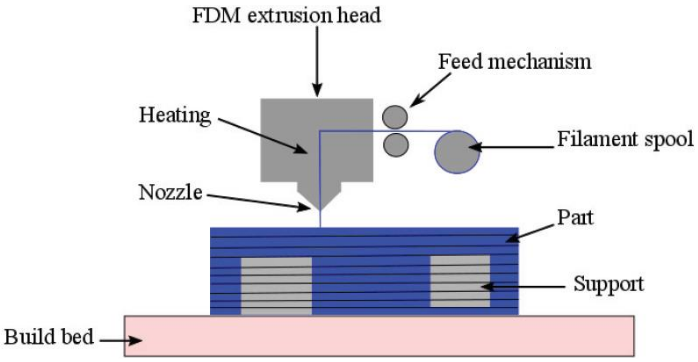


Figure 1: The principle of additive manufacturing

In order to highlight the particularities of the behavior of the plastics materials mechanically stressed, the tensile test is used as a reference test. The conditions and the way to perform the tensile test and the mechanical characteristics that can be determined by this test are regulated by the standard SR EN ISO 527 which represents the Romanian version of the European standard ISO 527.

In order for the results of tensile tests to be comparable, it is necessary that the specimens comply with certain conditions of shape, size and processing. The specimens used for the tensile test have the rectangular section, having a calibrated portion and two ends for fastening in the devices. The usual shapes and main dimensions of a specimen for tensile testing are shown in figure 2, according to standard D638-14.

The meanings of the notations in the figure are as follows:
W—Width of narrow section;
L—Length of narrow section;
WO—Width overall;
WO—Width overall;
LO—Length overall;
G—Gage length;
D—Distance between grips;
R—Radius of fillet.

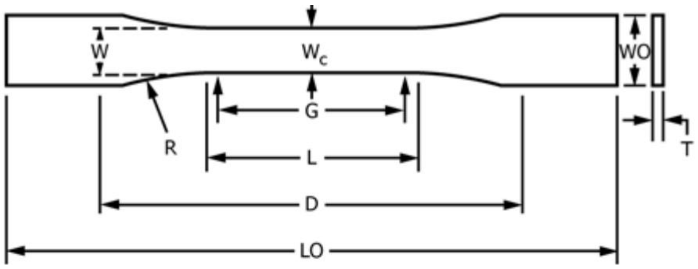


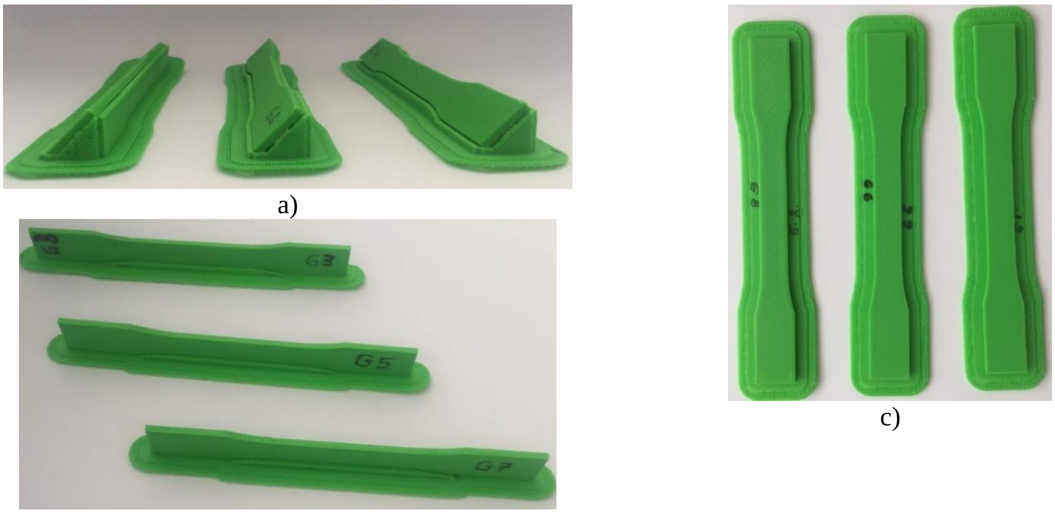
Figure 2: Tensile specimen

The experiment plan, according to the Taguchi method, used to determine the mechanical characteristics is presented in table 2.

