A Study on the Optimization of FDM Parameters for the Manufacturing of Compression Specimens from recycled ASA in the Context of the Transition to the Circular Economy

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ABSTRACT

The present study investigates the optimization of the FDM parameters, that is, the height of the deposited layer in one pass (L_h) and the filling percentage (I_d), for the manufacture of compression specimens from recycled ASA (rASA) in the context of transitioning to the circular economy. The Anycubic 4Max Pro 2.0 3D printer was utilized, where compression specimens were additively manufactured from rASA 45 using the following variable parameters: L_h = 0.10 mm, 0.15 mm, and 0.20 mm, and I_d = 50%, 75%, and 100%. All compression specimens were tested on the Barrus White 20 kN universal testing machine. It was found that the Compressive strength (Cs) is influenced by the two considered variable parameters of the Fused Deposition Modeling (FDM), L_h and I_d, but the overwhelmingly influencing parameter is I_d. According to the results of the FDM parameter optimization for the manufacture of compression specimens from rASA, L_h = 0.10 mm and I_d = 100%.

Keywords-FDM parameters; circular economy; recycled ASA; compressive strength; optimization

I. INTRODUCTION

The accelerated increase in the demand and supply of plastic materials has generated a new type of pollution, namely plastic pollution, which has a socio-economic impact [1-4]. At a global level, sustainable manufacturing strategies and additive manufacturing technologies are being implemented, promoting sustainable development [5-10]. Additive manufacturing technologies have revolutionized the way the parts are obtained, since they have introduced a new manufacturing model that stands out by adding successive layers of material according to the profiles of the 3D model [6-10]. The major advantages of additive manufacturing technologies involve the easy manufacturing of parts with complex geometries, low material and energy consumption, and sustainability. FDM is one of the most popular additive manufacturing technologies due to its equipment accessibility, diversified range of thermoplastic materials, and simplicity of use [11]. Given the dynamics of the production processes and plastic consumption, transitioning from a linear economy model to a circular economy production and consumption model has become essential. By implementing the latter in the field of additive manufacturing technologies through the extrusion of plastic masses, remarkable results can be obtained, such as increasing plastic materials' lifespan, reducing the amount of platic waste, and decreasing the production cost [12-16]. In this context, the specialized literature presents a series of research regarding the implementation of the production and consumption model based on the circular economy. In the field of additive manufacturing technologies through thermoplastic extrusion, the studies that refer to Acrylonitrile Styrene Acrylate (ASA) are limited. Authors in [17] presented a synthesis based on 88 studies on the technical performance and durability of 3D printing filaments made from recycled plastic. The findings demonstrated that the type of plastic and additives which were used play a key role in the performance, cost-effectiveness, and durability of the parts made from that filament.

Authors in [18] examined the impact of recycled Acrylonitrile Butadiene Styrene (ABS) on the mechanical behavior of the parts produced through additive manufacturing using FDM. It was found that in the third round of ABD FDMed recycling, the tensile strength decreased by 10% and the elongation at break decreased by 25%, while significant variations in porosity were observed, 9% – 22%. Given the lack of knowledge, identified in the specialized literature, this study's objective is to investigate and optimize the mechanical compression behavior of the FDM specimens, additively manufactured from rASA, by varying the height of the layer deposited in one pass (L_h) and the filling percentage (I_d) for the concept of production and consumption based on the circular economy to be integrated with additive technologies. The specimens were manufactured and tested under compression in the laboratories of the Faculty of Mechanical and Electrical Engineering at the Petroleum–Gas University of Ploiești.

II. DETERMINATION OF THE INFLUENCE OF THE FDM PARAMETERS ON THE COMPRESSION BEHAVIOR OF SAMPLES MADE FROM rASA

A. *Work Methodology*

Figure 1 shows the deployed methodology's stages concerning the experimental study on the FDM process parameter optimization for the manufacture of rASA compression specimens, in respect of the transition to the circular economy.

