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STRENGTH TESTING OF 3D PRINTED SPECIMENS

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RESEARCH ARTICLE

ABSTRACT: An important and interesting field of use of 3D printing is the production of parts exposed to physical stress. The strength of the component is influenced by many parameters. In addition to the material quality, fibre thickness, fibre direction, shape and size of the filling, possible composite fibre reinforcement, the conditions of use, e.g. UV light and air humidity also affect the component's load capacity. In our research, we examined 3D printed specimens. We examined the properties of four types of fibre fusion materials and five types of UV-hardening resins with tensile, bending, impact bending and twisting tests: PLA, PETG, ABS, ASA, Onyx, basic resin, water-washable resin, ECO resin, UV tough resin and ABS like resin test specimens made of materials were examined. The study also covered the effect of moisture content. We investigated the weight gain of the test specimens exposed to moisture as a function of time, and then the effect of the moisture content on the strength properties. After the tests, the surface of the specimens was examined with an electron microscope. The results can be well used to select the material and manufacturing technology of 3D printed parts exposed to physical stress and environmental effects.

KEY WORDS: *3D printing, strength test, composite 3D printing, moisture content*

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ISPITIVANJE ČVRSTOĆE 3D ŠTAMPANIH UZORAKA

REZIME: Važna i zanimljiva oblast primene 3D štampe je proizvodnja delova izloženih fizičkom opterećenju. Na otpornost komponente utiče mnogo parametra. Pored kvaliteta materijala, debljine vlakana, pravca vlakana, oblika i veličine ispune, mogućeg ojačanja kompozitnim vlaknima, uslova upotrebe. Na primer, UV zračennje i vlažnost vazduha takođe utiču na nosivost komponente. U našem istraživanju ispitali smo 3D štampane uzorke. Ispitivali smo svojstva četiri vrste materijala za ojačannje vlakanima materijala i pet tipova smola otpornih na UV-zračenjea testovima na zatezanje, savijanje, udarno savijanje i uvijanje: PLA, PETG, ABS, ASA, Oniks, osnovna smola, vodoperiva smola, ECO smola, smole otporne na UV zračenje i ABS pomoću uzoraka napravljenih odo ovih materijala. Studija je takođe obuhvatila uticaj sadržaja vlage. Ispitivali smo povećanje težine ispitivanih uzoraka izloženih vlazi u funkciji vremena, a zatim i uticaj sadržaja vlage na svojstva čvrstoće. Nakon testova, površina uzoraka je ispitivana elektronskim mikroskopom. Rezultati se mogu dobro iskoristiti za odabir materijala i tehnologije proizvodnje 3D štampanih delova izloženih fizičkom opterećenju i uticajima životne sredine.

KLJUČNE REČI: *3D štampa, ispotivanje čvrstoće, 3D štampa kompozia, vlažnost*

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INTRODUCTION

There is not one way, 3D printing can be carried out. Currently, there are seven standard manufacturing processes recognized by the American Society for Testing and Materials (ASTM). All of these processes are additive in nature and differ only in the way layers are laid out. Efforts are on to innovate new processes other than the additive types, but currently only additive manufacturing processes are applicable to 3D printing.

1 PRESENTATION OF USED 3D PRINTING TECHNOLOGIES

1.1 Operating mode of FDM 3D printers

Being an extrusion process, FDM (fused deposition modelling) involves a hot end and a cold end. The hot end is an extrusion head to which the fabrication material is supplied by unwinding plastic filament or metal wire off a coil. The wire or filament is feed to the head's nozzle in a worm-drive at a controlled rate. As the filament or wire enters the extrusion nozzle, it is heated past its glass transition temperature and gets melted.

When the molten filament or wire exits from the extrusion nozzle either exposed to air or an inert gas chamber, it solidifies immediately on a base or onto a preceding layer. The use of inert gas chambers is picking up high as it improves the adhesion of layers due to prevention from oxidation and improves the mechanical characteristics of the created object.

The extrusion nozzle is horizontally and/or vertically movable, while the base platform can move along the remaining third plane. The vertical and/or horizontal movement of the nozzle is controlled by a numerical mechanism, while its movement along the third plane is determined by a tool-path according to a computer aided manufacturing (CAM) software. The nozzle moves from bottom to up finishing deposition of each layer one after the other or remains stationary with respect to the moving platform. The motion of the nozzle is finally rectilinear in an XYZ plane guided by stepper motors. With recent innovations, deltabot has been successfully tried to move the nozzle end.

Usually in FDM, models are built using various types of thermoplastics and their support structures are generated simultaneously. The support structures are needed to keep the model in fixed orientation during the process. The materials used for creating support structures are respective soluble materials. There are two types of thermoplastics that are commonly used in FDM – Acrylonitrile Butadiene Styrene (ABS) and Polylactic acid (PLA). A number of other polymers like Polyamide (PA), lignin, Polycarbonate (PC), Polystyrene (PS), rubber etc. and some conductive materials are also used. [1]

1.2 Operating mode of SLA 3D printers

The basic operation of SLA (stereolithographic apparatus) printers is based on resins (polymers) that bind to UV light. These types of printers are capable of very detailed printing, but they are more complicated to use compared to the previously presented FDMs.