Table 2: The experiment plan used for the tensile test

Specimens Parameters	G1	G2	G3	G4	G5	G6	G7	G8	G9
Thickness of layer	0.14	0.14	0.14	0.19	0.19	0.19	0.29	0.29	0.29
Filling degree	30	60	90	30	60	90	30	60	90
Settlement angle	0	45	90	45	90	0	90	0	45

There were made 27 specimens, 3 partss for each type of specimen, varying the three parameters: the thickness of the layer, the degree of filling of the test bar and the angle of placement on the printer's plate [3], fig. 3.
The projected dimensions of the calibrated test area were: thickness - t = 3 mm and width- w = 13 mm.
The measured dimensions (thickness - t, and width - w,) of the test bars are presented in table 3.
The thickness of the layer represents the layer size deposited at a crossing of the printer head.
The degree of filling represents the inner filling of the part; the smaller it is, the faster will print the part.



a)

b)

c)

Figure 3: The appearance of the specimens depends on the angle of placement on the printer plate a) 45°, b) 90°, c) 0°

3. RESULTS AND DISCUSSIONS

In order to determine the mechanical properties of the specimens under static conditions, a traction machine of type INSTRON was used.

Procedure:

- Measuring the initial dimensions of the specimens and tracing the marks delimiting the initial length L0 and dividing marks of this length.
- Fixing the specimens to the tensile device fasteners.
- Choosing the tensile speed of 2.0 m / min and testing the samples until breaking.
- The tensile diagrams for each specimen were recorded. The values of the tensile strength and elongation are presented in table 4.

Table 3: The initial geometric elements of the specimens

	Specimens								
	G1			G2			G3		
	$G1_A$	$G1_B$	$G1_C$	$G2_A$	$G2_B$	$G2_C$	$G3_A$	$G3_B$	$G3_C$
w[mm]	13.3	13.2	13.2	13.1	13.3	13.2	13.2	13.2	13.3
t[mm]	3.1	3.2	3.1	3.3	3.2	3.4	3.2	3.2	3.3
	G4			G5			G6		
	$G4_A$	$G4_B$	$G4_C$	$G5_A$	$G5_B$	$G5_C$	$G6_A$	$G6_B$	$G6_C$
w[mm]	13.3	13.2	13.2	13.3	13.4	13.1	13.2	13.3	13.1
t[mm]	3.3	3.4	3.1	3.2	3.1	3.0	3.0	3.4	3.1
	G7			G8			G9		
	$G7_A$	$G7_B$	$G7_C$	$G8_A$	$G8_B$	$G8_C$	$G9_A$	$G9_B$	$G9_C$
w[mm]	13.2	13.3	13.1	13.2	13.1	13.3	13.1	13.2	13.3
t [mm]	3.3	3.1	3.4	3.4	3.3	3.2	3.1	3.2	3.3

Table 4: Strength values and elongation for ABS specimens

	Specimens								
	G1			G2			G3		
	G1$_A$	G1$_B$	G1$_C$	G2$_A$	G2$_B$	G2$_C$	G3$_A$	G3$_B$	G3$_C$
F[KN]	807	839	826	1137	1160	1117	1395	1446	1412
E[mm]	6.70	9.14	8.14	16.33	18.16	17.15	11.94	12.17	17.28
	G4			G5			G6		
	G4$_A$	G4$_B$	G4$_C$	G5$_A$	G5$_B$	G5$_C$	G6$_A$	G6$_B$	G6$_C$
F[KN]	1158	1176	1147	1358	1375	1312	1014	1034	1025
E[mm]	6.72	6.13	6.01	5.96	5.93	6.59	7.87	8.22	7.30
	G7			G8			G9		
	G7$_A$	G7$_B$	G7$_C$	G8$_A$	G8$_B$	G8$_C$	G9$_A$	G9$_B$	G9$_C$
F[KN]	1213	1300	1128	980	945	978	1410	1421	1418
E[mm]	6.13	6.60	7.66	11.85	8.22	7.85	16.51	16.45	16.32

For each specimen, the mechanical strength was calculated as the ratio between the maximum force and the initial section of the specimen; The average value was then calculated for each set of three specimens, the results being summarized in the table 5.

Through the statistical analysis, the regression equations of the elongation and the mechanical effort were determined and graphically represented, fig. 4, 5.

