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Study on optimization of thermoplastic extrusion parameters for manufacturing tensile specimens from PLA, ABS, PETG, rPETG, ASA, rASA

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Abstract. The paper presents the results of research on the optimization of the variable parameters of thermoplastic extrusion, namely the layer height deposited in one pass (H_s) and the filling degree (G_u) for the manufacture of tensile specimens from polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polyethylene terephthalate glycol (PETG), recycled polyethylene terephthalate glycol (rPETG), acrylonitrile styrene acrylate (ASA), recycled acrylonitrile styrene acrylate (rASA). In order to maximize the breaking strength of tensile specimens manufactured from PLA, ABS, PETG, rPETG, ASA, rASA, the variable parameters of thermoplastic extrusion were optimized using the Minitab 19 software and the Design of Experiments (DOE) and Response Optimization functions. Following the optimization of the variable parameters of thermoplastic extrusion, the optimal configuration of the process parameters was determined, which corresponds to the values: H_s = 0.10 mm and G_u = 100%.

Keywords: tensile strength, optimization, traction, Design of Experiments.

1. Introduction

Additive manufacturing technologies by extrusion of plastics are based on melting and extruding a thermoplastic filament through a heated nozzle and the successive deposition of the molten material on the printer's build platform [1-8]. The mechanical characteristics of parts obtained by thermoplastic extrusion are significantly influenced by the manufacturing parameters used, the parameters with a major impact on the mechanical characteristics being: the height of the layer

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deposited in one pass (H_s), the degree of filling (G_u), the printing speed (V_p), the extrusion temperature (T_e), the platform temperature (T_p), this being also highlighted in the works [10 – 21].

2. Research methods

To carry out this work, the results of studies and research published by the authors in specialized journals were used, in which the tensile behavior of specimens manufactured additively by thermoplastic extrusion of PLA, ABS, PETG, rPETG, ASA, rASA filaments was evaluated. The tensile specimens were manufactured and tested according to the ISO 527-1:2019 standard [9]. In the paper [10], the study on the influence of the parameters of the additive manufacturing technology by thermoplastic extrusion of PLA filament on the tensile characteristics is presented. To carry out the study, 12 sets of specimens were additively manufactured, each set consisting of 5 identical specimens. The variable parameters of thermoplastic extrusion used for the manufacture of tensile specimens from PLA filament are: the height of the layer deposited in one pass, H_s= (0.10; 0.15; 0.20) mm and the degree of filling, G_u = (25; 50; 75; 100)%. Following the tensile tests, the breaking strengths of the tensile specimens manufactured from PLA filament were determined, these being in the range (21 – 40.07) MPa. In the paper [11], the study on the evaluation of the influence of the variable parameters of thermoplastic extrusion on the tensile behavior of the specimens manufactured by thermoplastic extrusion of ABS filament is presented. In this context, using the variable parameters of thermoplastic extrusion, the height of the layer deposited in one pass, H_s = (0.10; 0.15; 0.20) mm and the filling degree, G_u = (50; 75; 100)%, 27 specimens of ABS filament were additively manufactured. All 27 specimens additively manufactured from ABS filament were tested in tension, the results of the breaking strengths being in the range (13.40 – 35.50) MPa. In the paper [12], the study on the evaluation of the influence of the variable parameters of thermoplastic extrusion on the tensile behavior of specimens additively manufactured from PETG filament is presented. Using the variable parameters of thermoplastic extrusion, the height of the layer deposited in one pass, H_s = (0.10; 0.15; 0.20) mm and the degree of filling, G_u = (50; 75; 100)%, 27 specimens were manufactured by thermoplastic extrusion of PETG filament. All 27 specimens manufactured additively from PETG filament were tested in tension on the Barrus White 20 kN machine, the results of the breaking strengths being in the range (15.47 – 28.25) MPa. In the paper [13], the authors present the study on the influence of thermoplastic extrusion parameters on the tensile behavior of specimens manufactured additively by thermoplastic extrusion of rPETG filament. In this context, for the study, 27 specimens were additively manufactured using variable thermoplastic extrusion parameters, the height of the layer deposited in one pass, H_s = (0.10; 0.15; 0.20) mm and the filling degree, G_u = (50; 75; 100)%. All 27 specimens manufactured additively from rPETG filament were tested in tension on the Barrus White 20 kN machine, the results of the breaking strengths being in the range (21.86 – 31.29) MPa. In the paper [14] the results of the research on the influence of the variable parameters of thermoplastic extrusion on the tensile behavior of the specimens manufactured by thermoplastic extrusion of the ASA filament are presented. In this context, using the variable parameters of thermoplastic extrusion, the height of the layer deposited in one pass, H_s = (0.10; 0.15; 0.20) mm and the filling degree, G_u = (50; 75; 100) %, 27 specimens of ASA filament were additively manufactured. All 27 specimens manufactured additively from ASA filament were tested in tension on the Barrus White 20 kN machine, the results of the breaking strengths being in the range (18.82 – 43.28) MPa. The paper [15] presents the results of the study on the influence of the variable parameters of thermoplastic extrusion on the breaking strengths of specimens manufactured additively from rASA filament. Using the variable parameters of thermoplastic extrusion, the height of the layer deposited in one pass, H_s = (0.10; 0.15; 0.20) mm and the filling degree, G_u = (50; 75; 100)%, 27 samples were additively manufactured from rASA filament, subsequently all 27 samples were tensile tested on the Barrus White 20 kN machine, the values of the breaking strengths of the samples additively manufactured from rASA filament being within the range (17.29 – 38.42) MPa.