This printing process is different from the production of components based on the principle of fibre fusion, as the liquid from which the test piece is built is located in a tub (VAT), the bottom of which is a thin, transparent film. Light can easily penetrate this FEP film, so its integrity and cleanliness are important. At the start of printing, the stage is immersed upside down in the tub full of resin, until only a very thin layer of resin remains between the stage and the film. Next, the thin layer is illuminated with directed UV light, and after the specific material has set, the stage is lifted and the set part is separated from the foil. After lifting, the table returns to the liquid, and leaving a thin medium between the already printed layer and the film, the UV exposure starts. This process is repeated until the given part is finished. [2]

There are three main categories of SLA processes, laser-based stereolithography (laser SLA), digital light processing stereolithography (DLP-SLA), and masked SLA (MSLA). For all these processes, a vat of photo-reactive liquid resin is selectively exposed to light in order to form very thin solid layers that stack up to create one solid object.

The laser SLA technology works by using a UV laser to draw each layer of the object and uses two mirrors driven by a motor, known as galvanometers or 'galvos' (one on the X axis and one on the Y axis), to rapidly aim the laser beam across the print area, solidifying resin as it moves along.

DLP-SLA uses a digital projector to flash a single image of each layer across the entire platform at once. Because the image of each layer is digitally displayed, it is composed of numerous square pixels, resulting in a layer formed from small rectangular bricks called voxels that stack up along the Z axis.

MSLA utilizes an LED array as its light source together with an LCD photomask in order to shape the light image from the LED array. Like DLP, the LCD photomask is digitally displayed and composed of square pixels. The pixel size varies based on how the LCD photomask is manufactured, and individual pixels are deactivated on the LCD to allow the LED light to pass through to form the resulting layer. Thus, the XY accuracy is fixed and does not depend on how well you can zoom/scale the lens as is the case with DLP [3].

2 FDM MATERIALS

2.1 Polylactic Acid (PLA)

Nowadays, the demand for bioplastics is increasing more and more. It is not necessary to use petroleum for their production, and they also comply with environmental protection aspects. A 2004 study (by the Fraunhofer Institute and Utrecht University) predicted the use of more than 1.4 million tons of biodegradable plastic by 2020, up from 0.9 million in 2000. The food industry is mainly interested in these materials, because oil-based plastics may lose their price advantage due to high oil prices, and environmentally friendly packaging can improve the image of the company and its product. [4]

PLA (polylactic acid) is a plant-based plastic, mostly made from corn starch, and is a thermoplastic material. Scientists from James Madison University examined the material from a food safety point of view, and came to the conclusion that PLA is safe and 'Generally Recognized As Safe' for its intended uses as a polymer for fabricating articles that will hold and/or package food [5]. Nevertheless, the colouring materials used for PLA can be harmful, and the surface of the printed parts can have small holes and cracks in which bacteria can settle. Based on this, PLA can only be safe if it is made into single-use items or used for simpler things, such as storing water. [6]

Certain properties of PLA are worse compared to other materials, so it is used more for the production of prototypes or ornaments. It already warps above 40 °C, it can withstand the cold well. It has a tensile strength of about 61-66 MPa and a flexural strength of 48-110 MPa. It is resistant to fats, oils, alcohol and UV light. It is printed between 185-205 °C, but in some cases these values may change. The molten plastic does not emit harmful gases during the printing process.

2.2 Polyethylene terephthalate glycol (PETG)

PETG is a variation of the highly popular Polyethylene Terephthalate (PET). PET is one of the most common plastics in the world today, and is being used for food containers, water bottles, and even clothing fibres. Its high mechanical strength, resistance to extreme temperatures, and ability to restrict moisture, has made it and its several variations useful for the food industry, as thermal insulation material, or as precursors for engineering resins.

Adding glycol during the polymerization process results in the formation of a "glycol-modified" PET, or PETG. The addition of glycol results in plastic that is more durable, less brittle, clearer, and easier to use. PETG has been widely used for outdoor signs due to its excellent printability and laminating characteristics. Other applications for PETG include medical and food containers, electronic devices, credit or gift cards, store fixtures, and prosthetic devices.

PETG has shown good chemical resistance, whether from acidic or alkali substances. It also retains the excellent moisture blocking characteristic of PET, making it a good choice for containers for water or other drinks. It also convenient for containers that are easier to grip due its softer and more pliable nature. [7]

Its tensile strength is 24-69 MPa, its hardness is 105-119 HRR, its bending strength is 39-89 MPa. In 3D printing, its main advantages are that it is less prone to warping and shrinkage, and it has very good layer adhesion. It combines the favourable properties of PLA and ABS. It is recommended for printing parts that are subject to permanent or sudden stress, such as protective and mechanical parts. It is printed between 220-245 °C, the table must be heated to approximately 70 °C, but 60 °C is sufficient for a glass table. It is recommended to store PET-G filament in an airtight container, even with the presence of silicate, which binds the moisture content of the air. If the filament is wet, it makes a hissing sound during printing, which is the sound of evaporating moisture. Exposure of the printed part to UV light can weaken it.

