A Study on the Influence of FDM Parameters on the Tensile Behavior of Samples made of ASA

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ABSTRACT

This paper presents the results of the study on the influence of FDM printing parameters on the tensile behavior of samples made of ASA. To perform the study, 27 tensile samples were made of ASA on Anycubic 4 Max 2.0 3D printer using as the height of the single-pass layer L_h = 0.10/0.15/0.20 mm and as filling percentage I_d = 50/75/100%. The results obtained from tensile testing of the samples on the universal testing machine demonstrate the way in which the FDM parameters influence the tensile strength, the percentage elongation at break, and the elastic modulus. The parameter that significantly influences the tensile characteristics of ASA samples made using FDM is the filling percentage (I_d).

Keywords-FDM parameters; ASA; tensile strength; elongation percentage; modulus of elasticity

I. INTRODUCTION

Additive manufacturing technologies are developing rapidly and have been adopted in many industrial sectors [1-6]. Thermoplastic extrusion (FDM) is one of the most popular additive manufacturing technologies due to its ease of use, wide range of equipment and materials, and low operating cost [7-14]. The main disadvantages of thermoplastic extrusion are its low printing speed, the quality and the weak mechanical characteristics of the parts, [15-17]. Therefore, the determination of the optimal parameters for increasing productivity and obtaining the maximum quality and mechanical characteristics is of utmost importance. Although there are studies on the influence of FDM parameters on the mechanical and quality characteristics of the materials used in this additive technology, in practice there is still a very wide range of problems that have not been explored yet.

Authors in [1] present the results of a study on the influence of the filling pattern (triangular and rectangular) on the breaking strength of ABS samples made by using FDM. The triangular filling pattern resulted in much better tensile behavior of ABS samples. In [2], the influence of FDM 3D printing parameters (L_h = height of the deposited layer at one pass, O_p = part orientation) on the tensile behavior of specimens made of ABS and Nylon 6 is examined. The samples were printed using L_h = 0.10/0.20/0.30/0.40 mm and O_p = -45/0/45/90°. The best results of the breaking strengths were obtained for the specimens printed with L_h = 0.10 mm and O_p = 90°. In [3], the influence of L_h and filling percentage I_d on the maximum breaking strength, elongation percentage at break, and elastic modulus of tensile samples made of PETG, were studied. The FDM parameters considered (L_h and I_d) influence the mechanical characteristics of the PETG out of which the tensile samples are made. The filling percentage (I_d) is the parameter that decisively impacts the maximum breaking strength and the elongation percentage at break of PETG samples, while the height of the single-pass layer is the parameter with the greatest influence on the elastic modulus of PETG.

In this paper, a study on the influence of the height of the single-pass layer (L_h) and the filling percentage (I_d) on the tensile behavior of ASA samples is presented. The novelty of this study consists in optimizing the FDM parameters to obtain the best results in terms of the tensile behavior of ASA samples. The ASA samples have been produced and tested in the laboratories of the Faculty of Mechanical and Electrical Engineering of the University of Oil and Gas in Ploiesti.

II. DETERMINING THE INFLUENCE OF FDM PARAMETERS ON THE TENSILE BEHAVIOR OF ASA SAMPLES

A. Methodology

To make the tensile samples, the ASA filament, produced by Everfill, and the Anycubic 4 Max Pro 2.0 3D printer, were used. Figure 1 illustrates the steps of the working methodology for the study on the influence of FDM parameters on the tensile behavior of ASA samples. Solidworks 2023 software was used to design the tensile samples (Figure 2). This software was used to produce the 2D model of the tensile sample and afterwards the 3D model which was then converted into STL format (Figure).

