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Authors: Marcin Snopczyński, Jarosław Kotliński, Ireneusz Musiałek

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Testing of mechanical properties of materials used in FDM technology

MARCIN SNOPCZYŃSKI
JAROSŁAW KOTLIŃSKI
IRENEUSZ MUSIAŁEK *

* Mgr Marcin Snopczyński (m.snopczynski@uthrad.pl), <https://orcid.org/0000-0001-8537-907X> – Wydział Mechaniczny, Uniwersytet Technologiczno-Humanistyczny im. Kazimierza Pułaskiego, Radom, Polska

Dr inż. Jarosław Kotliński (j.kotlinski@uthrad.pl), <https://orcid.org/0000-0001-8545-3348> – Wydział Mechaniczny, Uniwersytet Technologiczno-Humanistyczny im. Kazimierza Pułaskiego, Radom, Polska

Dr inż. Ireneusz Musiałek (ireneusz1981@wp.pl), <https://orcid.org/0000-0002-6069-0803> – Wydział Zamiejscowy w Sandomierzu Uniwersytetu Jana Kochanowskiego w Kielcach, Sandomierz, Polska

With the development of 3D printing technology, there is a development in the use of new printing materials. In practice, it often happens that the constructor does not have full data about the material that he wants to use. The article presents the results of tests of tensile strength of samples printed using the FDM method. 3D printing using the FDM method is widespread, however, the properties of the materials used in this method are still not fully understood. The aim of the research was to obtain information on strength parameters that form the basis for further analyzes.

KEYWORDS: 3D printing, strength tests, FDM

Introduction

FDM is a popular 3D printing method (e.g. in the case of machine elements manufacturing) due to the wide range of properties of available materials [1-4] and low prices of printers used in this method.

To be able to take full advantage of the properties of materials, one must first get to know them well. Information on material properties does not contain data on how to prepare samples for testing these properties. Samples intended for testing can be printed with different parameters, and thus may have different internal structure. For these reasons, standardized samples were tested - material properties determined in this way will be a reference point in further research on 3D printed cellular structures.

The following materials were selected for strength tests: PLA, PETG, smart ABS, PLA PRO, HIPS, ASA, polycarbonate (PC-IN), Nylon (PA12) and nanocarbon (PA12+CF).

Preparation of samples for strength tests

Samples for strength tests were prepared in accordance with PN-EN ISO 527-2: 2012 [5]. Sample models were created in Autodesk Inventor 2018 and saved in .stl file format. Fig. 1 shows the shape of the sample with its characteristic dimensions.

Model of each printed sample was set on the X axis (fig. 2). Data of the filaments, from which the samples were printed (fig. 3), are summarized in tab. I.

Fig. 1. Sample for strength tests

Fig. 2. Setting the sample on the 3D printer table - orientation relative to the X axis

Fig. 3. Sample for strength tests printed by the FDM method

TABLE I. List of optimal print parameters for the materials used

Filament	PLA PRO Devil Design	PLA PRO Spectru m	Smart ABS Spectrum	PETG Devil Design	ASA Devil Design	HIPS ArtFlex	PC-IN F3D	NANOCARB ON F3D	NYLON FIBERLOG Y
Head temperature	190°C	205°C	235°C	230°C	240°C	245°C	260°C	250°C	260°C
Table temperature	50°C	50°C	95°C	75°C	95°C	95°C	110°C	115°C	120°C
Material feed speed	35 mm/s	35 mm/s	30 mm/s	35 mm/s	35 mm/s	35 mm/s	25 mm/s	25 mm/s	25 mm/s
Cooling	First layer 20% next 100%	First layer 20% next 100%	No cooling	First layer 0% kolejne 20%	No cooling	No cooling	No cooling	No cooling	No cooling

Samples were made on the Anycubic i3 Mega 3D printer, for which a normalized machine code (G-code) was created in Cura 3.51. Filling of the samples constituted 100% of the material, assuming that the coating of each sample had an outer wall of 1.2 mm thick, made by three strokes of the print head, and the center was made up of fibers in the form of printed lines arranged at an angle of 45°.

