Mokslas – Lietuvos ateitis / Science – Future of Lithuania
ISSN 2029-2341 / eISSN 2029-2252
2018 Volume 10, Article ID: mla.2018.6250, 1–8
https://doi.org/10.3846/mla.2018.6250

Civil engineering
Statybos inžinerija

STRUCTURAL APPLICATION OF 3D PRINTING TECHNOLOGIES: MECHANICAL PROPERTIES OF PRINTED POLYMERIC MATERIALS

Olena SHKUNDALOVA, Arvydas RIMKUS, Viktor GRIBNIAK*

Vilnius Gediminas Technical University, Vilnius, Lithuania

Received 26 October 2018; accepted 05 November 2018

Abstract. Additive manufacturing and modern printing technologies using polymeric materials extend the limits of industrial production and encourage applying 3D printing technique in many fields. An item of any shape and size limited only by the printing pad of particular equipment can be reproduced from a variety of materials. Polymers is the object of this research. It is known that mechanical properties of the printed elements are closely related with the manufacturing technology and vary significantly depending on the chosen production parameters such as printing temperature, velocity, and infill density. Depending on the purpose, a particular type of polymer can be used in structural analysis. This work considers mechanical properties of four thermoplastic polymeric materials widely used for prototyping: polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), high impact polystyrene (HIPS), and polyethylene terephthalate (PETG). The study is focused on two fundamental mechanical characteristics, tensile strength and modulus of elasticity, of the printed material. Dumbbell-shaped samples were made of the PLA, ABS, HIPS and PETG polymers using 3D printing technique with the same filling density (≈ 20%) of the entry level. The tensile tests were carried out in Laboratory of Innovative Building Structures at Vilnius Gediminas Technical University. The predominant effect of the printing direction on the mechanical properties of the printed materials was demonstrated in this study. The corresponding experimental characteristics are presented in the manuscript.

Keywords: polymers, 3D printing, tensile test, mechanical properties, PLA, ABS, HIPS, PETG.

Introduction

Additive manufacturing represents a breakthrough in the era of new technologies. The 3D printing has become one of the fastest growing technologies (Hager, Golonka, & Putanowicz, 2016). This technology employs a digital computer model for production of a real physical object. The printed samples can have a different purpose. It can vary from 3D printing of toys to printing structures from metal or concrete. Depending on the task and printing materials, 3D printers are of different power and components and can be used for home and industrial applications. According to the standard terminology (International Organization for Standardization [ISO], 2015), the additive manufactory is divided into several categories: vat photopolymerisation, material jetting, binder jetting, material extrusion, powder bed fusion, sheet lamination, and directed energy deposition. For each of these categories, certain materials are used. The following materials are identified in this regard (Ngo, Kashani, lzano, Nguyen, & Hui, 2018): wax, clay, gypsum, concrete, metal, some of the food products, polymeric materials. Design of the printed object is based on computer modelling; however, structural application of the printed materials requires identification of the corresponding mechanical characteristics of the materials.

Recent investigations are focused on identifying the mechanical properties of printed polymeric materials. Letcher and Waytashek (2014) and Jerez-Mesa, Travieso-Rodriguez, Llumà-Fuentes, Gomez-Gras, and Puig (2017) carried out tensile tests for investigating fatigue resistance of samples printed of polylactic acid (PLA) polymer. Brooks and Molony (2016) investigated manufacturing aspects of reinforced samples made of PLA and acrylonitrile butadiene styrene (ABS) polymers. Aramid, carbon, and basalt filaments were used as the reinforcement. The specimens were subjected to tension, bending, and torsion. Fatigue resistance of such specimens was investigated in the reference (Brooks, Tyas, & Molony, 2017). Miller in co-authorship (Miller, Safranski, Wood, Guldberg, & Gall, 2017) investigated the influence of

*Corresponding author. E-mail: *viktor.gribniak@vgtu.lt*

the printed architecture on the monotonic and cyclic mechanical behaviour of elastomeric polyurethane subjected to tension. The reinforcement effect of Mg micro-particles on mechanical properties of samples made of poly-l-lactic acid and poly-d-lactic acid composites under compression was investigated in the reference (Cifuentes, Frutos, Benavente, Lorenzo, & González-Carrasco, 2017). Scaffaro, Lopresti, and Botta (2018) studied both tensile and flexural properties of biocomposites made of a PLA reinforced with Posidonia oceanica leaves. Pinto et al. (2017) and Zhou, Lei, Yang, Li, and Ren (2018) investigated mechanical properties of nanocomposites made of PLA reinforced with carbon nanofillers. These works clarify possibilities of using reinforced polymer as printed material.