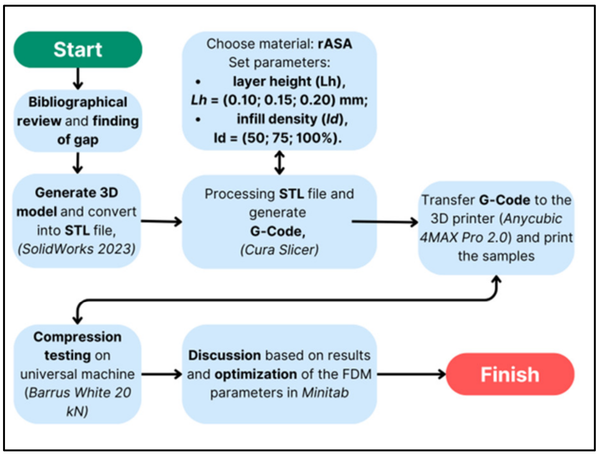

Fig. 1. The stages of the work/this work's methodology regarding the influence of the FDM parameters on the Cs of the samples made of rASA.

The digital model of the compression specimen was created using SolidWorks 2023. Figure 2 illustrates the compression specimen as modeled in SolidWorks 2023, according to [19].

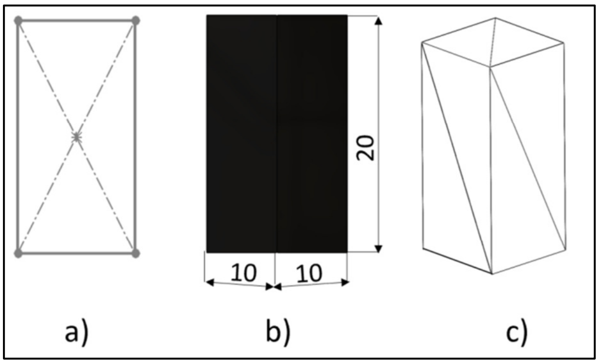

Fig. 2. Compression sample in Solidworks 2023: (a) 2D sketch, (b) 3D model, (c) STL model.

TABLE I. FDM PRINTING PARAMETERS FOR RASA COMPRESSION SAMPLES [6]

Constant parameters	Variable parameters				Material
	Height of the layer applied in one pass, L_h	Infill density, I_d			rASA
	(mm)	(%)			(pieces)
Part orientation: XY	0.10	50	75	100	45
Temperature of the extruder, (E_t) = 250 °C	0.15				
Temperature of the platform, (B_t) = 70 °C Printing speed, (P_s) = 30 mm/s Filling percentage, (I_p) = Grid	0.20				

The STL format file was processed in the Cura Slicer software, where utilizing the 3D printing parameters, displayed in Table I [6], the G-Code files were generated for the rASA specimens' fabrication. Figure 3 depicts the compression specimens in Cura Slicer [20].

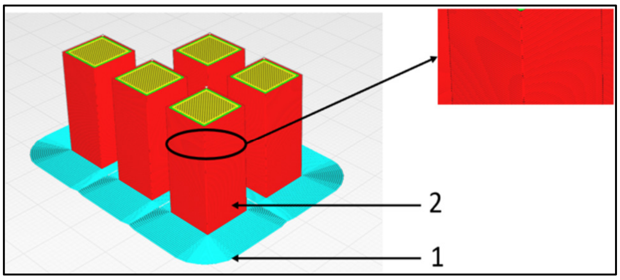

Fig. 3. Samples for compression testing in Cura Slicer: 1 – sample holder, 2 – sample made layer by layer.

Using the Anycubic 4 Max Pro 2.0 3D printer, 45 compression specimens were manufactured deploying ASA filament with 100% recycled Everfil brand material, as portrayed in Figure 4.

All 45 specimens, manufactured via FDM using 100% recycled rASA material, were tested in/under compression on a Barrus White 20 kN universal testing machine. The compression tests followed the ISO 604:2002 standard and were conducted at a speed of 10 mm/min [21].

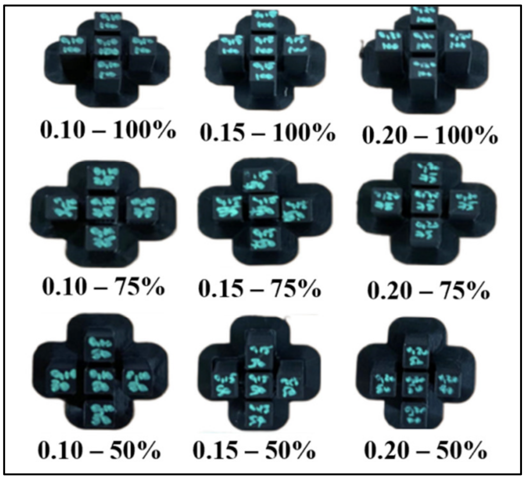

Fig. 4. The compression rASA test samples manufactured from rASA by FDM.