The regression equation, (1) describing the relationship between elongation, thickness of layer, filling degree and settlement angle.

The regression equation for elongation is:

$E = 5.64 - 6.6\,x + 0.0939y + 0.0063z;$ (1)

E- elongation;

x- thickness of layer;

y- filling degree;

z- settlement angle;

The normal probability plot, fig. 4, 5, is a graphical technique to identify substantive departures from normality. This includes identifying outliers, skewness, kurtosis, a need for transformations, and mixtures. Normal probability plots are made of raw data, residuals from model fits, and estimated parameters.

Residuals versus fits plot, is a scatter plot of residuals on the y axis and fitted values (estimated responses) on the x axis. The plot is used to detect non-linearity, unequal error variances, and outliers.

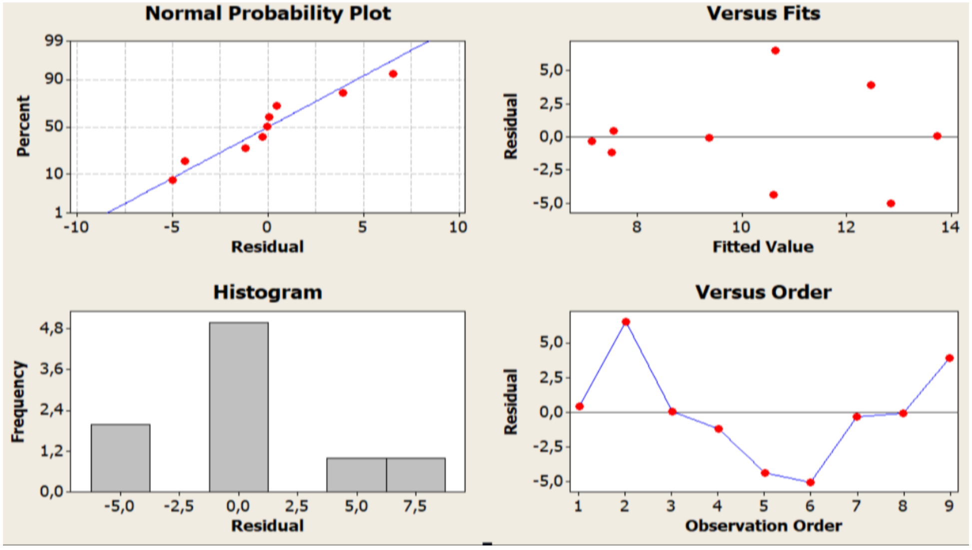


Figure 4: Graphic representation for elongation

The regression equation for mechanical strength is:

$TS = 13.3 + 19.6\,x + 0.0906\,y + 0.0796\,z;$ (2)

TS - mechanical strength;

x- thickness of layer;

y- filling degree;
z- settlement angle;