Tension, compression, and fracture test results of unidirectional 3D-printed PLA presented in the reference (Song et al., 2017). Impact resistance of the polymeric materials was the research object of the studies carried out by Sood, Ohdar, and Mahapatra (2010) and Dawoud, Taha, and Ebeid (2016). Tensile modulus and thermal stability of PLA reinforced by acrylonitrile butadiene rubber were studied in the reference (Talbamrung, Kasemsook, Sangtean, Wachirahuttapong, & Thongpin, 2016). The investigation of tensile and bending strength of PLA and its comparison with PLA/wood flour composite with interface improved by introduction of polymethyl methacrylate was the purpose of study of Lu and Yanhua (2018). Gomez-Gras, Jerez-Mesa, Travieso-Rodriguez, and Lluma-Fuentes (2018) investigated fatigue performance of fused filament fabrication PLA specimens. Mulrennan et al. (2018) investigated yielding behaviour of the extruded PLA sheets. Mechanical properties, water resistance, and impact strength of neat PLA comparable to biodegradable and compostable compositions, derived from PLA, potato thermoplastic starch and plant glycerin made by melt extrusion with epoxydized soybean oil are investigated in the reference (Przybytek, Sienkiewicz, Kucińska-Lipka, & Janik, 2018). Karger-Kocsis, Bárány, and Moskala (2003), Dupaix and Boyce (2005), and Szykiedans, Credo, and Osiński (2017) focused the research on the mechanical properties of polyethylene terephthalate (PETG). Melenka, Cheung, Schofield, Dawson, and Carey (2016), Tian, Liu, Yang, Wang, and Li (2016), Weng, Wang, Senthil, and Wu (2016), Zou et al. (2016), Ferreira, Amatte, Dutra, and Bürger (2017), Alaimo, Marconi, Costato, and Auricchio (2017), Spiridon and Tanase (2018), and Zhao, Hwang, Lee, T. Kim, and N. Kim (2018) investigated tensile behaviour of the printed materials.

The general agreement is that mechanical properties of the printed elements is closely related with the manufacturing technology and could vary significantly depending on the chosen production parameters such as temperature regime, velocity, infill density, and direction of the printing. Therefore, the particular characteristics of potentially applicable material must be estimated before considering the structural application problem. This work is dedicated for analysing the feasibility of structural application of the printed materials and printing technologies currently applied for prototyping in Laboratory of Innovative Building Structures at Vilnius Gediminas Technical University. The tensile properties (i.e. tensile strength and modulus of elasticity) of four different polymeric materials: PLA, ABS, high impact polystyrene (HIPS), and PETG, are investigated. For this purpose, dumbbell-shaped samples were printed and tested.

1. Test program

This section outlines the method for the tensile testing of specimens printed using four different polymeric materials: ABS, PLA, HIPS and PETG. The layout of the test sample, i.e. dumbbell-shaped element, was chosen according to the ASTM D638 Standard (ASTM, 2014). Figure 1 shows the geometry of the specimen. Test program contains 20 identical geometry samples. The elements were printed using different printing equipment and various extrusion parameters. Printing specification of the dumbbell-shaped test elements as well as the nominal mechanical characteristics of the materials (provided by the producers) are presented in Table 1. Same printing manner was applied for each printing layer for all the specimens: two solid "shells" were printed on the perimeter of the specimen, while inner part of the sample was printed with 20% infill at specified raster orientations (such printing layout is commonly used for prototyping purposes). It is important to note, that first and last two layers of the specimens were printed with 45° angle oriented 100% infill. Three printing directions were used for the printing layout: specimen #5 was printed along transversal axis of the element, while rest of the specimens – along longitudinal axis in two directions. Figure 2 shows the raster orientation of specimens. Figure 3 shows the printing process and the printed samples.

2. Experimental result

The tensile tests were carried out using an electromechanical machine Tinius Olsen h75 KS with capacity of 75 kN. The specimens made of ABS, PETG and HIPS were tested under displacement control at 0.2 mm/s loading rate. Due to ductile behaviour of polylactic acid, the loading speed of specimens made of PLA was increased up to 1.2 and 0.8 mm/s for the specimen #8 and specimens #9 and #10, respectively. The loading speed of sample #11 made of HIPS was also increased up to 0.8 mm/s.