Figure 1 shows the typical dimensions of tensile specimens manufactured additively by thermoplastic extrusion of filaments made of PLA, PETG, rPETG, ABS, ASA, rASA.

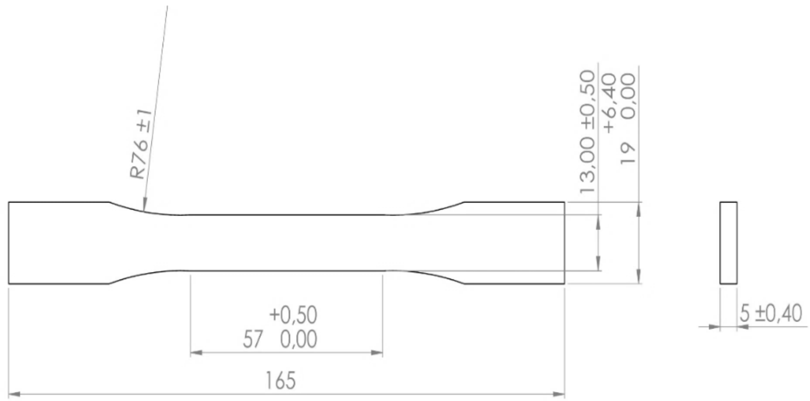

Fig. 1. Tensile sample.

3. Results and discussion

Figure 2 shows the average values of the tensile strengths of samples additively manufactured from PLA, ABS, PETG, rPETG, ASA, rASA.

