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COMPARISON DIFFERENT TYPES OF MATERIALS FOR 3D PRINTING FROM DIMENSIONAL RESPECT

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Abstract:

The aim of the work was to compare currently available and expanded materials for 3D printers using FFF technology. This technology is currently one of the most widespread additive technologies and therefore great attention is paid to the material for this type of 3D printing. The materials used in the experiments were PLA, ABS, PET-G, NYLON and a flexible material with the trade name FLEX. The experimental part consisted of printing test samples from each of these materials. The test sample had randomly selected geometric elements, which were then measured with a caliper and averaged values from 3 identical samples. The results show that a test sample was printed from all the set materials. The best results of accuracy and surface quality were achieved by ABS and PLA materials. In the case of ABS, there was a slight problem with thermal deflection. PET-G material also achieved very good accuracy results, but it required tuning of process parameters. NYLON and FLEX materials are problematic materials for 3D printing, which was also confirmed in tests. Samples from these materials did not achieve the required accuracy and the surface quality was very low. By optimizing the printing process and the input CAD model, some errors could be eliminated, but the print quality would still not reach the value of standard materials.

1 Introduction

3D printing is the process of producing three-dimensional solid objects from a digital file. The creation of a 3D object is achieved by the method of layering the material. The layering process indicates that there is a slow addition of material layer by layer until the product is formed. Each layer is visible on the manufactured part until the final machining (different types of finishing for different types of materials. 3D printing is the exact opposite of machining by drilling or milling using a finished piece of material. This manufacturing process allows complex shapes to be produced using less material than conventional machining methods [1].

Constant developments in this area led to development of alternate print technologies such as fused filament fabrication (FFF – also known as Fused

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Deposition Modeling FDM), digital laser printing (DLP), selective laser sintering (SLS), material jetting, selective laser melting (SLS), and Laminated Object Manufacturing (LOM) [2]. Today, with such large variety of available 3D print technologies, researchers have applied the technology to printing custom labware, environmental studies, tissue engineering, biological sensing, microfluidics, lab-on-a-chip devices, medicine, and electrochemical devices [3]. 3D printing has gained special attention from analytical chemists due to advantages like low fabrication cost, time efficiency, and flexibility to modify surfaces of materials. Additive manufacturing allows users to produce complex 3D structures with precision.

Fig. 1 outlines the steps associated with producing an actual 3D printed object. First, a computer aided design (CAD) software is used for designing a virtual 3D structure in silico. The CAD software also provides an idea of expected structural integrity of the finished product. The next step is the conversion of CAD file to STL (Standard Tessellation File) format, the basic idea behind tessellation is to covert the 2D outer surface of constructed 3D model into tiny triangles known as “facets” which are responsible in describing the surface geometry of object without any representation of texture, color or any other attributes associated with the model. Next step is to transfer the STL file to the computer which is connected to the 3D printer before the actual building of the object takes place on the build stage. Time required and spatial resolution for building can vary significantly depending on the 3D printer under use. After completion of the building, now the object is ready to remove off the printing bed. Depending upon the requirements of the final product, the final step, postprocessing can vary and involves steps like painting, sanding, gluing etc. [4].

3D printing has already become the most prevalent manufacturing technology in the case of prosthetics (e.g. bone and cartilage replacements), dental implants and hearing aids [5,6,7,8]. In other industries, e.g. in the aerospace and automotive sectors, a growing number of major players have adopted 3D printing beyond prototyping to directly manufacture end-use parts and products—Airbus, Ford, General Electric are just a few of many companies that make a significant use of 3D printing technologies [9].

2 Material and Methods

Experimental measurements were based on a comparison of the achieved accuracies and tolerances using the most common materials for FFF printing technology. FFF is an additive manufacturing process that belongs to the material extrusion family. In FFF, an object is built by selectively depositing melted material in a pre-determined path layer-by-layer. The materials used are thermoplastic polymers and come in a filament form. FFF is the most widely used 3D Printing technology: it represents the largest installed base of 3D printers globally and is often the first technology people are exposed to. In this article, the basic principles and the key aspects of the technology are presented. The materials used in the experiment were ABS, PLA, PET-G, NYLON and a flexible material with the trade name FLEX.