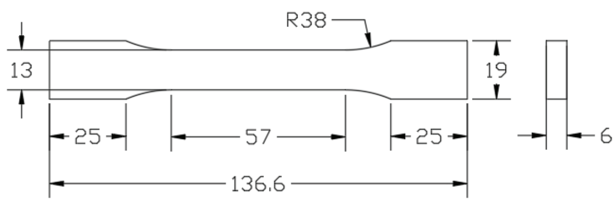


Figure 1. Geometry of the printed specimens for tensile tests (dimensions are in mm)

Table 1. Structure of the test program

Specimen number	Material	Nominal characteristics		Printer	Extrusion parameters		Filling density
		Modulus of elasticity, GPa	Tensile strength, MPa		Temperature, C°	Velocity, mm/s	g/cm^3
1–7	ABS	2.20	33.00	Fortus 250mc	235	50	0.910
8–10	PLA	1.88	28.10	Mass Portal Pharaoh ED	210	50	1.405
11–15	HIPS	1.18	16.90	Zortrax M200	255	30	0.480
16–20	PETG	1.39	40.18	Mass Portal Pharaoh ED	240	35	0.702

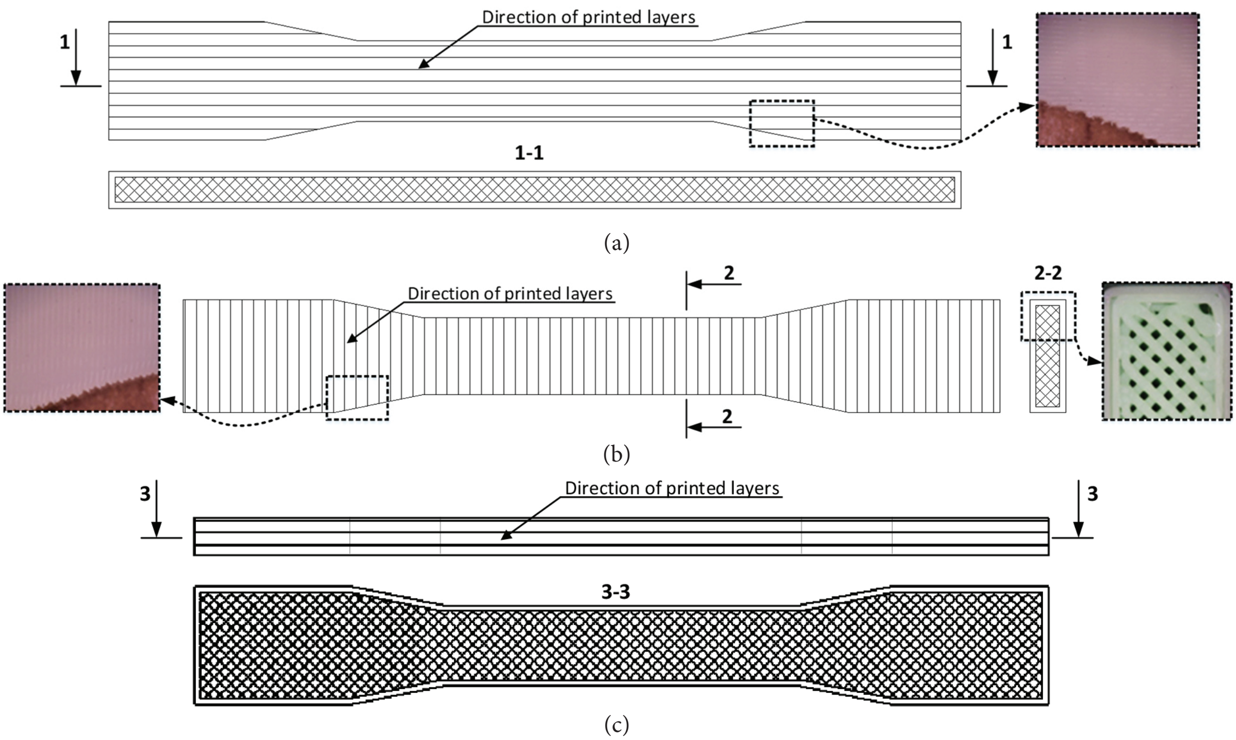


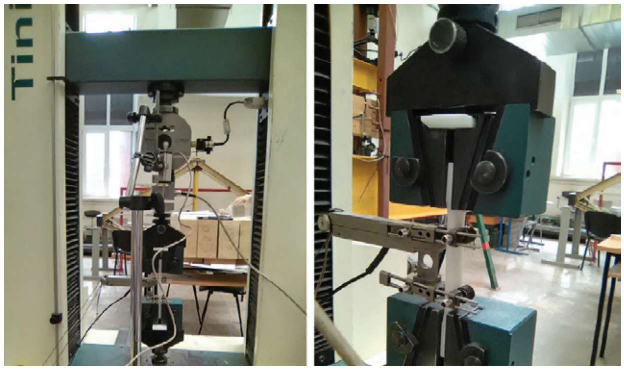
Figure 2. Raster orientation of samples: (a) longitudinal printing direction (samples #1–4, #6–10); (b) transversal printing direction (sample #5); (c) longitudinal printing direction (samples #11-20)

(a) (b) (c)

Figure 3. 3D printing: (a) printing process; (b) specimens printed of ABS (two top specimens) and PLA (three bottom specimens); (c) HIPS specimens (white) and PETG (black)