2.3 Acrylonitrile-Butadiene-Styrene (ABS)

Acrylonitrile-Butadiene-Styrene copolymer got many properties which include light weight, easy formability, abrasion resistance, etc. This is useful for industrial application, making decorative, wheel covers, air conditioning parts, plastic metallization serves to make electronic housing which shows it will be a demanding material in near future. [8]

In addition to injection moulding, it is also used for CNC milling, turning and 3D printing. This plastic is an oil derivative, so it does not decompose in its natural environment. As a result of oil refining, it has the properties of being relatively light, wear-resistant and easy to shape.

Henshaw et al. analyses the failure of a particular brand of automobile seat belts. The failures described were part of what nearly became the most expensive and widespread automobile recall in U.S. history, affecting about 8.8 x 106 vehicles and with a potential total cost of U.S. $109 . The failures were caused by the degradation and fracture of the seat belts' polymeric release buttons. [9]

The hardness of ABS is similar to PET-G (103-112 HRR). Its tensile strength is 42.55-44.8 MPa. It is printed at approximately 240 °C. During printing, the printer must be kept in a heated cabin so that the entire printing process takes place in a warm environment. Without a heated cabin, the layers can separate from each other. It withstands ambient temperatures of up to 90 °C. After printing, the ABS workpiece can be polished with acetone (acetone dissolves ABS).

2.4 Acrylonitrile Styrene Acrylate (ASA)

ASA stands for Acrylonitrile Styrene Acrylate, a thermoplastic that can be used as a good alternative to ABS. Due to its excellent properties and strength, it is also present in automotive components. Its natural colour is off-white, but it can be coloured. ASA material is produced by introducing a grafted acrylic ester elastomer during the copolymerization reaction between styrene and acrylonitrile. The reason for such a change is that ASA is more resistant to weathering and has UV resistance. Some versions also comply with food safety regulations, which is why toothbrushes and coffee machines are also manufactured from it. It is also used for injection moulding, the final product has a high gloss, high impact resistance and good chemical and heat resistance.

ASA plastic is used instead of ABS for mechanical parts that require durability in 3d printing. The finished piece is as strong and resistant as its ABS counterpart, but more resistant to weather and sunlight. It has a tensile strength of about 47 MPa, a flexural strength of 75.5 MPa, and a hardness of 103 HRR. For printing, a temperature between 240-280 °C on a 90-110 °C table is recommended.

3 PRESENTATION OF USED 3D PRINTERS AND MATERIALS

3.1 FDM TECHNOLOGY

The samples were produced with two Ender 3 printers. This type of structure has been one of the most popular FDM printers on the market for several years. Its popularity is due to its simple structure and good modifiability. Its operation is based on the right-angled X-Z principle already presented, the print head moves on an aluminium profile in the X direction, and a trapezoidal spindle ensures its movement in the Z direction. The stage moves in the Y direction on aluminium profiles. The printhead is manufactured with a PTFE tube, the disadvantage of which is that it melts above 230-240°C and emits harmful gases.

With this printing technology, we worked with four types of materials. All specimens were made with 100% filling.

3.2 PLA

This material is perhaps one of the most common in 3D printing. It was printed with a 205°C head, a 60°C glass table and a speed of 50 mm/s, and does not require a heated space.

3.3 PET-G

After PLA, it is perhaps the second most popular material due to its handling and durability. Its printing does not require significant modifications, it can also be used well with a basic level machine. During production, we worked with a 225°C head, a 75°C glass table and a speed of 50 mm/s.

3.4 ABS

ABS is already a big step forward compared to previous materials. It can be said to be more difficult to use, in addition to a few major modifications, it also requires a heated space, because it can separate in layers during printing, one of the causes of which is its greater shrinkage during cooling. It was printed with a converted head at 245°C. The temperature of the stage was set to 100°C, but not with a glass plate but with masking tape, on which we also applied sticky tape to prevent the specimen from detaching. Printing speed reduced to 60%, which corresponds to 30 mm/s. Figure 2 clearly shows its printing conditions. The surface of the finished test piece creates a matte effect.

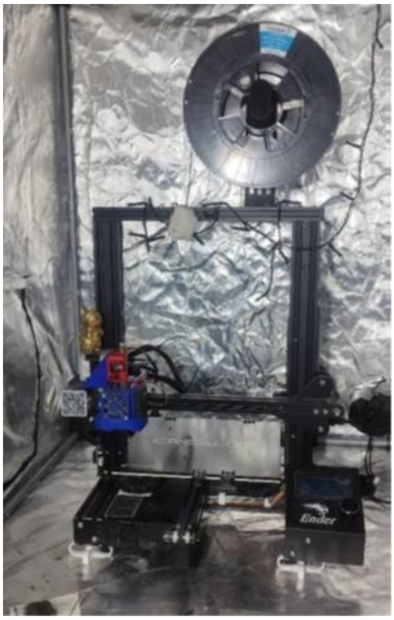

Figure 1. Ender 3 type 3D printer.