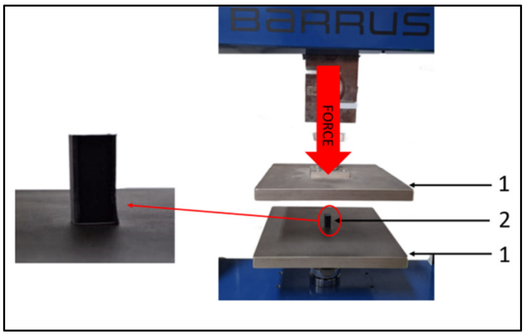

Fig. 5. Compression test on the Barrus White 20 kN universal testing machine: 1, 2 – plates, 2 – sample.

B. Results and Discussion

The compression test results of the tested samples are graphically represented in Figures 6-8.

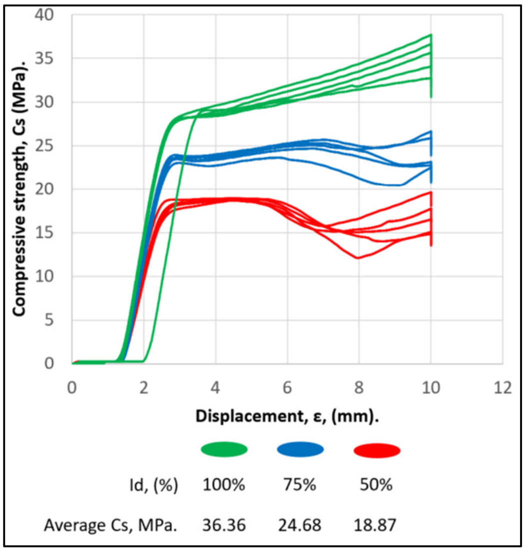

Fig. 6. The average values of the Cs for the rASA samples with L_h = 0.10 mm and I_d = 50%, 75%, and 100%.

Figure 6 illustrates the influence of the I_d on the Cs of the rASA samples. The maximum Cs values, 32.74 MPa – 37.71 MPa, were obtained for the compression samples with I_d = 100%. Decreasing the value of I_d from 100% to 75% led to a decrease in Cs of 38.52% – 41.57%, and by decreasing the filling percentage from 75% to 50%, Cs decreased by 26.33% – 35.0%. Figure 7 demonstrates that the I_d plays a decisive role in the Cs values of the rASA samples. The highest Cs values, 33.98 MPa-35.45 MPa, were obtained for the samples with I_d = 100%. The decrease in I_d from 100% to 75% led to a decrease in the Cs in the range of 29.47% – 33.36%, and by decreasing I_d from 75% to 50%, the Cs decreased by 48.08% – 50.09%.

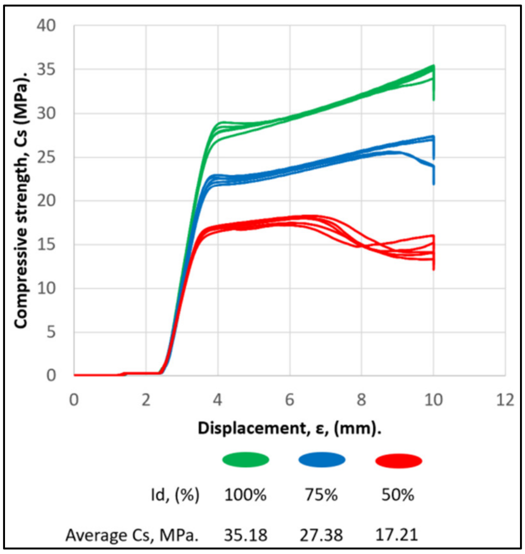

Fig. 7. The average values of the Cs for the rASA samples with L_h = 0.15 mm and I_d = 50%, 75%, and100%.

