OPTIMALIZATION OF PARAMETERS FOR 3D PRINT FOR ACRYLONITRILE-BUTADIENE-STYRENE BY FUSED DEPOSITION MODELLING

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Abstract - *The present work deals with optimalization of parameters for 3D printing of terpolymer acrylonitrile-butadiene-styrene (ABS) using Fused Deposition Modelling (FDM) by quality of production. It is very important to used good parameters for polymeric materials - temperature of 3D print, speed of 3D print and temperature of pad.*

We were tested ABS with different temperatures of 3D print with the same speed of printing. As an evaluation sample was chosen sample (dogbone). The samples were characterized by Differential scanning calorimetry (DSC), Melt flow index (MFI), 3D scanner, measurement of tensile and bending tests and measurement of notched toughness. The optimal melting point was determined with respect to the mechanical properties of the sample and the print quality.

Key Words: 3D print, printing parameters, ABS, fused deposition modelling, mechanical properties

1. INTRODUCTION

FDM is a technology of additive production that developed in the late eighties of the twentieth century, and in 1989 it was patented by S. Scott Crump, later founder of Stratasys, which has this term secured by a trademark. The FDM method was initially used by 3D printers for public [1-3]. The principle of FDM consists in melting plastic or metal in the form of a fiber inside the extrusion head that extrudes the melt onto the substrate and, by its two axis movement, gradually applies a very thin layer of material in the plane of the horizontal cross section of the future product. After applying the entire layer, the pad is reduced by the thickness of the layer in the vertical axis and the gradual deposition continues again until the entire product is formed. FDM is technology based on computer aided design (CAD). For the FDM process, thermoplastic materials, most ABS, PLA and nylon, or various exotic materials based on thermoplastics, are used. The FDM method can process many types of thermoplastics – from polypropylene (PP), polyamide (PA), polylactic acid (PLA), high impact polystyrene (HIPS) to terpolymer ABS [4-9]. Using FDM we can get prototypes, functional samples and for industry [10-12]

As a result of the ever-expanding use in the commercial and non-commercial sector, it is important for the expected mechanical, thermal properties to properly choose the 3D print temperatures and the own mats, which also have a great effect on the resulting product. It's also very important to choose the correct print speed. The influence of surface at FDM was dealt with by many scientific groups [13-15].

In present work we can choose suitable parameters for 3D print from ABS material according to use. We focused on testing the 3D print temperature with respect to the speed and temperature of the pad. The properties of the prepared samples were tested both in terms of mechanical and thermal properties, and in terms of the quality of the prepared samples. The results can be used for 3D printing from ABS material to achieve the required prototype properties.

1.1 Materials

ABS filament (Ø 3mm (Accuracy: 2.9-3.0 mm), ESUN, Shenzhen, China).

1.2 Methods

3D scan was obtained using FARO®Edge, number of axes 7, measuring range 1.8 m, repeatability 0.024 mm, precision 0.034 mm, weight 10.7 kg, temperature fluctuation 3 °C / 5min, and Polyworks software.

For testing of mechanical properties was used an Instron 3345 with a load 5 kN. Tensile test was made with speed 5 mm/min, load 5kN. Bending test was made with these parameters - speed 200N/ min, jaw gap 6 cm and load 5 kN.

Thermal properties were verified with DSC 200 F3 Maia with a temperature range of -170 °C to 500 °C. Measurements were performed in a nitrogen atmosphere at a heating rate of 10 °C/min. The sample weight ranged from 1 to 5 mg.

Viscoelastic properties were characterized by a melt flow index with parameters: Preheating w/o load 240s, test condition (temperature 220 °C, load 10 kg, measuring length 10 mm, step length 0.25 mm, measure starting time 300s, density of material 1.04 g/cm^3, Die: Diameter-Lugth 2.095 x 8.00 mm.

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3D printing was done using a 3D printer Prusa I3 plus using a 0.4 mm nozzle with a working area of 8000 cm^3 (200 x 200 x 200 mm) with an integrated LCD.