Figure 2 Printing of ABS tensile test specimens ASA

3.5 ASA

This type of plastic can be used with similar settings as the aforementioned ABS. They were printed at the same parameters in terms of temperatures and speeds. The final result of one successful print is shown in Figure 3. It can be clearly observed, both in the figure of ABS and ASA that the masking tape was wrinkled after the workpieces cooled down, which is the reason for their greater shrinkage.

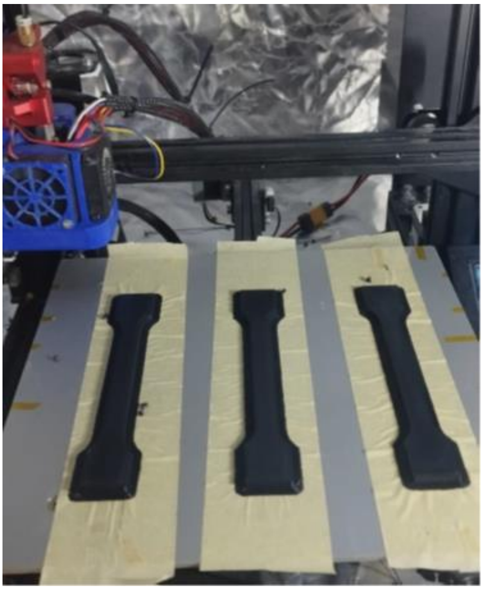

Figure 3 Printing of ASA tensile test specimens

4 SLA TECHNOLOGY

The Anycubic Photon S is an entry-level resin printer operating on the MSLA principle. It was still a popular structure a few years ago, but due to technological progress, printers that are much faster, have a larger stage, and are suitable for making more beautiful test pieces are now commercially available. The advantage of the printer we use is that there are two guide rails next to the trapezoidal spindle, which increases the stability of the table. In contrast, older models of the same age only used one.

Figure 4 Anyicubic Photon S

In the first step, we had to prepare the raw test pieces, for slicing them we used the factory program called anycubic photon workshop. The main printing parameters include a layer thickness of 0.05 mm, an exposure time of 70 s for the eight base layers, and 8 s for the other layers. The Photon S I used has a small stage and is one of the slower machines, so the production process required a lot of time.

4.1 Washing process

The previously presented wash and cure 2.0 structure can already be used for this process, but due to the need for a large amount of liquid, the washing was carried out manually in a box. This operation must be carried out with increased attention and with appropriate protective equipment, as the medium used for washing isopropyl alcohol and the resins used can cause skin irritation and allergic reactions. After the removal of the supports and the washing process, wiping and drying follow.

4.2 Post-treatment process

This process is shown in Figure 5. UV exposure lasted 2x2 minutes, interrupted by a 180° rotation. The average UV exposure time of the materials is 3 minutes, by increasing this time the structure of the material can be logarithmically strengthened, within certain limits.

Figure 5 Post-treatment of specimens

4.3 Moistening

We wanted to investigate the effect of the moisture content of the test specimens on the strength properties. We performed several tests on the printed samples. After printing, we measured the mass of the test specimens and their dimensions. The workpieces were divided into three groups, one group was soaked in water, the other was dried, and the third was placed in a room with average humidity (temperature between 18-24°C, 35-45% humidity). Further investigations summarize these experiments with test specimens with three types of properties. The diagrams show the measurement results of the water-soaked, dried and smooth test specimens left in the air.

TENSILE TEST RESULTS

PLA

This material did not tear immediately after the maximum load, minimal flow is observed. Its maximum elongation is 8% on average.

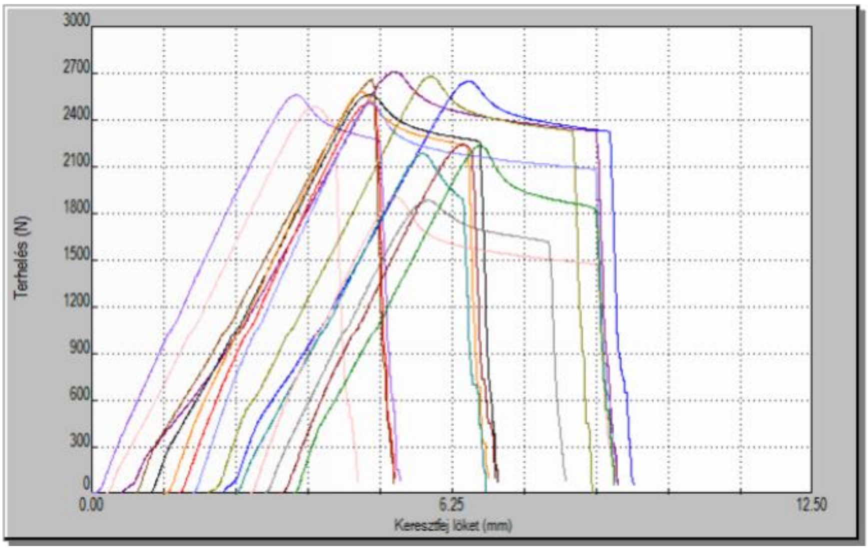

Figure 6 PLA tensile test results

Table 1 PLA test results (blue – moistened, green – dried)

