A Study on the Influence of FDM Parameters on the Compressive Behavior of ASA Parts

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ABSTRACT

The article presents the results of the study on the influence of FDM 3D printing parameters on the compressive behavior of test specimens made of ASA. In this context, 45 ASA test specimens, made by FDM on the Anycubic 4 Max Pro 2.0 printer, with height of the layer applied in one pass L_h equal to 0.10, 0.15, and 0.20 mm and filling percentage I_d equal to 50, 75, and 100%, were compressive tested on a Barrus White 20 kN universal testing machine. The two considered variable parameters influence the compression resistance of the ASA parts, with the influence of I_d being greater by 96.89% compared to the influence of L_h. It was measured that by increasing the filling percentage from 50% to 75%, the compressive strength increases by 38.10 – 39.31%, and by increasing the filling percentage from 75% to 100%, the compressive strength increases by 27.74 – 30.82%.

Keywords-FDM parameters; compressive stress; experimental test; optimization, ASA

I. INTRODUCTION

Additive manufacturing technologies stand out worldwide due to the many advantages they have compared to conventional manufacturing technologies (formative and subtractive) [1-7]. Some of the advantages of additive manufacturing technologies are reduced material losses, manufacturing of complex geometries without additional basing and fixing elements, simplicity in use, and low operating costs [8-17]. One of the most widely used additive manufacturing technologies is Fused Deposition Modeling (FDM), by means of which parts are made by adding successive layers of filament from the melted plastic mass [18-23]. For the efficient operation of the 3D printer and to maximize the mechanical characteristics of the 3D printed parts by thermoplastic extrusion (FDM), it is necessary to optimize the process parameters [9, 10, 15]. In [10], optimization of FDM parameters was conducted to improve the mechanical characteristics of parts made of ABS. The FDM parameters used to manufacture the specimens were: extrusion multiplier - M_e (0.85/0.93/1), extrusion temperature - T_e (220/230/240 °C), and the height of the deposited layer in one pass L_h (0.10/0.20/0.30 mm). The findings showed that the extrusion multiplier significantly influences the fracture strength and porosity of FDM-fabricated ABS specimens. After optimizing the FDM parameters, porosity was increased by 7.6%, tensile strength by 7.4%, and compressive strength by 8.38%. For the manufacture of tensile and compression specimens from ABS, the optimal FDM parameters were: M_e = 1; T_e = 240 °C; L_h = 0.10 mm.

Authors in [11] present the results of a study on the influence of the height of the layer deposited in one pass and the filling percentage, on the compressive strength of PETG samples. The considered parameters (L_h and I_d) influence the compressive strength of the PETG specimens manufactured by FDM, with the filling percentage (I_d) having the most influence. Authors in [12] present the effects of the printing parameters of FDM, the height of the deposited layer in one pass L_h, filling percentage I_d, and printing speed P_s on the mechanical properties of the samples made of PLA. The results of the study show that the breaking strength is significantly influenced by the height of the layer deposited in one pass (L_h), and the compressive strength is significantly influenced by the filling percentage (I_d).

Additive manufacturing technologies are of interest among researchers, but still there are topics that have not yet been addressed. In order to complete the existing gaps in the literature, we aim through this study to determine the influence of the FDM parameters L_h (layer height deposited in one pass) and I_d (filling percentage), on the compression behavior of the samples made of ASA in order to find the optimal parameters for obtaining the best mechanical characteristics. The specimens were manufactured and tested in compression by the authors in the laboratories of the Faculty of Mechanical and Electrical Engineering of the Petroleum – Gas University of Ploiesti.

II. DETERMINATION OF THE INFLUENCE OF FDM PARAMETERS ON THE COMPRESSIVE BEHAVIOR OF PARTS MADE OF ASA

A. *Methodology*

Figure 1 presents the steps of the work methodology to study the influence of FDM parameters on the compressive behaviour of ASA parts.