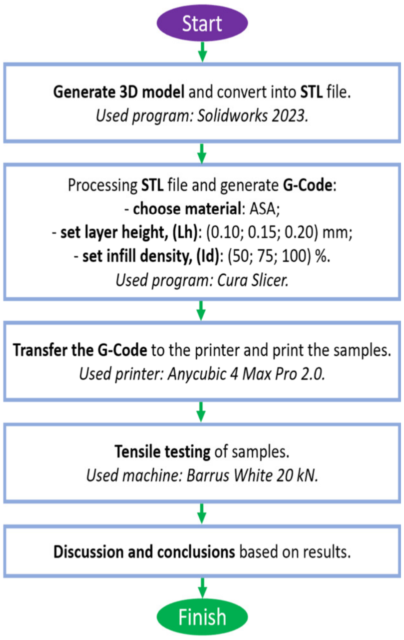

Fig. 1. The steps of the methodology used to investigate the influence of FDM parameters on the tensile behavior of ASA parts.

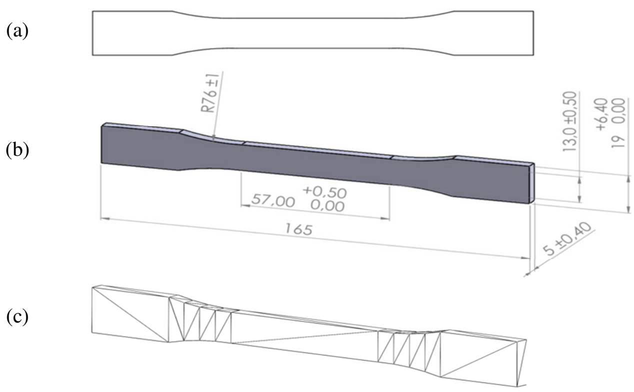

Fig. 2. Tensile test specimen in SolidWorks 2023: (a) 2D model, (b) 3D model, (c) STL model.

The G-Code file was generated using the Cura Slicer software, the STL file of the tensile specimen shown in Figure 2 and the FDM printing parameters shown in Table I, in order to manufacture the tensile samples on the Anycubic 4 Max Pro 2.0 3D printer (Figure 3). The G-Code file was transferred to the Anycubyc 4 Max Pro 2.0 3D printer, on which the 27 tensile samples (Figure 4) were produced using ASA filament (Everfil brand) with a diameter of 1.75 mm through FDM.

TABLE I. FDM PRINTING PARAMETERS FOR TENSILE SPECIMENS

<table>
<tr><th colspan="2" rowspan="3">Constant parameters</th><th colspan="2">Variable parameters</th><th>Material</th></tr>
<tr><th>Hight of the single-pass layer</th><th>Filling percentage</th><th>ASA</th></tr>
<tr><td>L_h</td><td>I_d</td><td>-</td></tr>
<tr><td>Part oriemtation, O_p</td><td>X-Y</td><td>(mm)</td><td>(%)</td><td>(parts)</td></tr>
<tr><td rowspan="3">Temperature of the extruder, E_t</td><td rowspan="3">240 °C</td><td rowspan="3">0.10</td><td>100</td><td rowspan="9">27</td></tr>
<tr><td>75</td></tr>
<tr><td>50</td></tr>
<tr><td rowspan="3">Temperature of the platform, B_t</td><td rowspan="3">90 °C</td><td rowspan="3">0.15</td><td>100</td></tr>
<tr><td>75</td></tr>
<tr><td>50</td></tr>
<tr><td rowspan="2">Printing speed, P_s</td><td rowspan="2">30 mm/s</td><td rowspan="3">0.20</td><td>100</td></tr>
<tr><td>75</td></tr>
<tr><td>Filling pattern, I_p</td><td>Grid</td><td>50</td></tr>
</table>

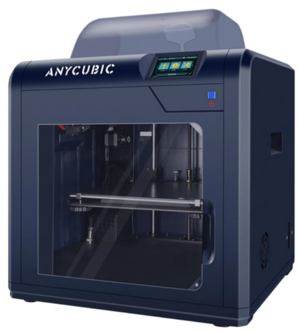

Fig. 3. The 3D printer - Anycubic 4 Max Pro 2.0, used to manufacture of tensile specimens from ASA through FDM.