The reaction of the specimen to the tension load was measured with the electronic load cell of the testing machine. The axial deformations were monitored using linear variable displacement transducer (LVDT). An extensometer (Model RDP TI E308) with a gauge length of 20 mm was used to measure strain of the test sample. The device Almemo 2890-9 was connected to the dynamometer for reading data from the strain gauge and LVDT with the help of the AMP WinControl program. In order to observe strain distribution and the fracture of the specimen, the front surface of the samples #15 and #20 was exposed to a digital image correlation (DIC) system. Images were captured by a digital camera (Cannon 77D) placed on a tripod at 0.5 m distance from the test specimens. The camera, incorporating wireless trigger system, have a resolution of 6000×4000 pixel. This system allows obtaining strain distribution maps from the digital images of the specimen surface using GOM Correlate software – the position of each point of the surface is identified by applying a particular correlation algorithm to the same points from reference image. The precise position of every surface point at every loading step allows tracking the movement of the points to obtain a distribution map of the surface strains. All tests were conducted at room temperature (approximately 20 °C). The testing equipment is shown in Figure 4.

The tensile tests were carried on until failure of the specimens. Table 2 summarizes results of the tensile tests. The corresponding load-displacement diagrams are presented in Figure 5. It can be observed that specimens



(a) (b)

Figure 4. Test setup: (a) the testing machine Tinius Olsen h75 KS; (b) strain monitoring using the extensometer TI E308

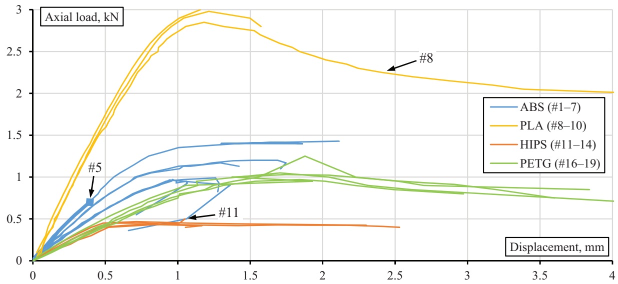


Figure 5. Load-displacement diagrams of the specimens

Table 2. Test results

Specimen number	Material	Loading rate, mm/s	Maximal axial load P_{max}, N	Corresponding displacement u_P, mm
1	ABS	0.2	966	0.94
2			990	1.26
3			971	0.96
4			1429	2.11
5			700	0.39
6			1170	1.29
7			1200	1.52
8	PLA	1.2	2850	1.18
9		0.8	2980	1.21
10			3000	1.16
11	HIPS	0.8	500	1.05
12		0.2	467	0.71
13			435	0.80
14			450	0.77
15*			429	–
16	PETG	0.2	1030	1.75
17			1250	1.88
18			970	1.84
19			1050	1.70
20*			1100	–

Note: *front surface of the specimen was exposed to a digital image correlation system (displacement was not monitored).

made of PLA sustain significantly higher axial load to failure than the specimens made of ABS, PETG and HIPS. Identical specimens made of ABS material demonstrates large scatter of the test result (load and displacement behaviour). Test results of the remaining specimens made of the same material indicates almost identical results. It is important to note, that PLA and HIPS specimens were tested using various loading rates. Insignificant scatter of the result indicates that the loading rate does not affect the test result.

Characteristic failure of the test samples is shown in Figure 6. It is noted that failure of PLA specimens is apparently ductile, while the other specimens experienced brittle failure. Strain distribution maps and fracture of the specimens made of PETG and HIPS captured using DIC system are presented in Figure 7.

3. Discussion of the result

The experimentally determined mechanical characteristics of the printed polymeric materials are presented in Table 3. It can be observed that the average elasticity modulus of the materials are higher than the corresponding nominal values provided by producers, while the tensile strength shows the opposite tendency. It might be related to an intricate determination of the cross-section area of test specimens, since all samples were printed with 20% infill.