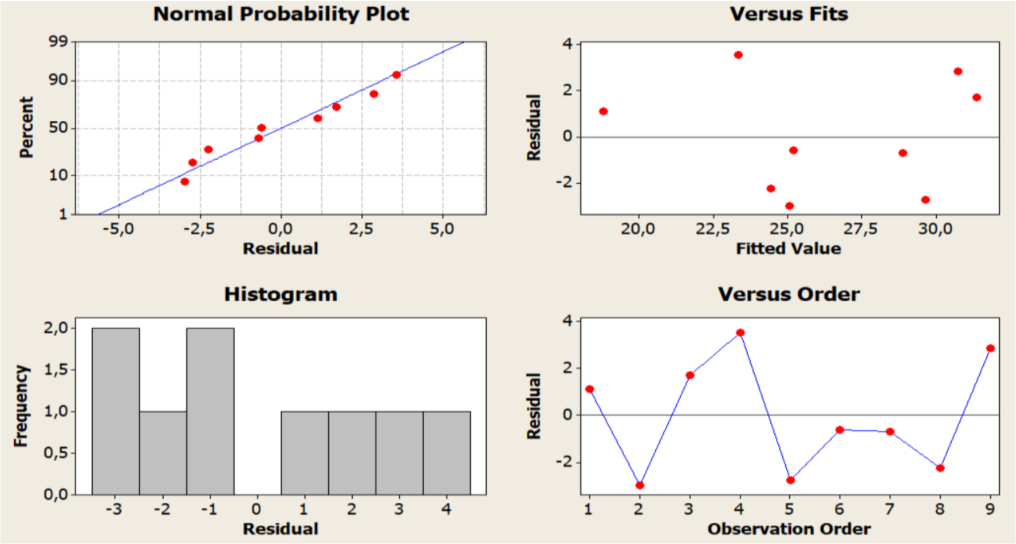
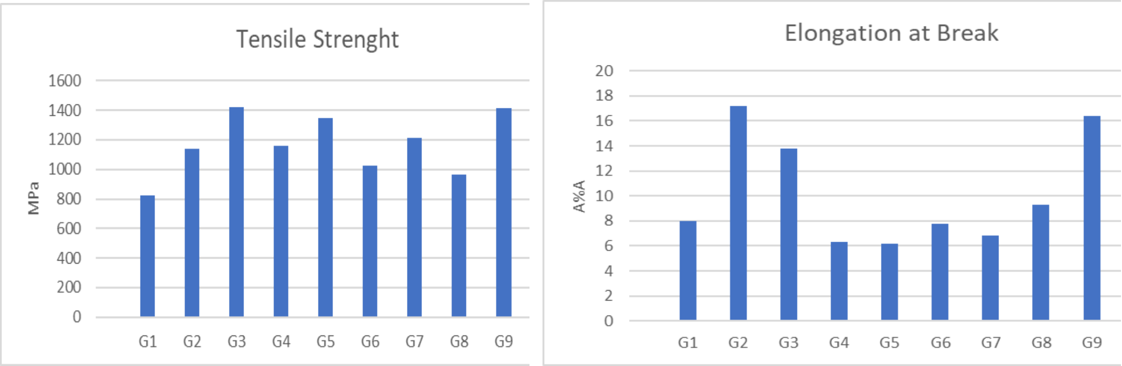


Figure 5: Graphic representation for elongation mechanical strength

Table 5: Mechanical strength

Specimen	Thickness of layer	Filling degree	Settlement angle	Breaking elongation	Strength [Mpa]
G1	0.14	30	0	8.0	19.9
G2	0.14	60	45	17.2	22.1
G3	0.14	90	90	13.8	33.1
G4	0.19	30	45	6.3	26.9
G5	0.19	60	90	6.2	26.9
G6	0.19	90	0	7.8	24.6
G7	0.29	30	90	6.8	28.2
G8	0.29	60	0	9.3	22.2
G9	0.29	90	45	16.4	33.6

The graphical representation of the two characteristics is presented in the next diagrams, figure 6.



a) b)

Figure 6: Diagrams for a) tensile strength, b) breaking elongation

4. CONCLUSIONS

Making parts with complex shapes involves depositing the layers of material in different configurations in terms of orientation to the horizontal plane and with different parameters established depending on the quality of the part or the desired productivity.

By varying the conditions for the achievement of the tests according to a statistical plan and the tensile test, the following conclusions were highlighted:

- The mechanical characteristics, the tensile strength and the elongation at break are strongly influenced by the printing parameters and the orientation of the specimens with respect to the horizontal plane. The tensile strength determined on test parts varies by up to 40% (G9/G1) and the elongation at break by up to 64% (G2/G5) between extreme values.
- Compared to the standard characteristics of the material, a decrease of up to 35% of the tensile strength and up to 44% of the elongation on break is observed.
- If it is required to make parts with certain mechanical characteristics we must take into account the variation of the mechanical characteristics according to the orientation of the sections of the piece and choose filaments from materials with higher characteristics or properly size the sections of the piece.
- The average value of the tensile strength is 26.4MPa, 20% lower than the standard value of the filament, and the average value of the elongation, of 10.2% is close to the standard value.
- There is also a variation of the dimensions of the specimen which are 1,5% larger than the projected ones.
- The residuals "bounce randomly" around the 0 line. This suggests that the assumption that the relationship is linear is reasonable.
- Plotting the residuals against the order in which the data was collected provides insight as to whether or not the observations can be considered independent. The plot shows no trend, then the error terms are considered independent and the regression assumption satisfied.
- The histogram we can considered symmetrical for elongation. That regression model is good.
- The histogram it’s still a bit asymmetrical for mechanical strength.

ACKNOWLEDGEMENTS

This paper is developed in the context of the project “ Researches regarding the optimization of CAD methods for the development of additive manufacturing in the automotive industry”, no. 5, financed by University of Pitesti.

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