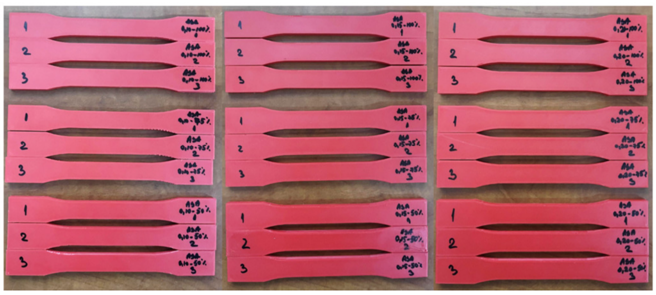

Fig. 4. ASA tensile test specimens manufactured by FDM on the Anycubic 4 Max Pro 2.0 printer.

At a speed of 5 mm/min, according to ASTM D638-14, the 27 ASA samples produced by FDM on the Anycubic 4 Max Pro 2.0 printer (see Fig. 3) were tested for tensile strength on the Barrus White 20 kN universal testing machine illustrated in Figure 5 [18, 19].

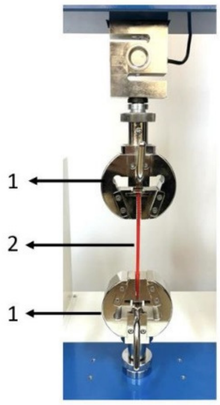

Fig. 5. Tensile test on Barrus White 20 kN machine: 1: grips; 2: specimen.

B. Results and Discussion

After the tensile tests, the following mechanical characteristics were determined: tensile strength, percentage elongation at break, and elastic modulus. Figure 6 presents the 27 ASA specimens after the tensile test.

Fig. 6. ASA specimens after the tensile test.

1) Influence of the FDM Parameters on Tensile Strength

Figure 7 presents the average tensile strength results obtained from the tensile test of the specimens shown in Figure 4, manufactured on the Anycubic 4 Max Pro 2.0 using the FDM printing parameters in Table I.

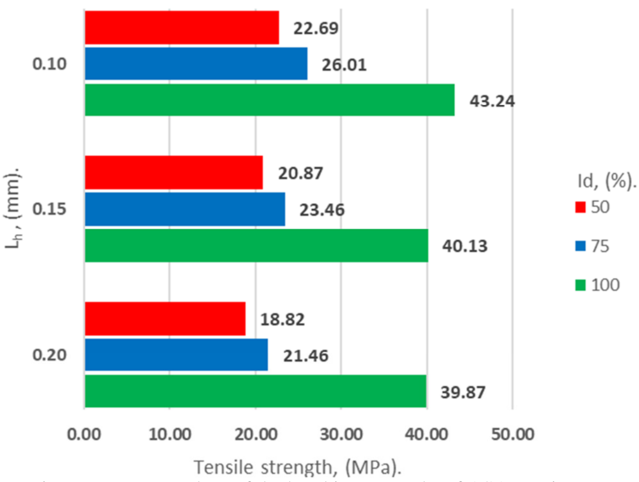

Fig. 7. Mean values of the breaking strengths of ASA specimens.

Analyzing Figure 7, we observe that the highest values of the ASA specimen breaking strengths (39.87 - 43.24 MPa), were obtained for specimens having 100% filling percentage. By decreasing the filling percentage from 100% to 75%, the average values of the breaking strengths decrease by 66.28 - 85.76%, whereas decreasing the filling percentage from 75% to 50% caused the average values of the breaking strengths to fall by 12.38 - 14.62 %. Using Minitab software, the average results of the breaking strengths and the FDM printing parameters from Table I, we plotted the Pareto chart shown in Figure 8. It can be seen that among the two parameters used (A = L_h and B = I_d), the filling percentage (B = I_d) has the most influence on the breaking strength of the specimens made of ASA through FDM.