Impact toughness was determined using a Charpy impact pendulum. It was measured by the difference between the hammer and the zero cuvette cell at the impact on the test specimen. The essence of the test is to determine the work required to break the examined body. The notched toughness is related to the cross-sectional area of the body.

2. Preparation of samples

Samples were prepared using a 3D printer using the FDM method. Three types of samples (Fig -1-3) Were prepared to test tensile, bending and impact properties. For 3D printing, print temperatures ranging between 245 and 285 ° C were selected at 80 ° C, the print speed was the same for all samples. The samples were printed at an angle of 45°. Samples were divided into horizontal and vertical fill prints for specimens tested by impact hammer.

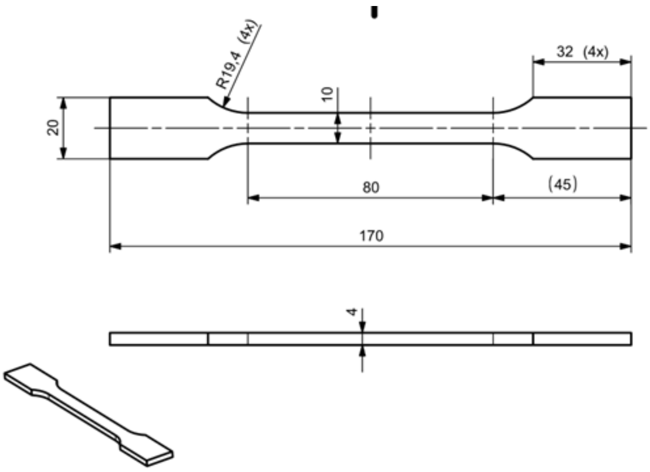

Fig – 1: Sample for tensile test.

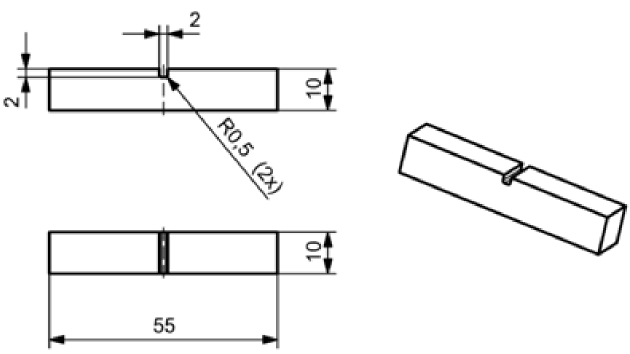

Fig – 2: Sample for testing of notched toughness.

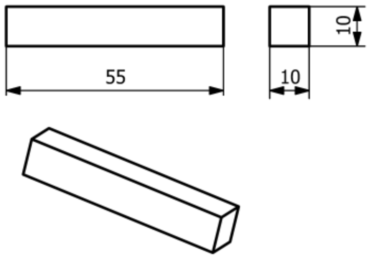

Fig-3: Sample for bending test.

3. Characterization of material

ABS material was characterized by DSC and we measured temperature of glass transition (Tg) 111.2 °C and δ specific heat capacity (Cp) 0.368 J/(g.K) (Fig -4).

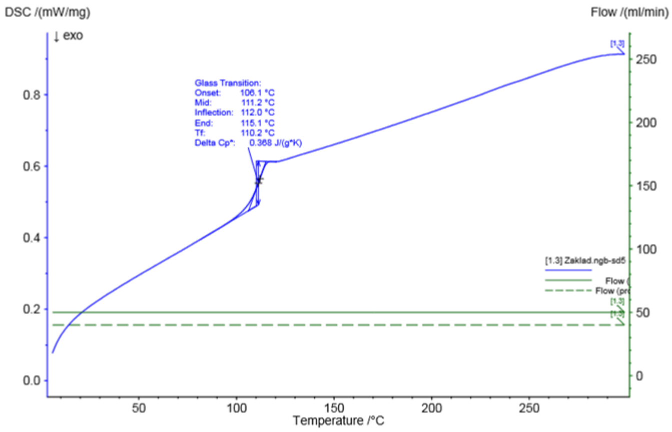

Fig-4: DSC for ABS material.