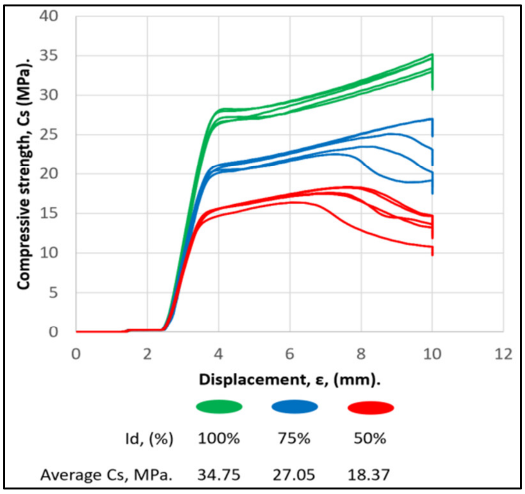

Fig. 8. The average values of the Cs for the rASA samples with L_h = 0.20 mm and I_d = 50%, 75%, and 100%.

Figure 8 exhibits how I_d decisively influences the Cs of the rASA samples. The maximum Cs values, 33.03 MPa – 35.21 MPa, were obtained for the samples with the filling percentage I_d = 100%. The decrease in the filling percentage from 100% to

75% determined the decrease in the Cs by 30.19% – 46.47%, and the decrease in I_d from 75% to 50% generated the decrease in the Cs by 37.55% – 47.26%. Using the Minitab 19 software, the average Cs values, and variable parameters L_h = 0.10 mm, 0.15 mm, 0.20 mm, and I_d = 50%, 75%, 100%, were obtained, and the graphs presented in Figures 9-12 were plotted [22]. Figure 9 shows the influence of the two considered variable parameters, L_h and I_d, on the Cs of the rASA samples.

In Figure 9, the influence of the variable FDM parameters, L_h and I_d, on the Cs of the rASA samples is analyzed. Of the two parameters considered, I_d is the one that significantly impacts the Cs of the rASA specimens.

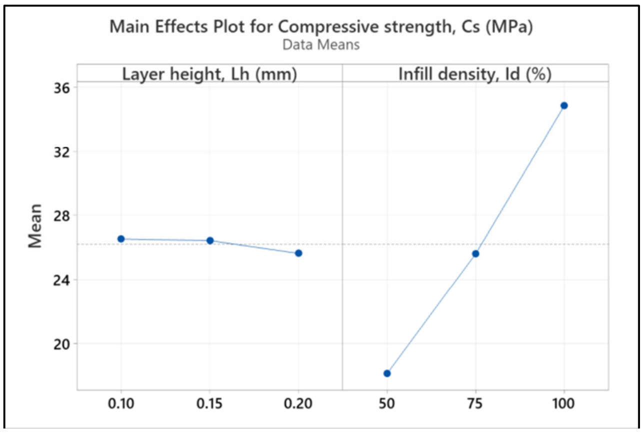

Fig. 9. Influence of the variable FDM parameters, L_h and I_d, on the Cs of the rASA specimens.

From the Pareto graph in Figure 10, it can be deduced that B = I_d) is the FDM parameter that decisively impacts the Cs of the rASA samples. The influence value of factor A = L_h is 1.42959 units, and the value of factor B = I_d is 26.6704 units. By comparing the influence of the 2 factors, A and B, it was noticed that the factor B has a greater influence by 1778. 17% on the Cs of the rASA samples.

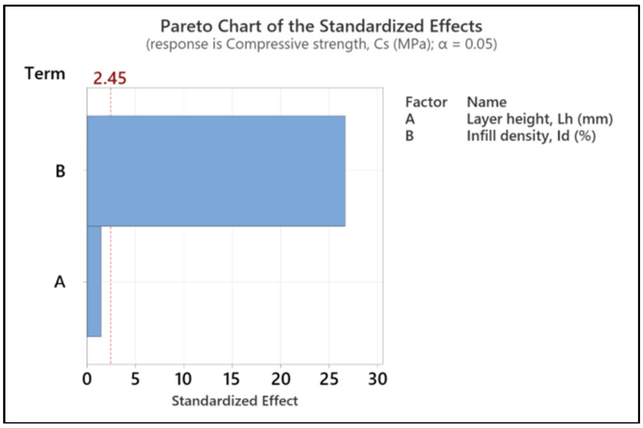

Fig. 10. A = L_h and B = I_d of the FDM influence on the Cs of the rASA specimens.

Analyzing the graph portrayed in Figure 11, it is noted that the percentage of filling overwhelmingly influences the Cs of the rASA specimens. In Figure 12, the FDM parameters were optimized to maximize the Cs values of the rASA samples [22].