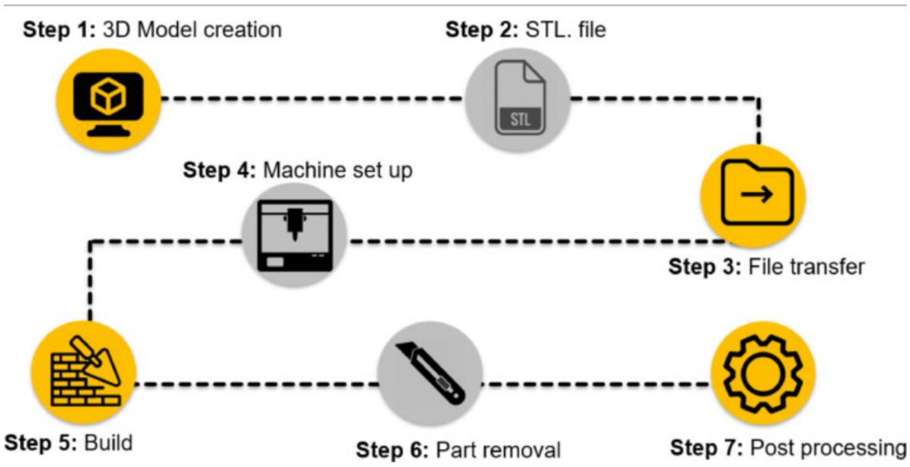

Fig. 1 Steps involved in 3D printing of an object [4]

ABS - Acrylonitrile butadiene styrene is a material based on oil thermoplastic, which is commonly found in timing pipe systems, automotive linings, protective work equipment or toys (Lego). ABS-made components have better strength, flexibility and durability over components made of PLA. ABS printing is more expensive and demanding (it produces unpleasant fumes when heated plastic) [10].
PLA - Polyactic Acid for short PLA is a biodegradable thermoplastic made from renewable sources such as corn starch or sugar cane. In addition to 3D printing, this material is also used for implants in the hospital sector, food packaging but also disposable tableware. The biggest advantage of PLA is that this material is very easy to work with when printing. Compared to ABS material, it works at lower melting temperatures (Tab. 1). PLA is the most widely used material used in 3D printing, not because it would be the best material, but because printing with it is easy. It is used wherever mechanical properties, strength, endurance or wear are not required. This material should not be used anywhere where there is a possibility of breakage, bending, high temperatures or direct UV radiation [10].
PETG - Polyethylene tetraflate glycol is a thermoplastic that is characterized by a particularly high percentage of transparency and a low amount of viscosity. No special accessories are required for printing, printing takes place with parameters similar to PLA [10].
Nylon - nylon fibre is one of the polyamides (PA) - linear polymers with regular amide bonds. Nylon is the first synthetic fibre made exclusively of carbon, water and air. The filament tends to be highly deformed, but the products excel in high strength, resistance and very high resistance to chemicals. Nylon is suitable for printing gears or screws [11,12].
FLEX - Flexible filament has a number of functions, making it an excellent choice for a wide range of applications. The material is resistant to abrasion, oil-based substances, chemicals and wear, making it ideal for use in the automotive industry. Extruded parts made of this material are resistant to low temperatures without becoming a brittle material. The printed products are not subject to severe deformation and almost always return to their original shape. The disadvantage of the flexible filament is that the material shrinks during printing and the printed part peels off from the printing substrate in several layers. To avoid this problem, it is necessary to improve the adhesion by adding a 10 mm single-layer bead around the printed part, which ensures heat dissipation over a larger area [13].
Printing took place on a 3D printer PRUSA I3 MK3 using FFF technology. The print parameters were the same for all materials. The diameter of the Tyrolean was 0.4 mm, the print speed was 200 mm/s and the filling was a rectangular pattern with a density of 80 %.

Tab. 1 Printing parameter and properties of the most used materials for 3D printing

	PLA	**ABS**
Extruder temperature	180-230 °C	210-250 °C
Bed temperature	20-60 °C	80-110 °C
Bed	optional	required
Enclosure	optional	recommended
Adhesion of the first layer	moderately difficult	moderately difficult
Vapors	Almost none	more and intensely
Moisture absorption	yes	yes

The evaluation of the accuracy and quality of the component created for the individual materials was evaluated by measuring the selected dimensional parameters and optical evaluation of the surface quality. Each test piece of a given material was printed 3 times. Using a caliper, 3 the selected dimensions were measured, and average value and standard deviation were calculated. Three identical measurements were performed for each measured parameter. From the average data thus obtained, graphical dependencies were created that show the actual dimension from the ideal. The dimensions that were evaluated were an inner diameter of Ø10 mm, an outer diameter of Ø6 mm, an element height on the part of 6 mm and an edge in the X-axis direction of the part of 20 mm.