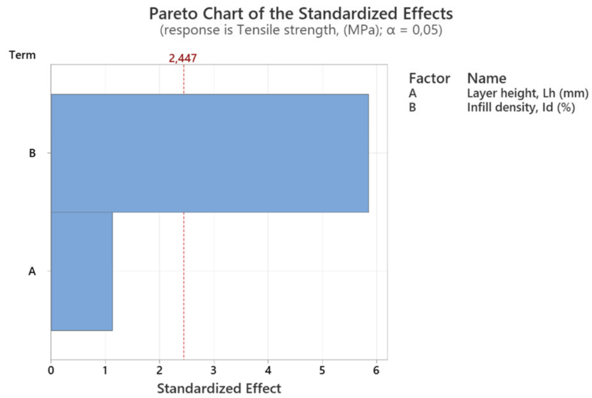

Fig. 8. Pareto chart of the influence of the parameters A = L_h and B = I_d on the tensile strengths of ASA tensile specimens.

The contour plot shown in Figure 9 was drawn using Minitab, the average results of the breaking strengths (Figure 7) and the FDM printing parameters from Table I. It can be seen that the filling percentage (I_d) has a significant influence on the breaking strength of ASA specimens.

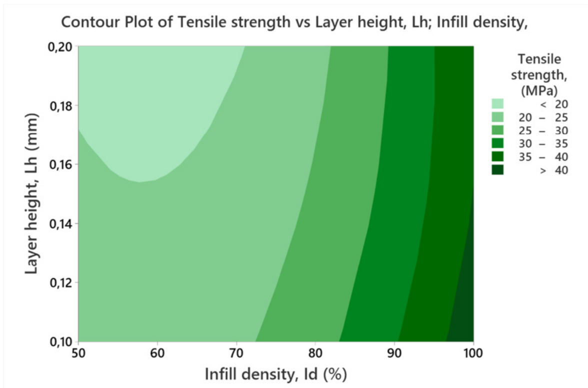

Fig. 9. Contour plot of the tensile strengths of ASA specimens.

2) Influence of the FDM Parameters on the Percentage of the Elongation at Break

Figure 10 illustrates the average results of the elongation at break percentage obtained from the tensile test on the universal testing machine of the manufactured using the FDM printing parameters of Table I.

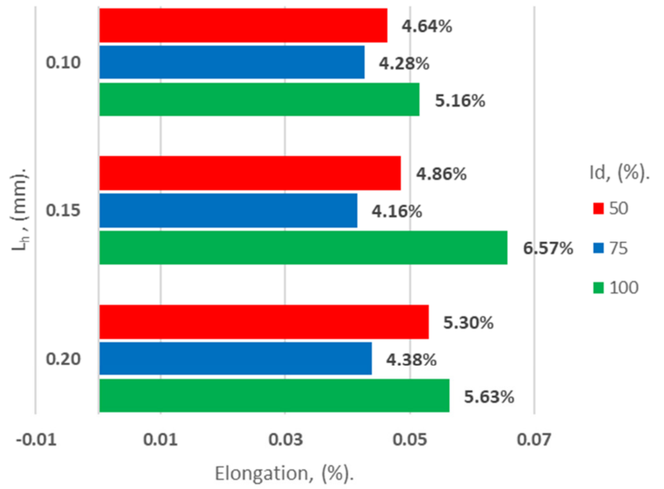

Fig. 10. Mean values of elongation at break percentage of the ASA specimens.

The highest values of elongation at break percentage of the ASA specimens (5.16 - 6.57%) were obtained for those with I_d = 100%. By decreasing the I_d from 100% to 75%, the average values decreased by 20.66 - 58.10%, whereas by decreasing I_d from 75% to 50%, the average values increased by 7.85 - 14.52%. Using Minitab software, the average results of elongation at break percentage of the ASA specimens and the FDM printing parameters in Table I, we plotted the Pareto plot shown in Figure 11. It can be seen that out of the 2 parameters used (A = L_h and B = I_d), the filling percentage (B = I_d) has a higher influence with 51.95% on the elongation at break percentage of the specimens.