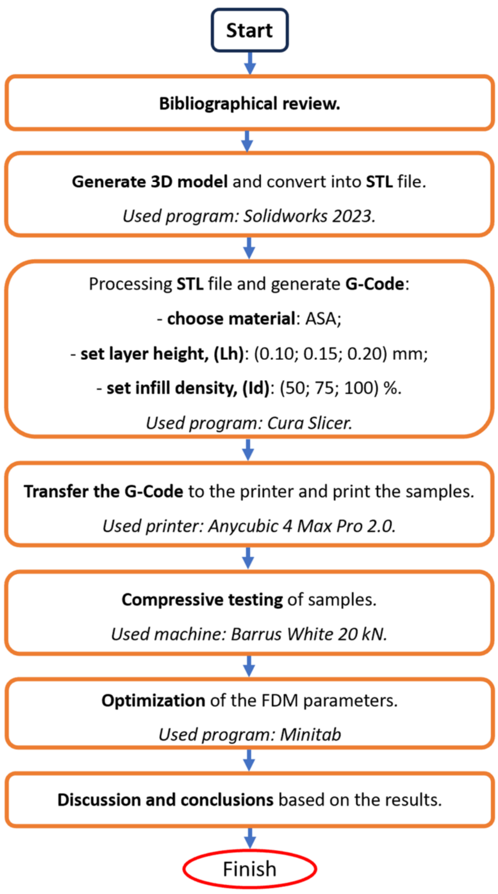

Fig. 1. Steps of the work methodology.

Using Solidworks 2023 software, [24] we produced the 2D sketch and 3D model of the specimen for compression, converting it from SLD to STL format (Figure 2). The file in STL format, corresponding to the specimen shown in Figure 2, was processed in the Cura Slicer program, in which we set the ASA material, entered the parameters shown in Table I and generated the G-Code file. The G-Code file was then transferred to the Anycubic 4 Max Pro 2.0 3D printer, on which the 45 compression specimens shown in Figure 4 were manufactured using Everfill 1.75 mm ASA filament, [11, 25].

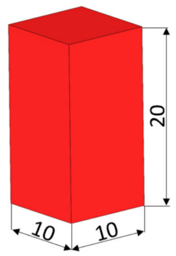

Fig. 2. Specimen for compressive testing in Solidworks 2022.

TABLE I. FDM PRINTING PARAMETERS FOR ASA COMPRESSION SPECIMENS.

Constant parameters	Variable parameters				Material
	Height of the layer applied in one pass	Filling percentage			ASA
	L_h	I_d			-
Part orientation (X-Y) Temperature of the extruder E_t = 250 °C Temperature of the platform B_t = 70 °C Printing speed P_s = 30 mm/s Filling pattern (I_p) = Grid	(mm)	(%)			(parts)
	0.10	50	75	100	45
	0.15				
	0.20				

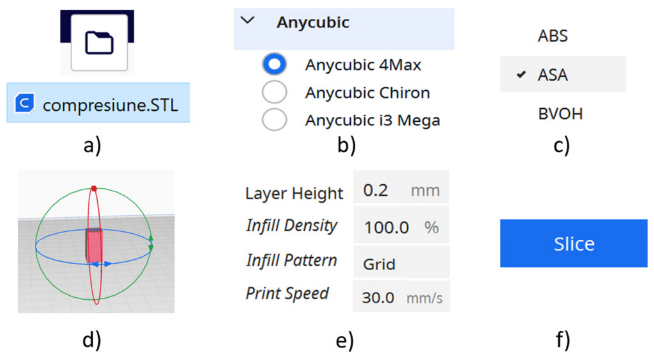

Fig. 3. Processing the STL file and generating G-Code file in Cura Slicer: (a) opening STL file; (b) choosing 3D printer - Anycubic 4 Max; (c) choosing material - ASA; (d) positioning the part on the 3D printer platform; (e) setting FDM parameters; (f) G-Code file generation.

The 45 specimens presented in Figure 4, manufactured by FDM from ASA on the Anycubic 4 Max Pro 2.0 printer using the parameters in Table I, were compression tested on a Barrus White 20 kN universal testing machine (Figure 5), according to ISO 604:2002, using a speed of 10 mm/min [26].