Specimen		Thickness (a) (mm)	Width (b) (mm)	Ft (N)	Fm (N)	Rm (N/mm^2)
1		4,00	10,00	54,0	2231,5	55,79
2		4,00	10,00	97,0	2238,5	55,96
3		4,00	10,00	85,5	1879,5	46,99
4		4,00	10,00	82,0	1901,0	47,53
5		4,00	10,00	9,0	2181,5	54,54
6		4,00	10,00	51,5	2646,0	66,15
7		4,00	10,00	-32,0	2675,5	66,89
8		4,00	10,00	75,5	2505,5	62,64
9		4,00	10,00	96,0	2504,0	62,60
10		4,00	10,00	99,5	2575,0	64,38
11		4,00	10,00	71,5	2559,0	63,97
12		4,00	10,00	63,0	2609,5	65,24
13		4,00	10,00	59,0	2706,0	67,65
14		4,00	10,00	70,5	2482,0	62,05
15		4,00	10,00	79,5	2556,0	63,90

4.4 PET G

The same results were obtained for PET-G as for PLA. The average values of the basic samples (1890.8 N and 47.3 N/mm2) and the dried ones (1912.7 N and 47.8 N/mm2) do not differ much. The results measured during the process can be found in Table 2.

The workpieces soaked in water, on the other hand, broke due to already changed properties. The average values are 1696.2 N and 42.4 N/mm2, which means a 10.3% deterioration.

After the maximum force, the workpieces did not break, but the material flowed and stretched for a while after breaking (Figure 7).

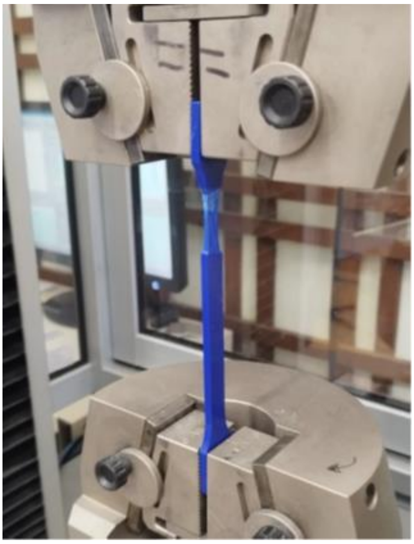

Figure 7 Deterioration of a PETG specimen

This deterioration can also be clearly observed in Figure 8, where the rupture curves of the moistened test pieces can be clearly distinguished. An average of 7%, and about 10% elongation after soaking, before breaking. It is typical for non-soaked specimens that the material broke after reaching the maximum load.

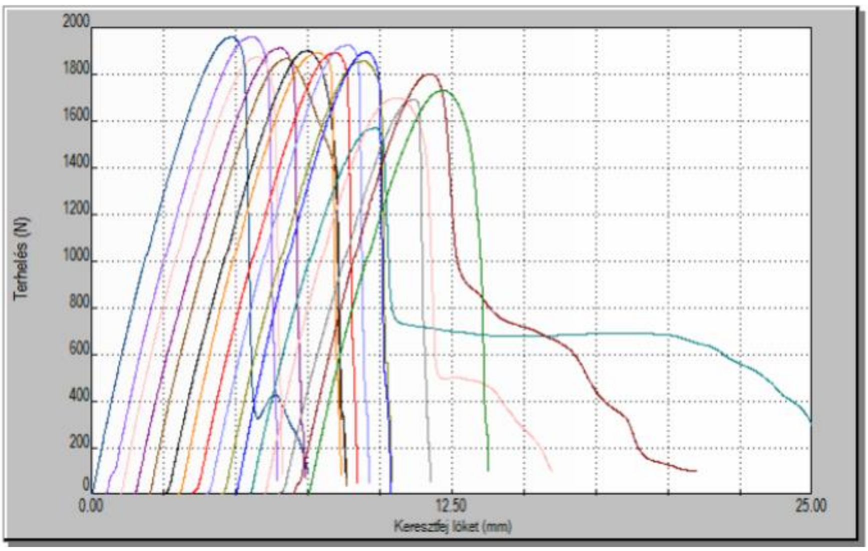

Figure 8 PET G tensile test results

Table 2 PET G test results (blue – moistened, green – dried)