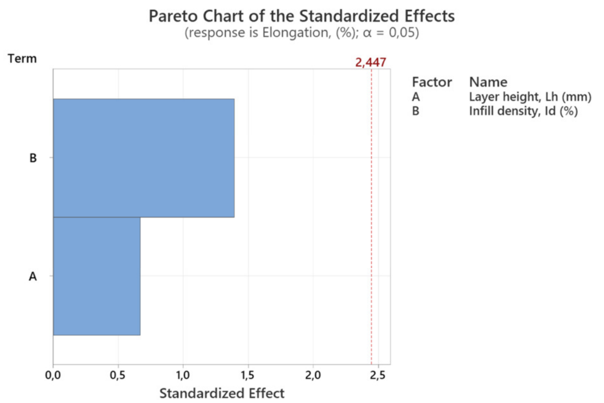

Fig. 11. Pareto chart showing the influence of the parameters A = L_h and B = I_d on the percentage at break elongation of the ASA specimens.

The contour plot shown in Figure 12 was drawn using Minitab software, the average results of elongation at break percentage of ASA, and the FDM printing parameters in Table I. We observe that I_d has a major influence on the elongation at break percentage of the specimens.

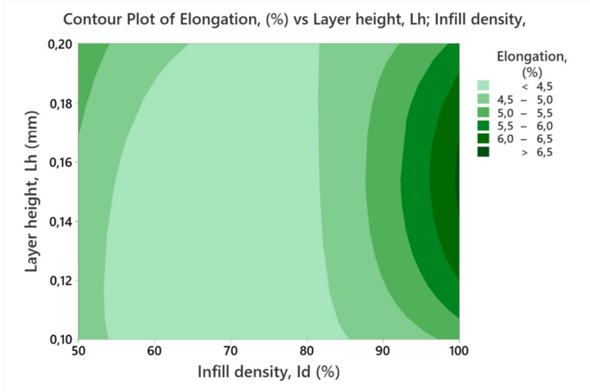

Fig. 12. Contour plot of elongation at break percentage of the ASA tensile specimens.

3) *Influence of the FDM Parameters on the Elastic Modulus*

Figure 13 shows the average elastic modulus results obtained from the tensile test of the specimens manufactured with the FDM printing parameters of Table I.

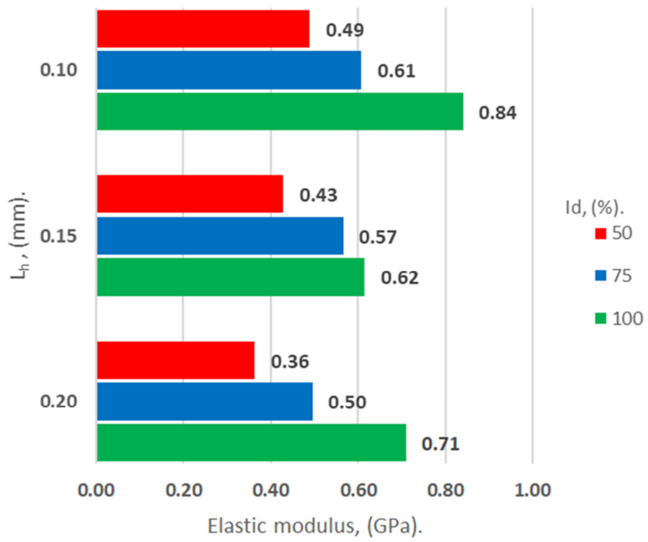

Fig. 13. Average values of the obtained elastic modulus.

The highest values of elastic moduli (0.62 - 0.84 GPa), were obtained for specimens having I_d = 100%. By decreasing I_d from 100% to 75%, the average values of I_d decreased by 8.74 - 43.38%, whereas further reducing the filling percentage from 75% to 50%, resulted in lower average values of elastic moduli by 24.37 - 36.57%. Using Minitab software, the elastic modulus values shown in Figure 13 and the FDM parameters in Table I, we plotted the Pareto chart shown in Figure 14. It can be seen that out of the two parameters used (A = L_h and B = I_d), the filling percentage (B = I_d) has a strong influence on the elastic modulus values obtained from tensile tests of the ASA specimens produced through FDM. Using Minitab software, the average elastic modulus results of the ASA specimens (Figure 13), and the FDM printing parameters from Table I, the contour plot shown in Figure 15 was drawn.