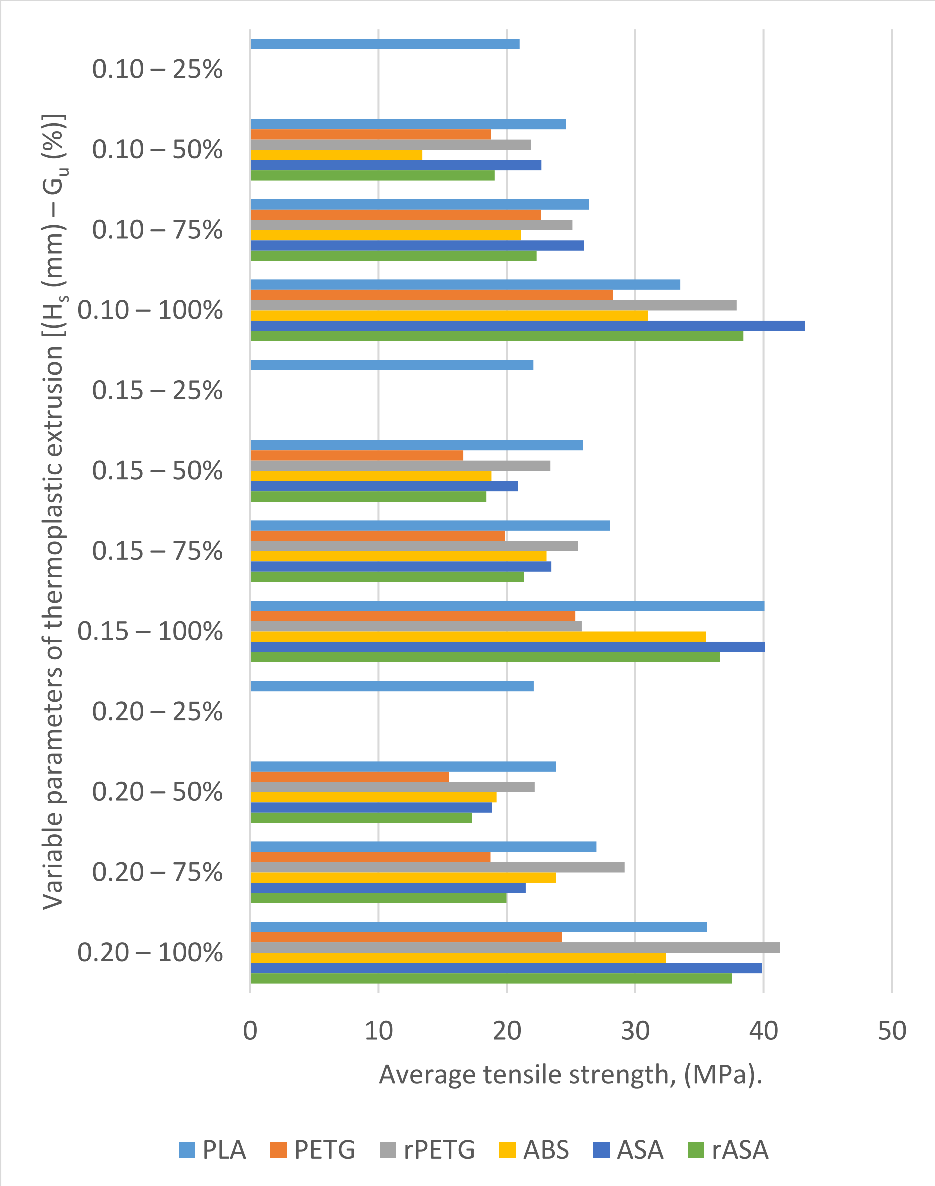

Fig. 2. Influence of variable thermoplastic extrusion parameters on the average breaking strengths of tensile specimens additively manufactured by thermoplastic extrusion of PLA, ABS, PETG, rPETG, ASA, rASA filaments

Analyzing figure 2 we observe the influence of the variable parameters of thermoplastic extrusion (Hs and Gu) on the average breaking strengths of specimens manufactured additively from PLA, ABS, PETG, rPETG, ASA rASA. The maximum average breaking strengths of tensile specimens were recorded for the set of specimens manufactured from ASA filament with Hs = 0.10 mm and Gu = 100%.

Reducing of G_u from 100% to 75%, generated a decrease in tensile strength by:

- (21.19 – 30.02) % for PLA samples;
- (31.94 – 32.96) % for ABS samples;
- (19.77 – 22.93) % for PETG samples;
- (2.86 – 29.33) % for rPETG samples;
- (39.86 – 46.17) % for ASA samples;
- (41.93 – 45.44) % for rASA samples.

Reducing of G_u from 75% to 50%, generated a decrease in tensile strength by:

- (7,49 – 9,85) % for PLA samples;
- (19.33 – 36.49) % for ABS samples;
- (17.20 – 17.31) % for PETG samples;
- (12.91 – 19.82) % for rPETG samples;
- (12.33 – 12.75) % for ASA samples;
- (13.44 – 14.67) % for rASA samples.

4. Optimization of parameters for additive manufacturing o tensile specimens by thermoplastic extrusion of PLA, ABS, PETG, rPETG, ASA, rASA filaments

Using Minitab software, the average results of the tensile strengths of additively manufactured tensile specimens by thermoplastic extrusion of PLA, PETG, rPETG, ABS, ASA, rASA filaments, and the process parameters of thermoplastic extrusion, their influence on the tensile strengths was statistically analyzed.

Figures 3 – 8 present graphs regarding the influence of the variable parameters of thermoplastic extrusion (A = H_s and B = G_u) on the tensile strengths of additively manufactured specimens of PLA, ABS, PETG, rPETG, ASA, rASA.

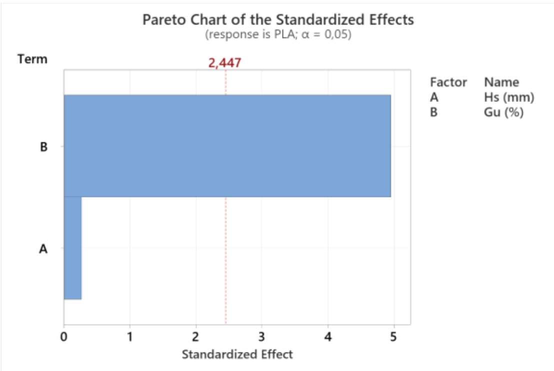

Fig. 3. Influence of thermoplastic extrusion parameters on the tensile strengths of additively manufactured PLA filament specimens.