Specimen		Thickness (a) (mm)	Width (b) (mm)	Ft (N)	Fm (N)	Rm (N/mm^2)
1		4,00	10,00	97,5	1728,5	43,21
2		4,00	10,00	99,5	1799,5	44,99
3		4,00	10,00	57,0	1689,0	42,22
4		4,00	10,00	98,5	1696,5	42,41
5		4,00	10,00	94,5	1567,5	39,19
6		4,00	10,00	-38,5	1892,5	47,31
7		4,00	10,00	52,5	1853,0	46,33
8		4,00	10,00	49,0	1923,0	48,08
9		4,00	10,00	47,0	1890,5	47,26
10		4,00	10,00	82,0	1887,5	47,19
11		4,00	10,00	72,0	1898,5	47,46
12		4,00	10,00	35,0	1864,5	46,61
13		4,00	10,00	69,0	1911,0	47,78
14		4,00	10,00	86,0	1871,5	46,79
15		4,00	10,00	62,0	1959,5	48,99
16		4,00	10,00	97,0	1957,0	48,92

4.5 ABS

The average value of the yield strength is 30.6 N/mm2, and the maximum tensile strength is 1223.9 N. The values of the test piece soaked in water are the same, and the dried one shows a 3% deterioration. In Figure 9, it can be observed that after the rapid run-up and the maximum tensile force, the specimens show yielding. During flow, an average load of 250-300 N less than the maximum is required (which is 20-25% of the original) to make the process sustainable. After some elongation (about 10-20%), the test pieces broke.

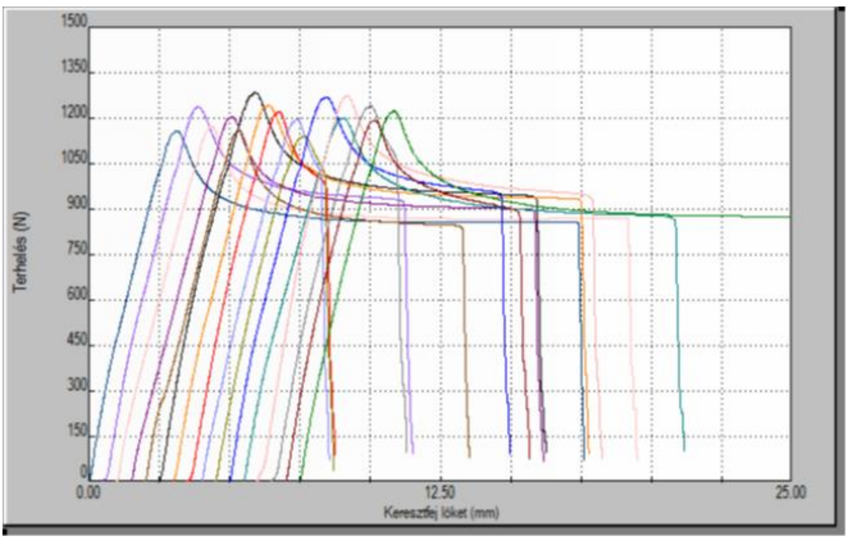

Figure 9 ABS tensile test results

Table 3 ABS test results (blue – moistened, green – dried)

Specimen		Thickness (a) (mm)	Width (b) (mm)	Ft (N)	Fm (N)	Rm (N/mm²)
1		4,00	10,00	88,0	1221,5	30,54
2		4,00	10,00	74,5	1190,5	29,76
3		4,00	10,00	96,0	1239,0	30,98
4		4,00	10,00	75,5	1272,0	31,80
5		4,00	10,00	99,0	1198,5	29,96
6		4,00	10,00	90,5	1268,5	31,71
7		4,00	10,00	36,5	1139,5	28,49
8		4,00	10,00	72,0	1194,0	29,85
9		4,00	10,00	88,5	1218,5	30,46
10		4,00	10,00	92,5	1241,0	31,02
11		4,00	10,00	98,0	1282,0	32,05
12		4,00	10,00	79,0	1156,0	28,90
13		4,00	10,00	68,5	1202,5	30,06
14		4,00	10,00	72,5	1170,5	29,26
15		4,00	10,00	94,0	1235,0	30,88
16		4,00	10,00	72,5	1156,0	28,90

4.6 ASA

Based on the data in Table 4, no significant difference can be established in the results of the test specimens made of ASA material. Average values are 1427.1 N maximum load and 35.7 N/mm2 tensile strength. A 1% increase can be achieved as a result of soaking, and a 2% deterioration can be experienced as a result of drying.

As a result of soaking, the material lost its elasticity, and no flow was observed after the maximum load, but the specimen immediately broke after a short run, which can be seen in Figure 10. With ASA, no large elongation can be observed, as with ABS, the specimen broke after 5-8% elongation.