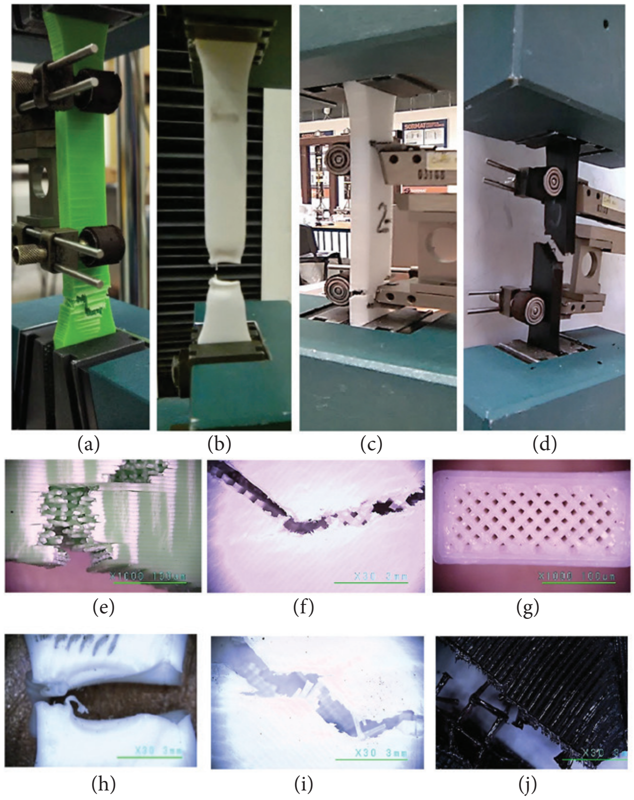


Figure 6. Failure of the samples made of: (a, e, f) ABS; (g) ABS (sample #5); (b, h) PLA; (c, i) HIPS; (d, j) PETG

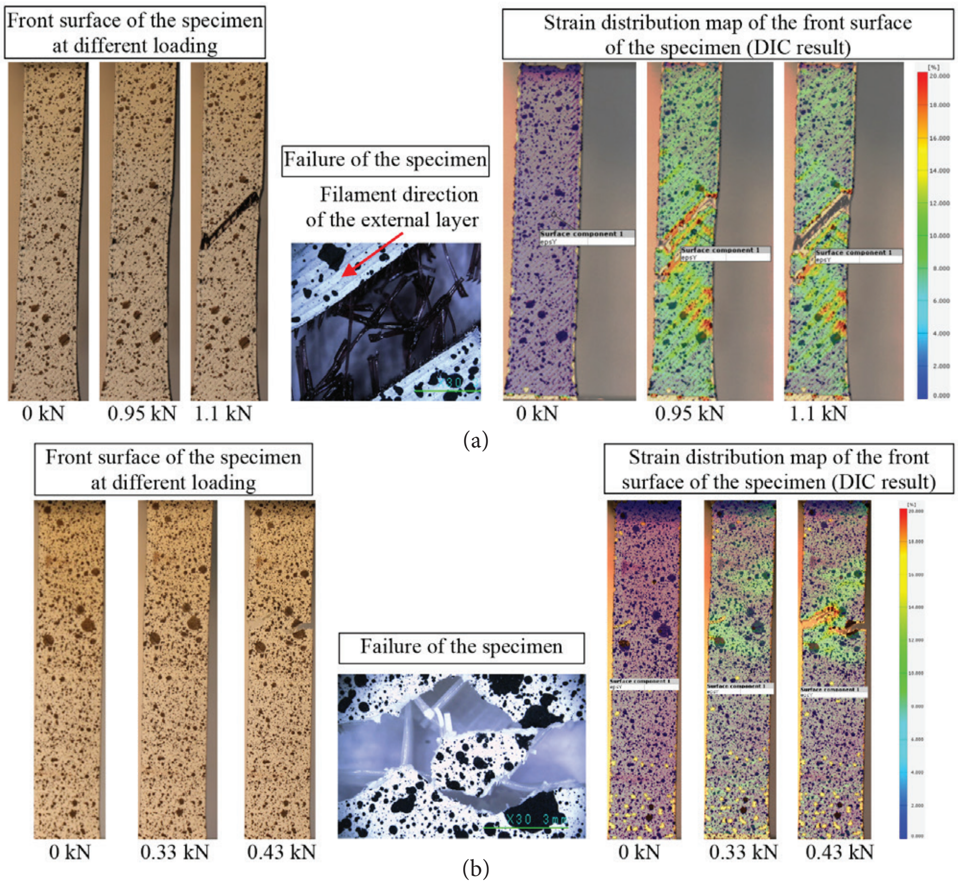


Figure 7. Fracture of the specimens: (a) #20 made of PETG and (b) #15 made of HIPS captured using DIC system

Table 3. Experimentally determined mechanical characteristic of the materials

Specimen number	Material	Tensile strength, MPa		Modulus of elasticity, GPa	
		Test value	Average	Test value	Average
1	ABS	12.39	13.53	2.20	2.71
2		12.69		2.17	
3		12.45		2.25	
4		18.32		3.27	
5		8.97		3.50	
6		14.49		2.73	
7		15.39		2.84	
8	PLA	36.54	37.74	5.43	5.75
9		38.21		5.59	
10		38.46		6.24	
11	HIPS	6.41	5.85	1.33	1.55
12		5.99		1.76	
13		5.58		1.52	
14		5.77		1.60	
15*		5.50		–	
16	PETG	13.21	13.85	1.54	1.54
17		16.03		1.85	
18		12.44		1.41	
19		13.46		1.35	
20*		14.10		–	

Note: *front surface of the specimen was exposed to a digital image correlation system (displacement was not monitored).