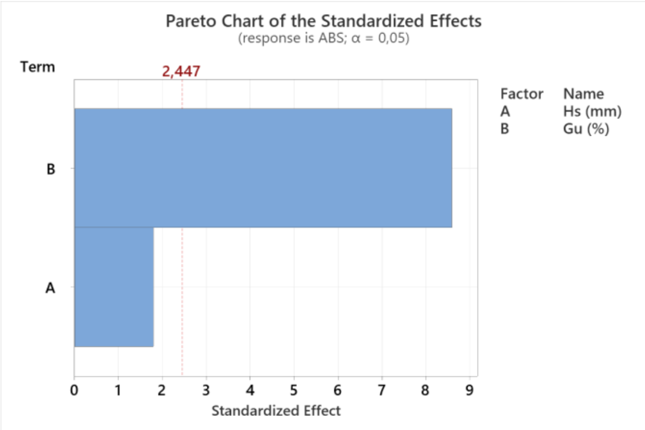

Fig. 4. Influence of thermoplastic extrusion parameters on the tensile strengths of additively manufactured ABS filament specimens.

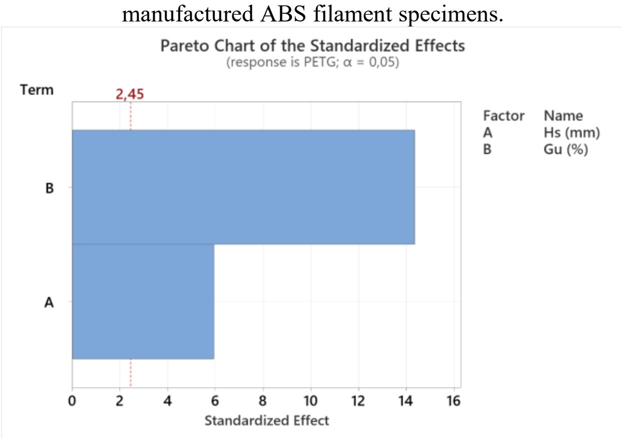

Fig. 5. Influence of thermoplastic extrusion parameters on the tensile strengths of additively manufactured PETG filament specimens.

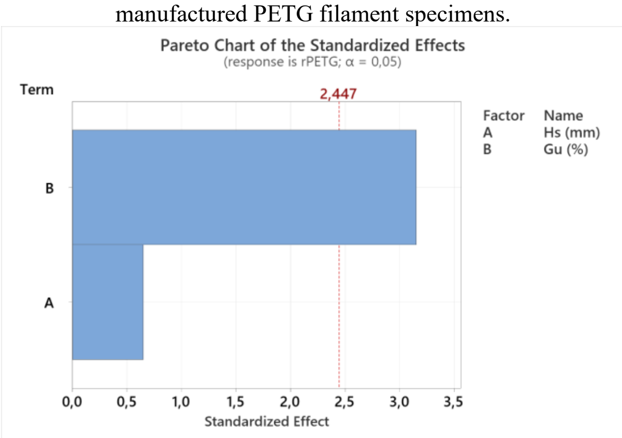

Fig. 6. Influence of thermoplastic extrusion parameters on the tensile strengths of additively manufactured rPETG filament specimens.

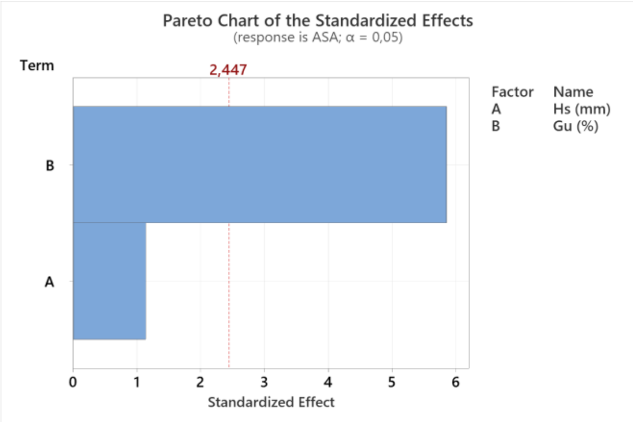

Fig. 7. Influence of thermoplastic extrusion parameters on the tensile strengths of additively manufactured ASA filament specimens.