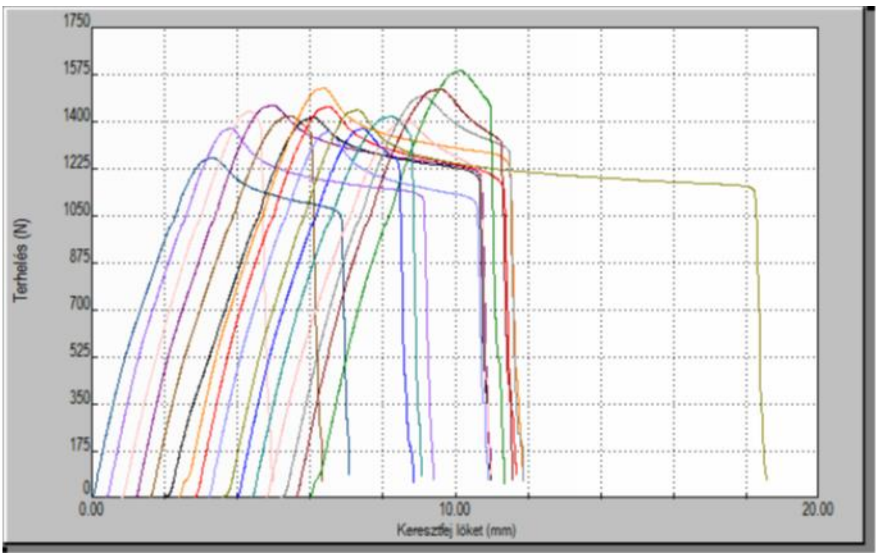

Figure 10 ASA tensile test results

Table 4 ASA test results (blue – moistened, green – dried)

Specimen		Thickness (a) (mm)	Width (b) (mm)	Ft (N)	Fm (N)	Rm (N/mm²)
1		4,00	10,00	54,0	1586,5	39,66
2		4,00	10,00	65,5	1519,0	37,97
3		4,00	10,00	64,0	1492,0	37,30
4		4,00	10,00	90,0	1401,0	35,03
5		4,00	10,00	85,0	1417,0	35,42
6		4,00	10,00	59,0	1372,0	34,30
7		4,00	10,00	65,5	1441,5	36,04
8		4,00	10,00	68,0	1361,0	34,03
9		4,00	10,00	88,5	1453,0	36,33
10		4,00	10,00	80,5	1523,0	38,08
11		4,00	10,00	66,0	1412,0	35,30
12		4,00	10,00	62,0	1419,0	35,47
13		4,00	10,00	98,0	1458,5	36,46
14		4,00	10,00	61,0	1436,0	35,90
15		4,00	10,00	69,0	1373,5	34,34
16		4,00	10,00	89,0	1264,0	31,60

4.7 Onyx glass fiber reinforced carbon plastic

This material is different from the FDM materials previously examined and was produced using the Onyx Pro printer located at the university. The printer handles two materials at the same time and adds glass fibre to the base carbon fibre nylon for reinforcement. The following data were obtained during the tearing of the test specimens, which can be found in Table 5. It can be observed that the material's maximum load and tensile stress are far ahead of those of the previously presented materials. (Among the other materials, PLA had the highest values, half that of onyx nylon.) For the printing of the onyx specimens we used a Markforged Onys Pro 3D printer (Figure 11).