TABLE II. SPECIFICATIONS OF 3D PRINTER ANYCUBIC 4 MAX PRO 2.0, USED FOR FDM MANUFACTURING OF ASA SPECIMENS FOR COMPRESSION [25, 27

Anycubic 4 Max Pro 2.0 – technical specifications	
Printing volume	270×205×205 mm
Printing resolution	0.05 – 0.30 mm
Positioning accuracy	X = 0.0125 mm
	Y = 0.0125 mm
	Z = 0.002 mm
Nozzle diameter	0.4 mm
Printer speed	max. 80 mm/s
Supported materials	ABS/TPU/PLA/ASA/PETG
Dimensions	454x466x410 mm
Weight	18.5 kg

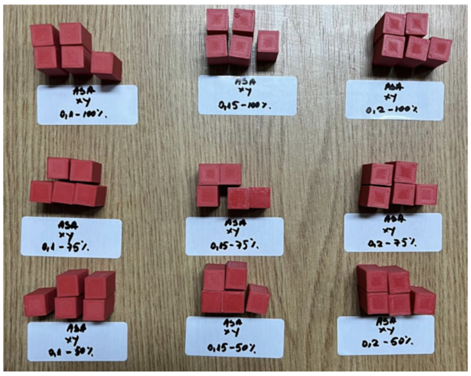

Fig. 4. Compression specimens made of ASA by FDM.

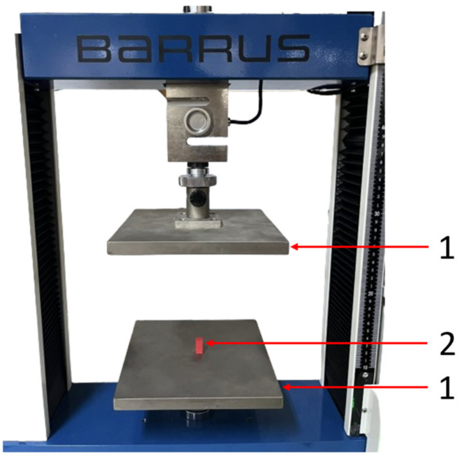

Fig. 5. Compression test on Barrus White 20 kN machine: 1 - machine platens; 2 - specimen before compression test.

B. Results and Discussion

The results of the compression tests on the 45 specimens are summariζed in Tables III-V and plotted in Figures 6 - 8.

TABLE III. RESULTS OF COMPRESSION TESTS FOR ASA WALLS WITH L_h = 0.10 mm

Infill, I_d, (%)	Compressive stress, C_s, (MPa)					
	Sample number					
	1	2	3	4	5	Average
50	15.96	15.61	16.80	17.66	16.07	16.42
75	28.57	28.01	28.76	28.97	28.60	28.58
100	38.55	37.87	38.68	36.53	38.58	38.04

TABLE IV. RESULTS OF COMPRESSION TESTS FOR ASA WALLS WITH L_h = 0.15 mm

Infill, I_d, (%)	Compressive stress, C_s, (MPa)					
	Sample number					
	1	2	3	4	5	Average
50	15.82	14.01	14.60	15.22	15.57	15.04
75	25.39	27.49	22.63	27.53	26.23	25.85
100	34.13	36.17	32.70	35.56	33.57	34.43

TABLE V. RESULTS OF COMPRESSION TESTS FOR ASA WALLS WITH L_h = 0.20 mm

Infill, I_d, (%)	Compressive stress, C_s, (MPa)					
	Sample number					
	1	2	3	4	5	Average
50	16.24	16.76	16.26	17.06	15.93	16.45
75	28.90	28.64	29.11	27.72	28.34	28.54
100	37.95	37.43	37.62	37.83	37.58	37.68

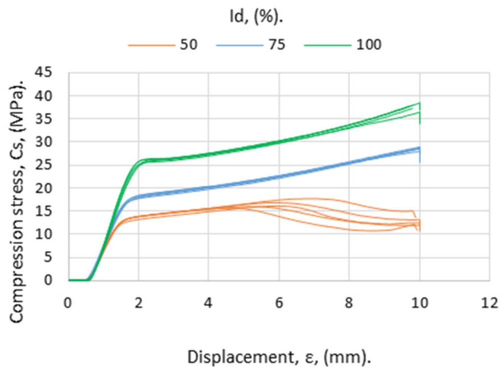

Fig. 6. Average compressive strength values for ASA specimens with L_h = 0.10 mm and I_d = 50/75/100%.