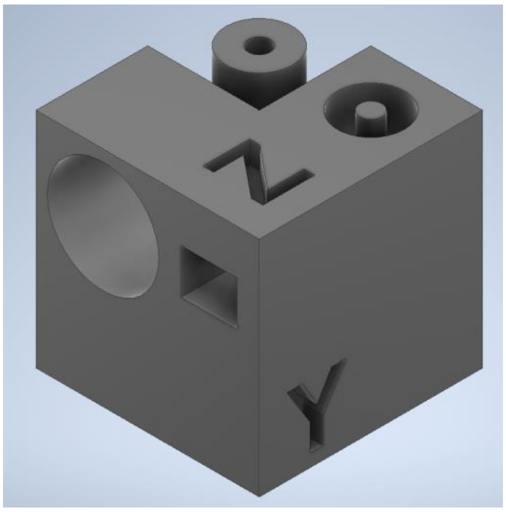

Fig. 2 Model of test specimens

3 Results and Discussion

Test components made of PLA material (Fig. 3) achieved very good results in dimensional stability and accuracy. There were also no significant optical and surface defects on the components. Minor errors occurred on the letters X and Z due to insufficient air access from the fan. The last damage remains the reduced space of the hole in the cylinder on the test cube, which was created due to the thickness of the printing layer.

The parts extruded from the ABS material were also free of significant damage or inaccuracies, but the first cube deformed the first layers, all three damaged the letter X, and the internal holes in the samples narrowed due to the thermal extensibility of the material. This material is a modified version of the most used plastic in the world PET. It was formed by adding G-modified glycol, which is added to the material composition during polymerization. The result is a stronger fiber, less brittle, but very difficult to print. After requesting the process parameters, the printing of the components went without major problems. The surface and dimensions of the components were at a very good level comparable to PLA and ABS materials.

NYLON is one of the strongest filament materials for FFF printers. Nylon is a synthetic polymer based on polyamides. It is durable, strong, flexible and a bit flexible. Nylon is a hygroscopic material and must be stored in a dry place and dried before each print. Printing this material is very demanding, as evidenced by our results. Samples of this material had many surface defects and damage, as well as dimensional accuracy was very poor.

Flexible material FLEX is suitable for printing seals and components with the need for high material flexibility. When printing, we used a single-layer edge around the sample to ensure adhesion, as the flexible material tended to shrink. Some samples were visually damaged, but the biggest problem with printing from this material is smaller holes and holes, which was also shown in the resulting values. Also, the surface of samples showed significant imperfections (Fig. 4).