Four samples were printed for each material. In tab. I, the optimal print parameters adopted for each material in accordance with the manufacturer's recommendations are presented. For all prints: 1.75 mm filament, 0.4 mm nozzle; the layer height 0.2 mm, was applied [6].

Research

Determination of strength properties was carried out on the basis of a static tensile test using a Labor Tech Lab Test 6.20 testing machine. The test conditions were in accordance with the PN-EN ISO 527-2: 2012 standard.

As a result, strength parameters of selected materials were determined, such as: maximum tensile stress, yield strength, modulus of elasticity and stress-elongation relationships.

Results and analysis

The test results are presented in tab. II. For each material: maximum breaking force, relative elongation at break, yield point, relative elongation at yield, and modulus of elasticity, are given. All samples had the same initial cross-sectional area, therefore it was possible to determine the breaking strength for each material. In addition, the maximum breaking stress was determined.

Fig. 4 presents selected samples after rupture. Fig. 5 shows a graph of tensile force as a function of elongation.

Fig. 4. Selected samples after rupture - from above: PLA PRO, smart ABS, nanocarbon, PC-IN polycarbonate, ASA

TABLE II. List of optimal print parameters for each material

Material	Breaking force value [N]	Tensile strength [MPa]	Relative elongation at break [mm]	Yield point [N]	Relative elongation at yield point [mm]	Modulus of elasticity [GPa]
HIPS	391,58	9,79	4,88	127,16	0,19	31,25
NYLON	1420,66	35,52	13,12	1384,08	4,94	23,31
SmartABS	1875,64	46,89	3,65	0	0	8,59
PLA PRO	1889	47,23	5,52	43,98	0,15	10,29
ASA	1903,28	47,58	4,8	0	0	4,97
PETG	2222,54	55,56	5,325	70,1	0,28	18,83
PLA	2303,56	57,59	6,485	42,72	0,19	5,59
Polycarbonate	2572,12	64,30	6,04	0	0	0,52
NANOCARBON	3002,68	75,07	5,49	2970,4	5,04	0,62

Fig. 5. Graph of tensile force as a function of elongation

Based on the analysis of test results, it can be concluded that nanocarbon, that is a combination of nylon and carbon fiber, has the highest breaking strength. PC-IN polycarbonate is another very durable material, the strength of this material is 14% lower than that of nanocarbon. In addition, there are two groups of materials with very similar strength:

- PLA and PETG with 23-26% less strength than nanocarbon,
- smart ABS, ASA and PLA PRO with 37% less strength than nanocarbon.

PA12 nylon strength is more than half as compared to nanocarbon.

Nylon was the most elongated during the tensile test. The elongation of this material was more than double that of other materials. In turn, smart ABS has the smallest extension. The elongation of smart ABS was only 27% elongation of nylon.

Smart ABS, ASA and PC-IN polycarbonate materials are brittle, therefore the yield strength of these materials could not be determined.

PLA PRO material has twice the elasticity and 18% less strength compared to PLA.

Conclusions

All samples were tested according to the same methodology, in accordance with PN-EN ISO 527-2: 2012, therefore the results obtained for individual materials are comparable.

As expected, nanocarbon (75 MPa) has the highest tensile strength; at the same time, it has one of the smallest modulus of elasticity (0.62 GPa). PC-IN polycarbonate, similar to nanocarbon, with tensile strength of 64 MPa and the smallest of the tested materials, has the modulus of elasticity 0.52 GPa. Both materials can be used to build high-strength machine parts.

PLA and PETG materials have similar tensile strength - 58 MPa and 56 MPa, respectively. However, where greater elasticity is required, PETG should be used, since this material has nearly 3.4 times greater modulus of elasticity than PLA, which is 19 GPa.

HIPS has the lowest tensile strength (10 MPa) - commonly used as a support material when printing with ABS. It has the largest modulus of elasticity of all tested materials - in the order of 31 GPa.

The obtained results were in line with expectations and can be used to select materials for the construction of machine parts (where tensile strength is an important parameter) and as a base and reference point for further research.

Samples of materials printed at the highest working temperatures of the print head and the working table have better mechanical properties and have higher tensile strength than other materials.

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