An analysis of Figure 6 shows that the compressive strength (C_s) increases along with the filling percentage (I_d). The best results, 36.53 MPa - 38.68 MPa, were obtained for specimens having filling percentage I_d = 100%. By increasing the filling percentage from 50% to 75%, the compressive strength increased by 63.98% - 79.42%, and by increasing the filling percentage from 75% to 100% the compressive strength increased by 30.40% - 33.52%.

Analysing Figure 7, it is observed that the compressive strength (C_s) is decisively influenced by the filling percentage (I_d). The best results, 32.70 MPa - 36.17 MPa, were obtained for specimens having filling percentage I_d = 100%. By increasing the filling percentage from 50% to 75%, the compressive strength increased by 61.55% - 74.02%, whereas by increasing the filling percentage from 75% to 100% the compressive strength increased by 31.35% - 44.54%.

From Figure 8, it can be observed that C_s is strongly influenced by I_d. The best results, 37.43 MPa – 37.95 MPa, were obtained for specimens with filling percentage I_d = 100%. By increasing the filling percentage from 50% to 75% the compressive strength increased by 70.66% - 74.01%, while by increasing the filling percentage from 75% to 100% the compressive strength increased by 30.38% - 35.03%.

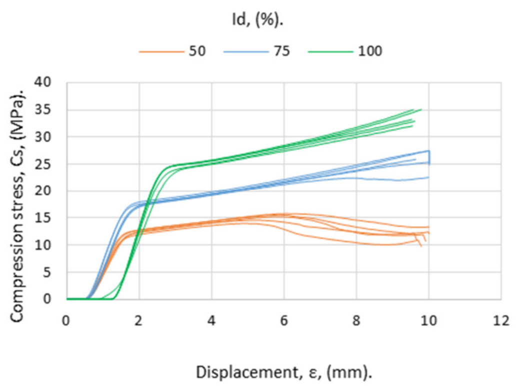

Fig. 7. Average compressive strength values for ASA specimens with L_h = 0.15 mm and I_d = 50/75/100%.

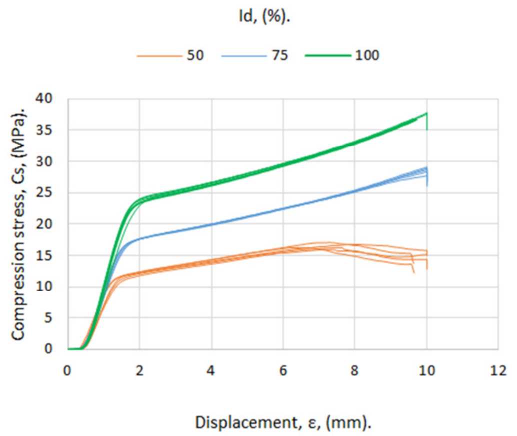

Fig. 8. Average compressive strength values for ASA specimens with L_h = 0.20 mm and I_d = 50/75/100%.

Based on the average compressive strength results (see Tables III - V), we plotted the graph shown in Figure 9 in Minitab software illustrating how the variable parameters L_h and I_d of the FDM influence the C_s of the ASA specimens.

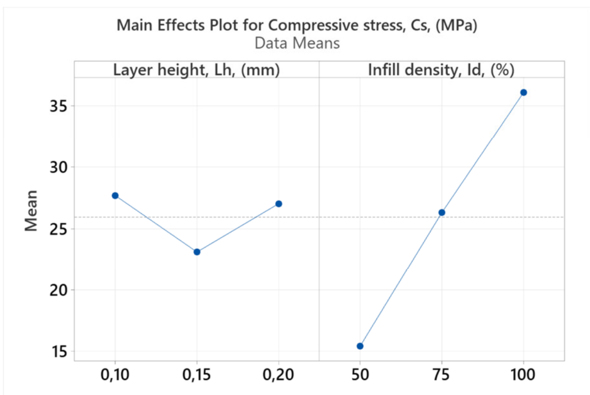

Fig. 9. Fig. 9. Influence of variable FDM parameters L_h and I_d on the compressive strengths of ASA specimens.