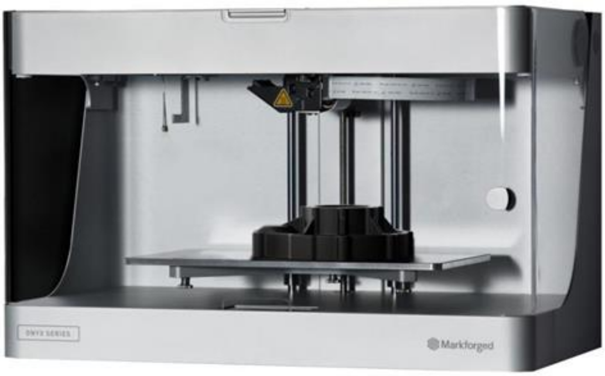

Figure 11 Markforged Onyx Pro 3D printer

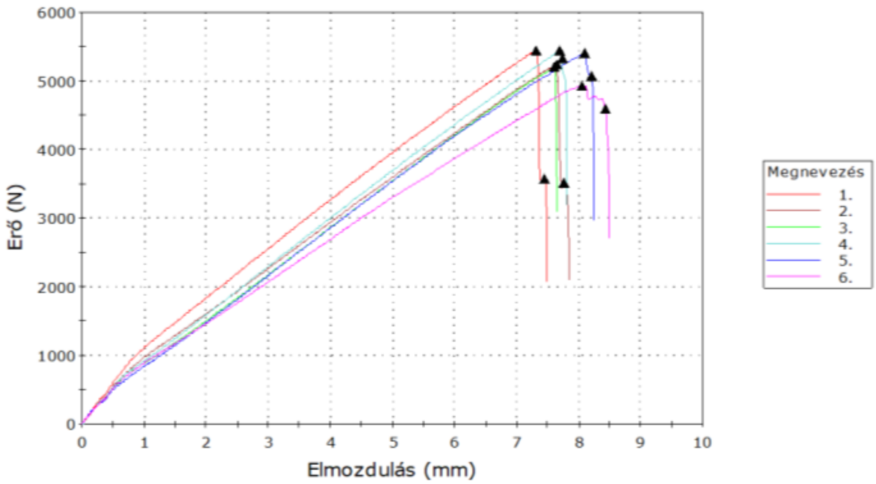

Figure 12 Onyx tensile test results

Table 5 Onyx test results

Specimen	Modulus (MPa)	Elongation associated with maximum force (%)	Maximum tensile stress (MPa)	Maximum load (N)	Elongation at break (%)	Tensile stress at the moment of rupture (MPa)
1	3455	6,36	136,14	5446	6,47	89,17
2	3164	6,65	130,93	5237	6,75	87,76
3	2971	6,62	129,87	5195	6,62	129,87
4	3092	6,69	136,02	5441	6,72	133,12
5	2787	7,04	135,18	5407	7,14	127,05
6	2949	7	123,35	4934	7,33	114,65
Average	3069,67	6,73	131,92	5276,67	6,84	113,60

5 BASIC RESIN

Compared to the basic values (maximum load of 1615.2 N and tensile strength of 40.4 N/mm2), a 12% improvement can be achieved by drying. As a result of soaking in water, the deterioration is 53%, the properties of the material change, its elasticity increases, instead of the average 3-4 mm long elongation, the material can deform 5-6 mm before tearing. Figure 13 clearly shows that the graphs of the three materials with different moisture content can be separated more easily, the difference between their properties has increased. After reaching the maximum load, the workpieces are broken, no flow is observed. Elongation of approximately 9% is observed when drying, 10% at room temperature, and approximately 15% when soaking. After the maximum load, the test pieces broke immediately.

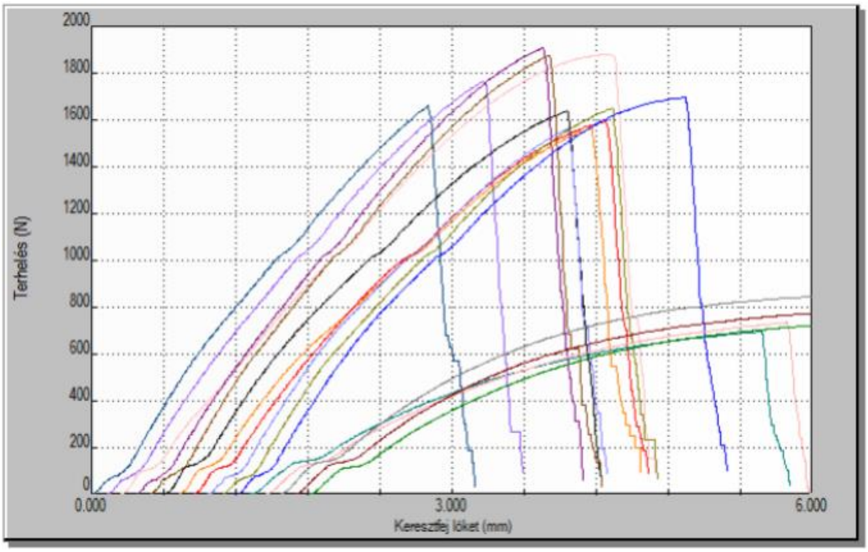

Figure 13 Basic resin tensile test results

Table 6 Basic resin test results (blue – moistened, green – dried)

Specimen		Thickness (a) (mm)	Width (b) (mm)	Ft (N)	Fm (N)	Rm (N/mm²)
1		4,00	10,00	-28,0	751,5	18,79
2		4,00	10,00	-13,5	820,5	20,51
3		4,00	10,00	23,0	867,5	21,69
4		4,00	10,00	-18,5	730,5	18,26
5		4,00	10,00	35,0	691,5	17,29
6		4,00	10,00	97,5	1693,0	42,33
7		4,00	10,00	67,0	1648,5	41,21
8		4,00	10,00	88,5	1560,5	39,01
9		4,00	10,00	86,0	1591,5	39,79
10		4,00	10,00	95,5	1563,0	39,08
11		4,00	10,00	75,0	1634,5	40,86
12		4,00	10,00	33,0	1872,5	46,81
13		4,00	10,00	61,5	1906,5	47,66
14		4,00	10,00	90,5	1879,0	46,97
15		4,00	10,00	92,0	1743,0	43,58
16		4,00	10,00	30,0	1656,5	41,41

6 CONCLUSIONS

When carrying out the tensile test for PLA, a 20% deterioration due to soaking is observed at the maximum load. With PET-G, there are no differences at maximum load, but differences can be found in elongation. The water samples did not break, but flowed. ABS and ASA materials are minimally affected by the moisture content ratio. In the case of resins, it can be said that the workpieces suffer a greater load and less deformation as a result of drying, but a greater elongation and a lower maximum load as a result of soaking.

Overall, it can be stated that the results of the experiments can help the application of these materials. In the future, more detailed and informative experiments must be carried out, but these experiences can serve as guidelines for the design of 3D printed parts exposed to physical stress.

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