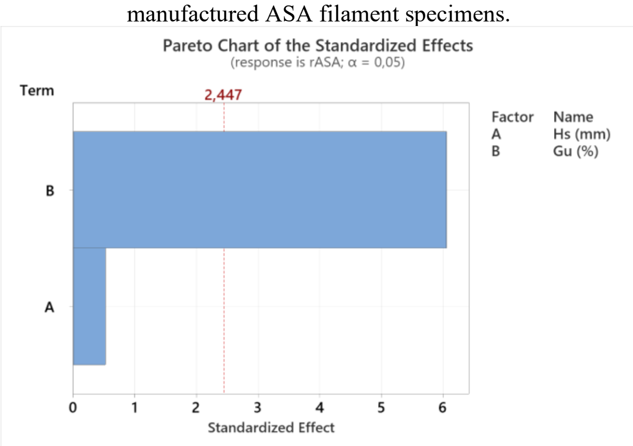

Fig. 8. Influence of thermoplastic extrusion parameters on the tensile strengths of additively manufactured rASA filament specimens.

The Pareto charts in Figures 3 – 8 show the influence of the variable parameters of thermoplastic extrusion (A = H_s and B = G_u) on the breaking strengths of tensile specimens additively manufactured from PLA, ABS, PETG, rPETG, ASA, rASA. According to Figures 3 – 8, the factor B = G_u decisively influences the breaking strengths of tensile specimens additively manufactured by thermoplastic extrusion of PLA, ABS, PETG, rPETG, ASA, rASA filaments.

Using Minitab and the Response Optimization function, the thermoplastic extrusion parameters, the average values of the breaking strengths of the specimens manufactured additively by thermoplastic extrusion of filaments made of PLA, ABS, PETG, rPETG, ASA, rASA, the variable parameters of the thermoplastic extrusion H_s = (0.10; 0.15; 0.20) mm and G_u = (50, 75, 100) % were optimized with the aim of maximizing the breaking strengths.

Figure 9 presents the optimization graphs of the variable parameters of thermoplastic extrusion for the manufacture of tensile specimens from PLA, ABS, PETG, rPETG, ASA, rASA.

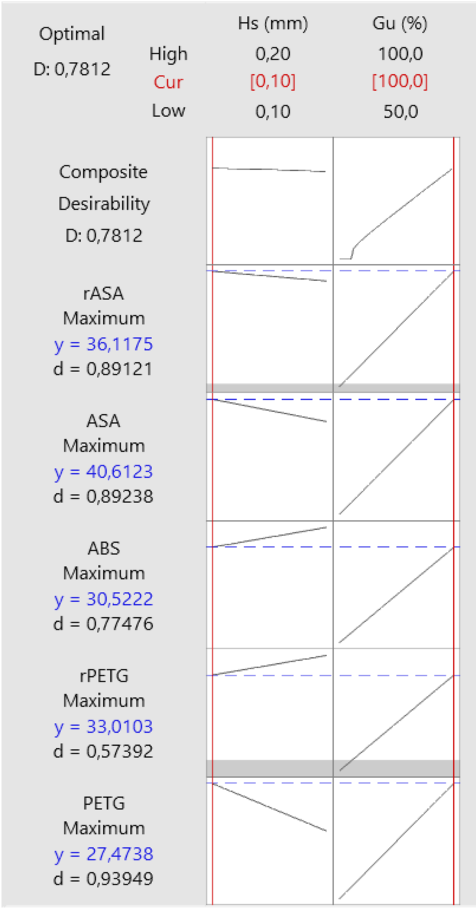

Fig. 9. Thermoplastic extrusion parameter optimization graphs (Hs and Gu) for maximizing the tensile strengths of additively manufactured specimens made of PLA, ABS, PETG, rPETG, ASA, rASA.

Analyzing Figure 9, it is observed that the optimal parameters of thermoplastic extrusion, for maximizing the breaking strengths of specimens manufactured from PLA, ABS, PETG, rPETG, ASA, rASA, are $H_s = 0.10$ mm and $G_u = 100\%$.

5. Conclusions

The paper presents the study on the optimization of thermoplastic extrusion parameters for the manufacture of tensile specimens from PLA, ABS, PETG, rPETG, ASA, rASA. To carry out the study, representative works from the specialized literature were analyzed that evaluate the influence of variable parameters of thermoplastic extrusion (H_s – layer height deposited in one pass and G_u – filling degree) on the breaking strengths of additively manufactured specimens from PLA, ABS, PETG, rPETG, ASA, rASA. Using the Minitab software, a statistical analysis was performed on the influence of variable parameters of thermoplastic extrusion on the breaking strengths of additively manufactured tensile specimens from PLA, ABS, PETG, rPETG, ASA, rASA, the parameter corresponding to the significant influence being Gu. Using Minitab and the Response Optimization function, the optimization of the variable parameters of thermoplastic extrusion was carried out, with the aim of maximizing the breaking strengths of specimens made of PLA, ABS, PETG, rPETG, ASA, rASA, their optimal configuration being H_s = 0.10 mm and G_u = 100%.

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