According to the chart in Figure 9, out of the two variable parameters, the filling percentage has a major impact on the compressive strength of the ASA specimens. The second parameter, L_h, has an insignificant influence. The same conclusions can be drawn from an analysis of the Pareto chart in Figure 10. Figure 10 shows that the filling percentage (B = I_d) has a strong influence on the compressive strength values obtained from the compression tests of ASA specimens, 96.89% higher than the influence of the height of the layer applied in one pass (A = L_h).

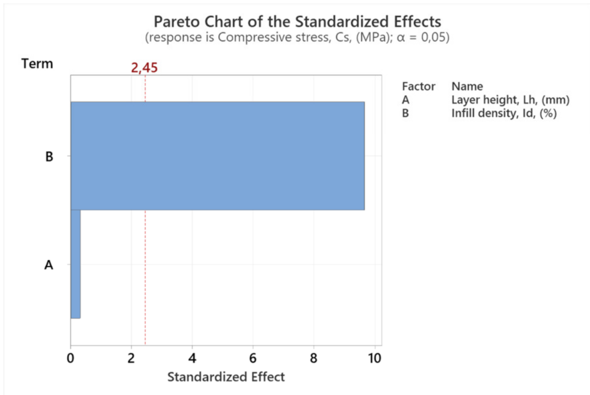

Fig. 10. Pareto plot on the influence of the variable parameters A = L_h and B = I_d of FDM on the compressive strengths of ASA specimens.

Using Minitab software and the FDM parameters in Table I, L_h = 0.10/0.15/0.20 mm and I_d = 50/75/100 %, the contour graph of compressive strengths for ASA specimens was plotted (Figure 11). From Figure 11, it can be concluded how the variable parameters L_h and I_d of the FDM influence the compressive strengths of the ASA specimens. It can be concluded that increasing the filling percentage (I_d) has a significant influence on the increase of the compressive strengths of specimens made of ASA.

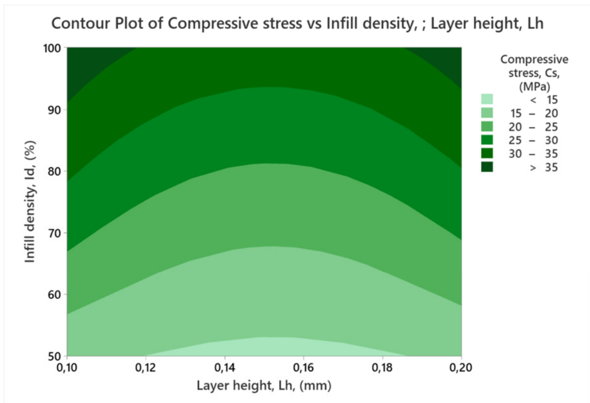

Fig. 11. Contour plot of compressive strengths for ASA specimens manufactured by FDM.

III. CONCLUSIONS

The paper presents the results of a study on the influence of FDM printing parameters on the compressive behavior of specimens made of ASA. Using the ASA filament with a diameter of 1.75 mm, Everfill brand, 45 specimens (Figure 5) were produced on the Anycubic 4 Max Pro 2.0 printer, with a layer height of L_h = 0.10/0.15/0.20 mm and a filling percentage of I_d = 50/75/100%, and were subsequently compression tested on a Barrus White 20 kN universal testing machine. The two considered variable parameters, L_h and Id influence the compression strength (C_s) of the ASA parts, with the I_d being the one with significantly higher influence, 96.89% higher than that of L_h. This conclusion is in accordance with the findings in [11, 12, 28]. Raising the filling percentage (I_d) increases the compressive strength of ASA FDM specimens (see Figure 10). The maximum value of compressive strength (38.68 MPa) was recorded for specimens with L_h = 0.10 mm and I_d = 100%. The minimum value of compressive strength (14.01 MPa) was recorded of specimens with L_h = 0.15 mm and I_d = 50%.

Comparing the results obtained in this study with those obtained in [11], it is found that the compressive strength (C_s) of ASA specimens is higher by 20.27% – 23.94% compared to the compressive strength (C_s) of PETG specimens. Comparing the results obtained of this work with those obtained in [28], the compressive strength of the ASA specimens is lower by 18.97 – 37.01% compared to the compressive strength (C_s) of the ABS specimens and lower by 42.27 – 45.83% compared to that of PLA specimens.

Regarding future work, we aim to extrapolate the current study to materials from recycled PETG and ASA.

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