ABS was characterized by MFI measurement. The Avg. Mass-Flow Rate was 17.8 g/ 10min with standard deviation 0.31 g/ 10min. The Avg. Volume-Flow Rate was 17.1 cm^3/ 10 min with standard deviation 0.298 cm^3/ 10 min. We determined rheological data as shear rate, shear stress and viscosity. Shear rate was 31.562 s^{-1}, shear stress 89631 Pa and viscosity 2839.821 Pa.s. We can see Mass-Flow Rate data during measurement in the Fig -5. We selected the following temperatures of nozzle for testing ABS material using 3D print from 245 °C to 285 °C by these parameters.

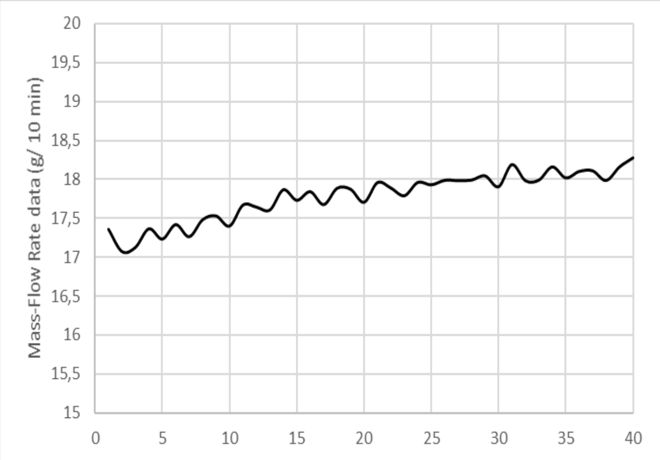

Fig-5 : Mass-Flow Rate data during measurement.

The tensile test of ABS material was done with these results maximum load 224.17 N, tensile pressure at maximum load 31.71 MPa, modulus of elasticity 1227.79 MPa and tensile deformation at maximum load 4.79 %.

3. Characterization of the prepared samples

The samples were prepared at five temperatures of nozzle and at the same temperature of pad 80 °C and the same speed of printing. The prepared samples were tested by tensile test, bending test, testing of notched toughness and using DSC and 3D scanner.

The samples for testing of notched toughness were prepared with two types of notch printing – horizontal and vertical. We can see results of tensile test in Table 1, bending test in Table 2 and testing of notched toughness in Table 3.

The best results for the tensile test can be observed in the sample with temperature of 3D print 285 °C – maximum load 1225.9 N, tensile stress at maximum load 28.4 MPa, modulus of elasticity 1342.1 MPa and tension deformation at maximum load 2.9 %. The worst results of tensile test we can see in sample with temperature of 3D print 245 °C – maximum load 829.1 N, tensile stress at maximum load 19.8 MPa, modulus of elasticity 997.5 MPa and tension deformation at maximum load 3.3 %. We can see that the tension deformation at maximum load is the best for sample with 3D print temperature 245 °C. This fact is confirmed in Table 2 too. The best results of bending test we can see for sample with temperature of 3D print 245 °C – maximum load 1347.7 N, bending elongation at maximum load 2.2 mm and bending stress at maximum load 61.5 MPa. The worst results we can see for sample with 3D print temperature 285 °C – maximum load 1216.5 N, bending elongation at maximum load 1.9 mm and bending stress at maximum load 55.5 MPa. These results are very important for 3D print from this material.

Table -1: Results of tensile test.

Temperature of 3D print (°C)	Maximální Zatížení	Tahové napětí při Maximální Zatížení	Modul (Automatický Youngův modul pružnosti)	Tahová deformace (Protažení) při Maximální Zatížení
245	829,1	19,77	997,48965	3,27
255	992,747	23,04	1111,67405	3,24
265	1131,632	26,57	1243,77107	3,15
275	1195,053	28,1	1301,07783	3,02
285	1225,971	28,35	1342,13449	2,91

Table -2: Results of bending test.