Fracture character of the printed specimens is highly dependent on the printing layout and material properties. Strain distribution map of the front surface of the specimen #20 is presented in Figure 7a, while the printing direction is shown in Figure 2c. It is evident that ultimate strain is localized between printed filaments in the specimen made of PETG that causes local failure of the material. The same failure character was observed in specimen #5 printed of ABS: failure crack forms between filaments. It could be noted that the latter fracture manner is characteristic of the relatively brittle materials, such as ABS, HIPS, PETG. Specimens made of PLA experienced fundamentally different ductile failure (Figures 6b and 6h).

All considered specimens had a relatively low infill density that is commonly used for prototyping purposes. For such specimens, the orientation of the filament in the external layers and mechanical characteristics of the bond between the filaments become predominant parameters responsible for the ultimate resistance and failure character of the printed materials. The bond properties between the printed layers are highly sensitive to the extrusion parameters, i.e. extrusion temperature and velocity. Together with the infill density, these parameters are responsible for temperature accumulation process in the printed object that directly correlates with quality of the resultant product (including the printing tolerance). Combination of these parameters is the object of the future research.

Conclusions

This study investigates the mechanical properties and tensile failure of four thermoplastic polymeric materials: acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), high impact polystyrene (HIPS), and polyethylene terephthalate (PETG). The effect of the printing layout on the mechanical properties of the printed materials was emphasized. Based on the tensile tests of printed dumbbell-shaped samples, the following conclusions can be made:

- The loading rate has no significant effect on the results of tensile tests of printed specimens. Insignificant scatter of the test result (load and displacement behaviour) of PLA and HIPS specimens tested using various loading rates was obtained.
- Experimentally determined modulus of elasticity of the polymeric materials are significantly higher than the corresponding nominal values provided by producers. It can be related to an intricate determination of the cross-section area of test specimens and the level of infill density.
- Orientation of the printed filament characterizes strain distribution in the printed specimens. The ultimate strains are localized between printed filaments that induces failure of the printed material. Brittle failure due to debonding of the printed filaments is characteristic of the thermoplastic polymeric material such as ABS, HIPS, PETG.

Acknowledgements

The authors gratefully acknowledge the financial support provided by the Research Council of Lithuania (Research Project S-MIP-17-62).

References

Alaimo, G., Marconi, S., Costato, L., & Auricchio, F. (2017). Influence of meso-structure and chemical composition on FDM 3D-printed parts. *Composites Part B: Engineering*, *113*, 371-380. https://doi.org/10.1016/j.compositesb.2017.01.019

ASTM. (2014). *ASTM D638-14: standard test method for tensile properties of plastics*. ASTM International, West Conshohocken, PA. https://doi.org/10.1520/D0638-14

Brooks, H., & Molony, S. (2016). Design and evaluation of additively manufactured parts with three dimensional continuous fibre reinforcement. *Materials and Design*, *90*, 276-283. https://doi.org/10.1016/j.matdes.2015.10.123

Brooks, H., Tyas, D., & Molony, S. (2017). Tensile and fatigue failure of 3D printed parts with continuous fibre reinforcement. *International Journal of Rapid Manufacturing*, *6*(2-3), 97-113. https://doi.org/10.1504/IJRAPIDM.2017.082152

Cifuentes, S. C., Frutos, E., Benavente, R., Lorenzo, V., & González-Carrasco, J. L. (2017). Assessment of mechanical behavior of PLA composites reinforced with Mg micro-particles through depth-sensing indentations analysis. *Journal of the Mechanical Behavior of Biomedical Materials*, *65*, 781-790. https://doi.org/10.1016/j.jmbbm.2016.09.013

Dawoud, M., Taha, I., & Ebeid, S. J. (2016). Mechanical behaviour of ABS: An experimental study using FDM and injection moulding techniques. *Journal of Manufacturing Processes*, *21*, 39-45. https://doi.org/10.1016/j.jmapro.2015.11.002

Dupaix, R. B., & Boyce, M. C. (2005). Finite strain behavior of poly(ethylene terephthalate) (PET) and poly(ethylene terephthalate)-glycol (PETG). *Polymer*, *46*(13), 4827-4838. https://doi.org/10.1016/j.polymer.2005.03.083

Ferreira, R. T. L., Amatte, I. C., Dutra, T. A., & Bürger, D. (2017). Experimental characterization and micrography of 3D printed PLA and PLA reinforced with short carbon fibers. *Composites Part B: Engineering*, *124*, 88-100. https://doi.org/10.1016/j.compositesb.2017.05.013