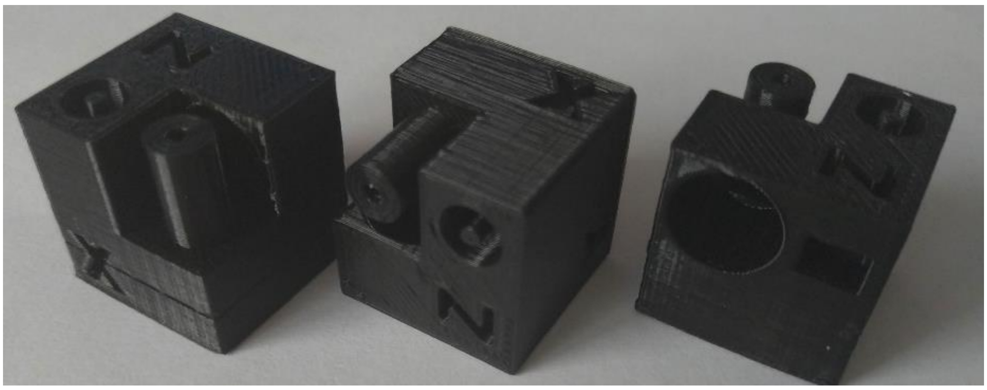

Fig. 3 Test specimens made of PLA material

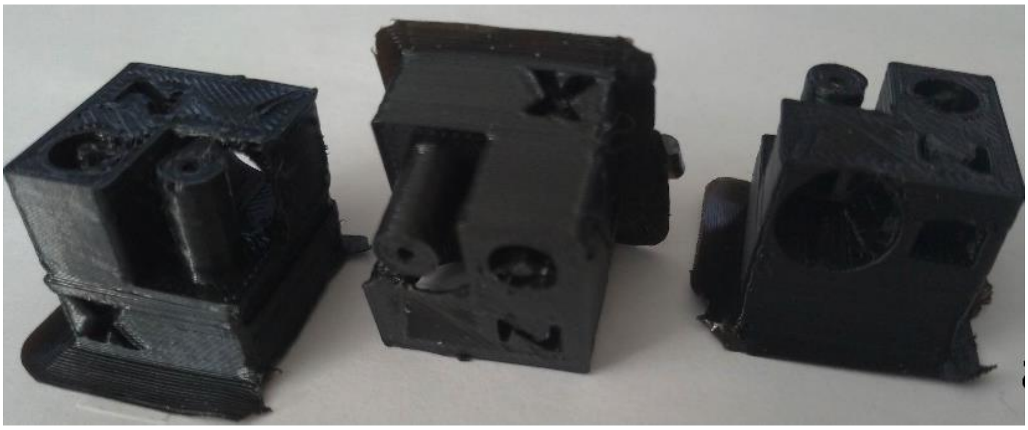

Fig. 4 Test specimens made of FLEX material

The measured and calculated average values of the actual dimensions are listed in Tab. 2. The average values of the measured elements and their standard deviation are also given there. A graphical representation of the results together with the deviations in the form of error bars and an indication of the ideal value of the measured parameters is shown in Fig. 5. As the graph shows in terms of accuracy, the standard ABS and PLA materials are best used. The deviations measured for these materials were within the general tolerances of ISO 2768-m.