Temperature of 3D print (°C)	Maximum load (N)	Bending elongation at maximum load (mm)	Bending stress at maximum load (Mpa)
245	1347,67	2,21	61,45
255	1346,59	2,21	60,25
265	1293,48	1,99	58,83
275	1224,02	2,04	55,82
285	1216,52	1,93	55,47

In Table 3 we can see results of testing notched toughness. The best results we can see for sample with 3D print temperature 255 °C – for vertical print 1.79 J.cm^{-2} and for horizontal print 1.91 J.cm^{-2}. The results don't show large differences.

Table -3: Results of testing notched toughness.

	Notched toughness [J.cm2]	
Temperature of 3D print (°C)	Vertical 3D print	Horizontal 3D print
245	1,78	1,77
255	1,79	1,91
265	1,79	1,88
275	1,79	1,85
285	1,75	1,78

The quality of the prepared samples (dogbones) were assessed by 3D scanner (Fig -6). The smallest deviation showed samples with temperature 3D print 275 °C. In Table

4 we can see distances of samples. Nominal distance was 170.0 mm.

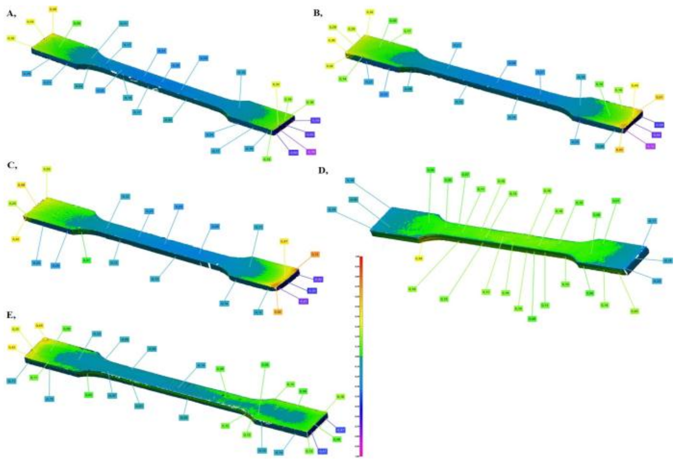

Fig -6: The scans of the prepared samples (dogbones).
A - sample printed at 245 °C, B - sample printed at 255 °C, C - sample printed at 265 °C, D - sample printed at 275 °C, E - sample printed at 285 °C.

Table -4: Results of values distance of the prepared samples.

Temperature of 3D print (°C)	Value of distance (mm)	Deviation (mm)
245	168.78	- 1.22
255	168.79	- 1.21
265	168.45	- 1.55
275	169.23	- 0.77
285	168.93	- 1.07

DSC was used for thermal characteristics of the prepared samples. The results are in Table 5. We can see that short contact ABS material with nozzle of 3D printer is without bigger degradation of material. We can see that material at higher temperature forms networking because ABS material contains three kind of monomers (Fig -7) with double bonds in structures. These double bonds form networking with higher temperature. We can monitor this effect with Tg when with temperature of 3D print the value of Tg decreases.

Table -5: Results of DSC.

Temperature of 3D print (°C)	Tg (°C)	Δ Cp (J/(g.K))
245	114.0	0.355
255	112.8	0.345
265	112.8	0.344
275	112.7	0.320
285	111.4	0.310

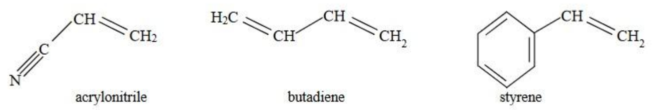

Fig -7: Monomers contained in ABS material.

3. CONCLUSIONS

The presented work deals with the selection of suitable parameters for 3D printing using FDM. The results show that it is very important to choose the appropriate 3D print temperature and substrate temperature for this material. For prototypes that should exhibit better flexibility, it is advisable to choose temperatures around 245 ° C. On the contrary, for samples without preference of flexibility, it is advisable to choose temperatures around 275 ° C. Due to the short contact time of the ABS material with the nozzle there is no degradation of the material, as confirmed by DSC.

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BIOGRAPHIES

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