Gomez-Gras, G., Jerez-Mesa, R., Travieso-Rodriguez, J. A., & Lluma-Fuentes, J. (2018). Fatigue performance of fused filament fabrication PLA specimens. *Materials and Design*, *140*, 278-285. https://doi.org/10.1016/j.matdes.2017.11.072

Hager, I., Golonka, A., & Putanowicz, R. (2016). 3D printing of buildings and building components as the future of sustainable construction. *Procedia Engineering*, *151*, 292-299. https://doi.org/10.1016/j.proeng.2016.07.357

Jerez-Mesa, R., Travieso-Rodriguez, J. A., Llumà-Fuentes, J., Gomez-Gras, G., & Puig, D. (2017). Fatigue lifespan study of PLA parts obtained by additive manufacturing. *Procedia Manufacturing*, *13*, 872-879. https://doi.org/10.1016/j.promfg.2017.09.146

International Organization for Standardization. (2015). *ISO/ASTM 52900:2015 additive manufacturing – general principles – terminology*. ASTM International, West Conshohocken, PA. Retrieved from https://www.iso.org/standard/69669.html

Karger-Kocsis, J., Bárány, T., & Moskala, E. J. (2003). Plane stress fracture toughness of physically aged plasticized PETG as assessed by the essential work of fracture (EWF) method. *Polymer*, *44*(19), 5691-5699. https://doi.org/10.1016/S0032-3861(03)00590-1

Letcher, T., & Waytashek, M. (2014). Material property testing of 3D-printed specimen in PLA on an entry-level 3D printer. In *ASME Proceedings* (pp. 1-8). https://doi.org/10.1115/IMECE2014-39379

Lu, W., & Yanhua, Z. (2018). Jointly modified mechanical properties and accelerated hydrolytic degradation of PLA by interface reinforcement of PLA-WF. *Journal of the Mechanical Behavior of Biomedical Materials* (in press). https://doi.org/10.1016/j.jmbbm.2018.08.016

Melenka, G. W., Cheung, B. K. O., Schofield, J. S., Dawson, M. R., & Carey, J. P. (2016). Evaluation and prediction of the tensile properties of continuous fiber-reinforced 3D printed structures. *Composite Structures*, *153*, 866-875. https://doi.org/10.1016/j.compstruct.2016.07.018

Miller, A. T., Safranski, D. L., Wood, C., Guldberg, R. E., & Gall, K. (2017). Deformation and fatigue of tough 3D printed elastomer scaffolds processed by fused deposition modeling and continuous liquid interface production. *Journal of the Mechanical Behavior of Biomedical Materials*, *75*, 1-13. https://doi.org/10.1016/j.jmbbm.2017.06.038

Mulrennan, K., Donovan, J., Creedon, L., Rogers, I., Lyons, J. G., & McAfee, M. (2018). A soft sensor for prediction of mechanical properties of extruded PLA sheet using an instrumented slit die and machine learning algorithms. *Polymer Testing*, *69*, 462-469. https://doi.org/10.1016/j.polymertesting.2018.06.002

Ngo, T. D., Kashani, A., lzano, G., Nguyen, K. T. Q., & Hui, D. (2018). Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. *Composites Part B: Engineering*, *143*, 172-196, https://doi.org/10.1016/j.compositesb.2018.02.012

Pinto, V. C., Ramos, T., Alves, A. S. F., Xavier, J., Tavares, P. J., Moreira, P. M. G. P., & Guedes, R. M. (2017). Dispersion and failure analysis of PLA, PLA/GNP and PLA/CNT-COOH biodegradable nanocomposites by SEM and DIC inspection. *Engineering Failure Analysis*, *71*, 63-71. https://doi.org/10.1016/j.engfailanal.2016.06.009

Przybytek, A., Sienkiewicz, M., Kucińska-Lipka, J., & Janik, H. (2018). Preparation and characterization of biodegradable and compostable PLA/TPS/ESO compositions. *Industrial Crops and Products*, *122*, 375-383. https://doi.org/10.1016/j.indcrop.2018.06.016

Scaffaro, R., Lopresti, F., & Botta, L. (2018). PLA based biocomposites reinforced with Posidonia oceanica leaves. *Composites Part B: Engineering*, *139*, 1-11. https://doi.org/10.1016/j.compositesb.2017.11.048

Song, Y., Li, Y., Song, W., Yee, K., Lee, K. Y., & Tagarielli, V. L. (2017). Measurements of the mechanical response of unidirectional 3D-printed PLA. *Materials and Design*, *123*, 154-164. https://doi.org/10.1016/j.matdes.2017.03.051

Sood, A. K., Ohdar, R. K., & Mahapatra, S. S. (2010). Parametric appraisal of mechanical property of fused deposition modelling processed parts. *Materials and Design*, *31*(1), 287-295. https://doi.org/10.1016/j.matdes.2009.06.016