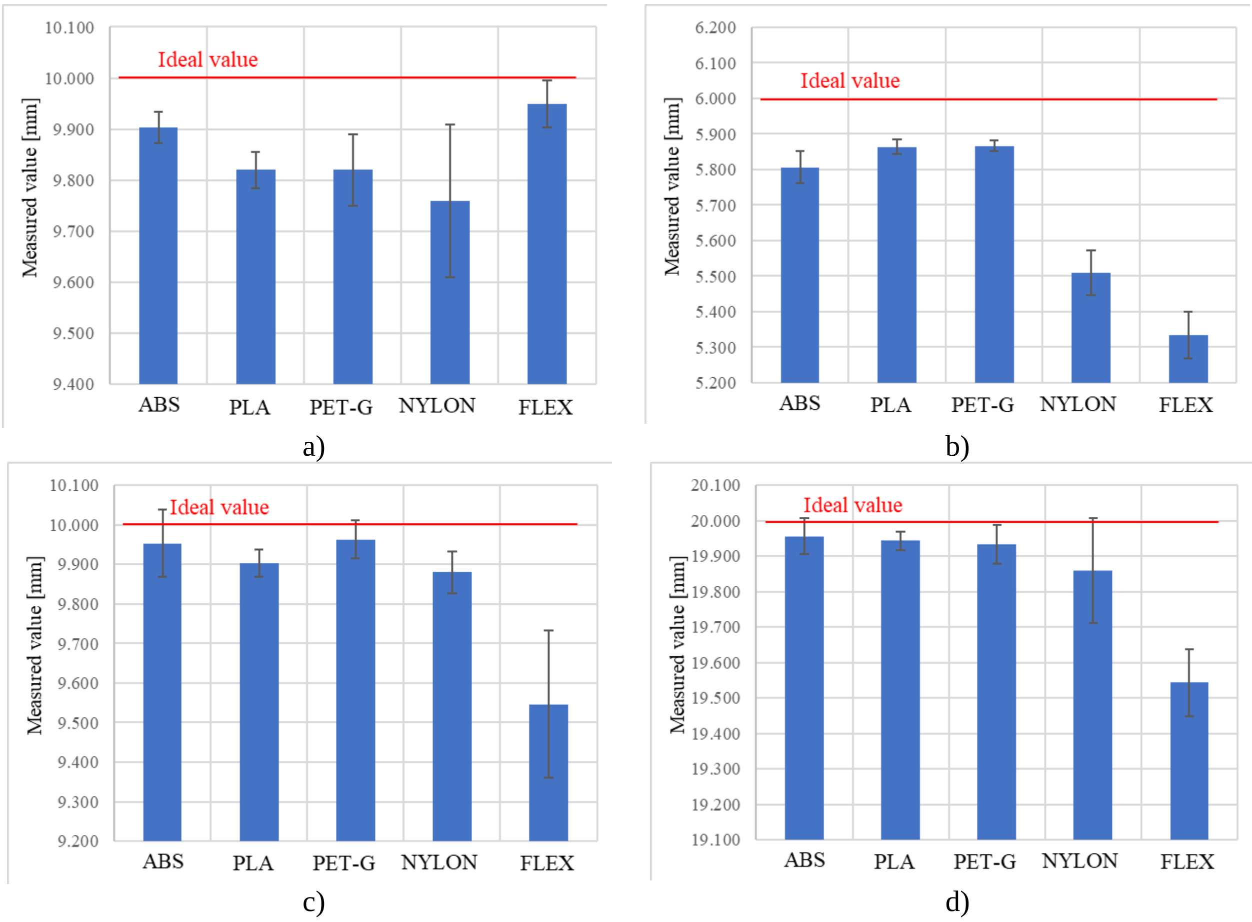

Fig. 5 a) Obtained actual values of inner diameter Ø10 mm, b) Obtained actual values of outer diameter Ø6 mm, c) Obtained actual values of element height 10 mm, d) Obtained values of part edge length 20 mm in X direction

Tab. 2 Measured and calculated values of geometric dimensions of printed samples

		ABS	PLA	PET-G	NYLON	FLEX
Diameter Ø 10 mm	Sample 1 [mm]	9.91	9.86	9.9	9.59	9.94
	Sample 2 [mm]	9.93	9.79	9.78	9.87	10
	Sample 3 [mm]	9.87	9.81	9.78	9.82	9.91
	Average value [mm]	9.903	9.820	9.820	9.760	9.950
	Standard deviation [mm]	0.031	0.036	0.069	0.149	0.046
Diameter Ø 6 mm	Sample 4 [mm]	5.81	5.87	5.85	5.49	5.35
	Sample 5 [mm]	5.76	5.84	5.87	5.46	5.39
	Sample 6 [mm]	5.85	5.88	5.88	5.58	5.26
	Average value [mm]	5.807	5.863	5.867	5.510	5.333
	Standard deviation [mm]	0.045	0.021	0.015	0.062	0.067
Height 10 mm	Sample 7 [mm]	9.89	9.94	9.91	9.92	9.76
	Sample 8 [mm]	9.92	9.9	10	9.82	9.46
	Sample 9 [mm]	10.05	9.87	9.98	9.9	9.42
	Average value [mm]	9.953	9.903	9.963	9.880	9.547
	Standard deviation [mm]	0.085	0.035	0.047	0.053	0.186
Length 20 mm	Sample 10 [mm]	19.97	19.94	19.88	19.95	19.51
	Sample 11 [mm]	19.9	19.92	19.93	19.94	19.65
	Sample 12 [mm]	20	19.97	19.99	19.69	19.47
	Average value [mm]	19.957	19.943	19.933	19.860	19.543
	Standard deviation [mm]	0.051	0.025	0.055	0.147	0.095

The surprise is the PET-G material, which also reached all dimensions within a given tolerance. NYLON material no longer reached the given tolerance in most of the examined dimensions. The worst result was the FLEX material, whose deviations were in some cases up to 0.7 mm.

4 Conclusion

The aim of the work was to compare currently available and expanded materials for 3D printers using FFF technology. This technology is currently one of the most widespread additive technologies and therefore great attention is paid to the material for this type of 3D printing. From the achieved results of this work, it can be stated that all selected materials, i.e. ABS, PLA, PET-G, NYLON and FLEX were able to print the test part. In the case of ABS, PLA and PET-G, there was no significant printing problem, and the process parameter was based on software or manufacturer's recommendations. The accuracy achieved with these materials met the ISO 2768-m standard. However, there were significant problems with NYLON and FLEX printing. In the case of NYLON material, it could also be caused by air humidity, which affected the print. This type of material should be placed in a hermetically sealed container during printing and only the part of the filament associated with the extruder should be exposed to atmospheric moisture. FLEX is a very difficult to print flexible material, where achieving accurate dimensions often depends on a trial-and-error method, and it is always necessary to adjust the geometry of the model and add or remove material for each geometric element to achieve the final dimension within the required tolerance.

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