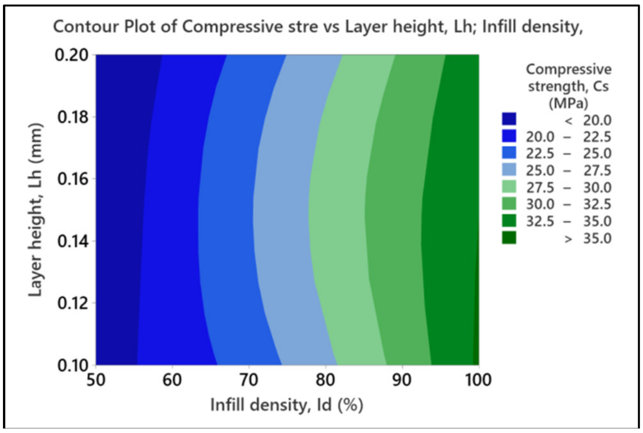

Fig. 11. Contour plot of the Cs values for the rASA specimens manufactured by FDM.

Examining the graphs illustrated in Figure 12, it can be concluded that the I_d is the parameter that decisively influences the Cs results of the rASA samples. The optimal parameters for the manufacture of compression specimens from rASA are L_h = 0.10 mm and I_d = 100%.

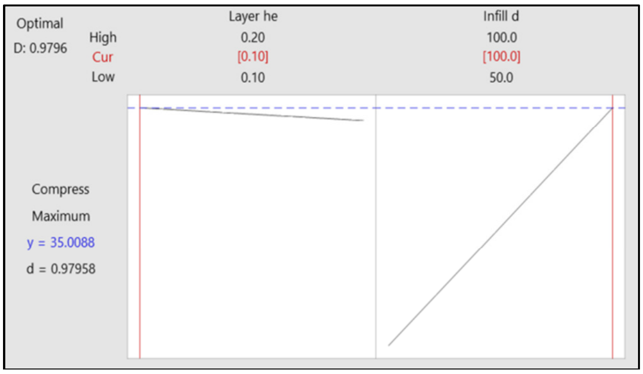

Fig. 12. Optimization graphs of the FDM parameters (L_h and I_d) for maximizing the Cs of the rASA specimens.

III. CONCLUSIONS

This study explores the optimization of the FDM parameters, height of the layer deposited in one pass L_h and filling density I_d, for the manufacture of compression specimens from recycled ASA (rASA) in light of transitioning to the circular economy. Utilizing the Anycubic 4 Max Pro 2.0 3D printer, 45 compression specimens were additively manufactured employing the ASA Everfil filament with 100% recycled material. Figure 5 shows the Barrus White 20 kN universal testing machine was used to test all 45 specimens in/under compression according to ISO 604:2002 at a speed of 10 mm/min. It was found that the variable parameters considered, L_h and I_d, do affect the Compressive strength (Cs) of the additively manufactured rASA samples. Among these, I_d is the parameter that decisively influences the Cs, as shown in

Figures 9-11, which is also highlighted in the specialized literature. The maximum Cs of 34.80 MPa was achieved by the additively manufactured sample with parameters L_h = 0.10 mm and I_d = 100%. In contrast, the minimum Cs of 14.38 MPa was recorded for the sample with parameters L_h = 0.10 mm and I_d = 50%. Minitab 19 software was implemented to optimize the FDM parameters in order to maximize the Cs values. The optimal parameters identified were L_h = 0.10 mm and I_d = 100%. Comparing the results obtained in this paper with those attained in [6] for virgin ASA, the following conclusions can be drawn:

- Average of the 45 results for rASA: 25.43 MPa.
- Average of the 45 results for ASA: 26.78 MPa.
- The average of the results for rASA is 5.04% lower compared to the average of the results obtained for ASA.
- The minimum Cs value for rASA is 2.57% higher than the minimum Cs value for ASA.
- The maximum Cs value for rASA is 11.13% lower than the maximum Cs value for ASA.

This study constitutes a preliminary step in the investigation of the transition to a circular economy in the field of additive manufacturing technologies through plastic extrusion. The results of this study, as well as the results of [7, 17, 18], demonstrate that the use of recycled plastics in the field of additive manufacturing technologies represents a feasible solution to the management of plastic waste. The use of the production and consumption model based on a circular economy becomes a worth considering opportunity due to its numerous benefits: reduction of the amount of waste, reduction of the production costs, and sustainability. The authors proposed that the study be extrapolated on other types of materials, namely rASA, and rPETG, with different recycled material percentages, and also on other types of mechanical tests.

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