Spiridon, I., & Tanase, C. E. (2018). Design, characterization and preliminary biological evaluation of new lignin-PLA biocomposites. *International Journal of Biological Macromolecules*, *114*, 855-863. https://doi.org/10.1016/j.ijbiomac.2018.03.140

Szykiedans, K., Credo, W., & Osiński, D. (2017). Selected mechanical properties of PETG 3-D prints. *Procedia Engineering*, *177*, 455-461. https://doi.org/10.1016/j.proeng.2017.02.245

Talbamrung, T., Kasemsook, C., Sangtean, W., Wachirahuttapong, S., & Thongpin, C. (2016). Effect of peroxide and organoclay on thermal and mechanical properties of PLA in PLA/NBR melted blend. *Energy Procedia*, *89*, 274-281. https://doi.org/10.1016/j.egypro.2016.05.035

Tian, X., Liu, T., Yang, C., Wang, Q., & Li, D. (2016). Interface and performance of 3D printed continuous carbon fiber reinforced PLA composites. *Composites Part A: Applied Science and Manufacturing*, *88*, 198-205. https://doi.org/10.1016/j.compositesa.2016.05.032

Weng, Z., Wang, J., Senthil, T., & Wu, L. (2016). Mechanical and thermal properties of ABS/montmorillonite nanocomposites for fused deposition modeling 3D printing. *Materials and Design*, *102*, 276-283. https://doi.org/10.1016/j.matdes.2016.04.045

Zhao, X. G., Hwang, K. J., Lee, D., Kim, T., & Kim, N. (2018). Enhanced mechanical properties of self-polymerized polydopamine-coated recycled PLA filament used in 3D printing. *Applied Surface Science*, *441*, 381-387. https://doi.org/10.1016/j.apsusc.2018.01.257

Zhou, Y., Lei, L., Yang, B., Li, J., & Ren, J. (2018). Preparation and characterization of polylactic acid (PLA) carbon nanotube nanocomposites. *Polymer Testing*, *68*, 34-38. https://doi.org/10.1016/j.polymertesting.2018.03.044

Zou, R., Xia, Y., Liu, S., Hu, P., Hou, W., Hu, Q., & Shan, C. (2016). Isotropic and anisotropic elasticity and yielding of 3D printed material. *Composites Part B: Engineering*, *99*, 506-513. https://doi.org/10.1016/j.compositesb.2016.06.009

KONSTRUKCINIS 3D SPAUSDINIMO TECHNOLOGIJŲ TAIKYMAS: SPAUSDINTŲ POLIMERINIŲ MEDŽIAGŲ MECHANINĖS SAVYBĖS

O. Shkundalova, A. Rimkus, V. Gribniak

Santrauka

Modernūs gamybos procesai ir spausdinimo technologijos, naudojant polimerines medžiagas, plečia pramoninės gamybos ribas bei skatina taikyti 3D spausdinimo technologijas daugelyje sričių. Tokios technologijos leidžia gaminti bet kokios formos elementus iš įvairių medžiagų, o jų dydį lemia tik naudojamos spausdinimo įrangos galimybės. Pagrindinis šio tyrimo objektas – polimerinės medžiagos. Spausdintų elementų iš polimerinių medžiagų mechaninės savybės glaudžiai siejamos su gamybos technologija ir gali stipriai varijuoti keičiant gamybos proceso parametrus – spausdinimo temperatūrą, greitį, užpildo tankį. Polimero tipas kartu su jo mechaninėmis savybėmis parenkamas atsižvelgiant į konstrukcinį uždavinį. Šiame darbe nagrinėjamos plačiai prototipų gamyboje taikomų termoplastinių polimerinių medžiagų – polietileno rūgšties (PLA), akrilonitrilo butadieno stireno (ABS), polistireno (HIPS) ir polietileno tereftalato (PETG) – mechaninės savybės. Tyrime dėmesys skiriamas dviem pagrindinėms mechaninėms medžiagų charakteristikoms – tempiamajam stipriui ir tamprumo moduliui. Taikant 3D spausdinimo technologiją buvo pagaminti kaulo formos bandiniai iš PLA, ABS, HIPS ir PETG medžiagų. Bandinių užpildo tankis siekė ≈ 20 % paviršiaus spausdinimo sluoksnio tankio. Elementų tempimo bandymai atlikti Inovatyvių statybinių konstrukcijų laboratorijoje Vilniaus Gedimino technikos universitete. Šiame tyrime buvo parodyta spausdinimo krypties įtaka spausdintų medžiagų mechaninėms savybėms. Taip pat pateiktos eksperimentiškai nustatytos polimerinių medžiagų mechaninės savybės.

Reikšminiai žodžiai: polimerai, 3D spausdinimas, tempimo bandymas, mechaninės savybės, PLA, ABS, HIPS, PETG.