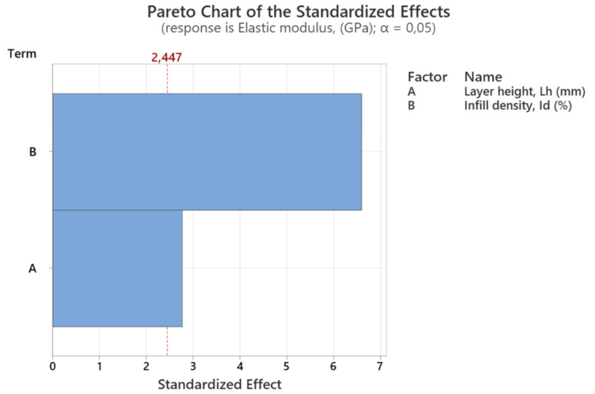

Fig. 14. Pareto chart of the influence of the parameters A = L_h and B = I_d on the elastic modulus values obtained in the tensile test of ASA specimens.

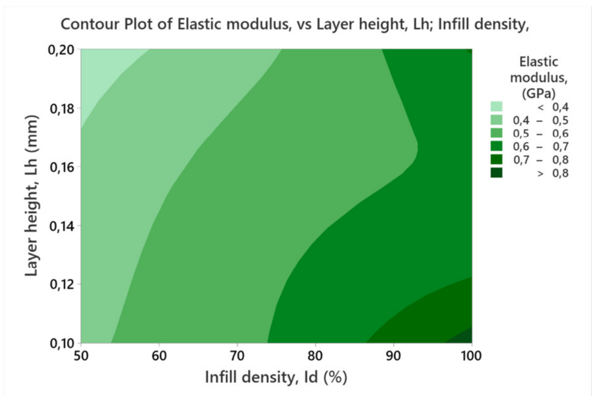

Fig. 15. Contour plot of the obtained elastic modulus values.

Analyzing the contour plot in Figure 15 it can be observed how increasing the filling percentage (Id) increases the elastic modulus values obtained in the tensile test of ASA specimens.

III. CONCLUSIONS

The current paper presents the results of a study on the influence of FDM printing parameters on the tensile behavior of specimens made of ASA, printed on an Anycubic Pro Max 2.0 3D printer, using the parameters presented in Table I (height of the single-pass layer: L_h = 0.10/0.15/0.20 mm and filling percentage: I_d = 50/75/100%), ASA filament with a diameter of 1. 75 mm, a total of 27 specimens were manufactured and tensile tested on a Barrus White 20 kN universal testing machine. The variable parameters considered (L_h and I_d) influence the tensile behavior (tensile strength, elongation at break percentage, elastic modulus) of the specimens.

Raising the filling percentage (I_d) increases the breaking strengths of ASA FDM specimens. Comparing the results obtained in this study with those obtained in [3], it is found that the breaking strength of ASA specimens is higher by 17.72 - 34.68% compared to the breaking strength of PETG specimens.

A higher filling percentage (I_d) leads to an increase in the elongation at break percentage of the specimens manufactured by FDM from ASA. The minimum value of elongation at break percentage (4.16%) was recorded after tensile testing of specimens produced by FDM from ASA with L_h = 0.15 mm and I_d = 75 % and the maximum value (4.68%) was recorded after tensile testing specimens produced by FDM from ASA with parameters L_h = 0.15 mm and I_d = 100%.

Increasing the height of the single-pass layer (L_h) and the filling percentage (I_d) also influences the elastic modulus of tensile specimens made by FDM from ASA. The minimum value of elastic modulus (0.36 GPa) was recorded for specimens with L_h = 0.20 mm and I_d = 50% and the maximum (0.84 GPa) for specimens with L_h = 0.10 mm and I_d = 100%.

The novelty of this work is the determination of the influence of FDM parameters (L_h and I_d) on the tensile behavior of samples made of ASA, and the presentation of the optimal parameter combination for the best tensile strength results. In order to obtain the best results in terms of tensile behavior of parts made of ASA (breaking strength, elongation at break percentage, elastic modulus), we optimized the FDM parameters using Minitab software.

In the future, we want to extrapolate the study to recycled materials from PETG and ASA.

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