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Research Article

ANALYSIS OF PRINTING PARAMETERS FOR PRODUCTION OF COMPONENTS WITH EASY3DMAKER PRINTER

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ABSTRACT

The presented article deals with analyses and testing appropriate parameters for the production of components manufactured with rapid prototyping technology – Easy-3DMaker printer. The quality of the printed component with a specific shape is analyzed. The analyzed materials are ABS Printplus and PLA Printplus. These materials are printed at different temperatures and speeds. combinations of different settings were tested in order to find the best conditions for printing with different nozzles. The quality of individual printed samples is assessed visually and by touch. The efficiency in terms of print time under various conditions was also analyzed. The main benefit of testing is the establishment of appropriate conditions for printing components on a Easy3DMaker printer. The article does not focus on mechanical properties of the examined samples.

Keywords: 3D printer, printing parameters, ABS, PLA.

INTRODUCTION

At present rapid prototyping methods are widely used. The application of this method minimizes production costs, improve quality and increase productivity [3, 5]. The speed of production, price, quality and precision are most important parameters in the production of prototype [8]. All these requirements can be achieved with different methods of prototype production. Frequently used methods are e.g. Stereolithography (SL) and Selective Laser Sintering (SLS) that use powerful lasers and are installed outside engineering offices [4]. Another alternative technology is Fused Deposition Modeling (FDM). This without-laser method allows creating a physical model using molten plastic filaments applied in layers on build platform with foam base. Working materials are most likely non-toxic thermoplasts or waxes. These are in the extrusion head heated up to a temperature slightly higher than their melting point. Then they pass through an extrusion nozzle with defined bore diameter to achieve desired thickness of extruded material. The impact of high local temperatures in the contact area a strong link between molten filament and component's surface is created. The first layer of filament is fastened on the built platform with a help of thin film of glue, adhesive tape or similar material with high adhesion. Typical layer thickness is within the range of 0.1 mm to 0.25 mm. This type of printing requires creating material supports. There are several ways to create material supports. The first way is that they are printed from same material as the rest of the component but with different conditions. The second way is that they are printed form different material using a second nozzle. The advantage of the second method is that none of the materials is mixed with each other and can be easily separated after printing (e.g. means an aqueous solution or ultrasound). FDM technology is an interesting compromise between production precision, speed and durability of model. A big advantage of FDM

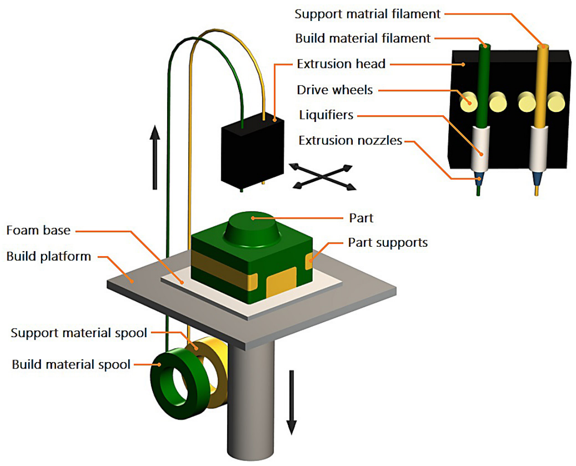


Fig. 1. Principle of FDM technology [7]

technology is a possibility of deployment components in normal office environment. Easy3DMaker printer used in our analysis is also based on this technology [7]. The principle of FDM technology is shown on Figure 1.

ANALYSIS OF APPLIED MATERIALS FOR 3D PRINTING

Currently, plastics are most widely used materials for 3D printing. They are often used in design, architecture, automotive, aircraft technology, and healthcare and electronics industry. The most common plastics are ABS (acrylonitrile butadiene styrene) and PLA (polylactic acid) [3].

ABS Material

ABS polymers are combinations of monomers acrylonitrile butadiene styrene with significantly better chemical resistance and toughness than polystyrene and with retaining sufficient of rigidity. It is a heterogeneous material. In a continuous phase of styrene acrylonitrile copolymers are scattered small particles of polybutadiene rubber. ABS polymers have similar morphological structure as impact polystyrene. They are characterized by low resistance to weathering and aging caused by the influence of light. ABS polymers can be well processed by all common technological procedures used in thermoplastic injection, rolling, molding, thermoforming and stamping. Quantitatively, most significant (55%) is injection at 180°C to 250°C, followed by extrusion on worktops at 150°C to 215°C (35%). The use of other technologies is 10%. ABS can be well glued, welded and finished. In terms of price, ABS polymers are more expensive than high impact polystyrene or polyolefins, but much cheaper than polyamides and polycarbonates. They have a low density (1.02 to 1.08 $g \cdot cm^{-3}$) and therefore their use is advantageous, compared to the volume unit. The material used for our analysis is ABS Printplus. It is specifically designed for 3D printing. High precision of filament ensures high print quality. Low dependence on accurate of extrusion head and durability of printed component are the major advantages of this material. The material is not recommended for ordinary printing of large objects where the longest dimension exceeds 80mm. Printed component can be easily machined by grinding, drilling and surface can be modify by printing [1].

PLA Material

Polylactic acid belongs to the group of biodegradable polyesters. Polylactic acid has a structure of linear polyester. Lactic acid for lactide preparation may be obtained by glucose fermentation . The raw material is obtained by digestion of starch extractable from normal farming crops, mostly maize, sugar beet and sugarcane. Due to the PLA interesting properties, such as transparency, low value of ductility, excellent mechanical strength and biodegrability is application of PLA very diverse. It is used as a packaging material in a form of bottles or crucibles. Technologically, it is possible to use any known technology like injection, extrusion, molding and the like. Polylactic acid is, along ABS, the most widely used material for thermoplastic extrusion method of 3D printing, including FDM technology. For the purposes of 3D printing it is usually supplied in a form of a wire with diameter at 1.75 mm to 3 mm. Compared to ABS, PLA is easier and faster to handle at the same printing conditions. PLA prod-ucts are considerably less resistant to high temperatures but are less susceptible to distortion and errors. It does not require the strict application of heated worktops. From a material point of view, the products of PLA are less flexible and have higher gloss [9, 10].

THE EASY3DMAKER PRINTER

Easy3DMaker printer is an easily manageable printer. Due to its properties, it is used by hobby modelers, designers of small forms and all users which need their 3D designs materialize in qual-

Table 1. Important parameters of 3D printer Easy3D-Maker [2]

Printing material	ABS, PLA
Dimensions of workspace	200×200×230 [mm]
Total modeling space	9200 [cm^3]
Resolution of layer	0.08 / 0.125 / 0.25 [mm]
Dimensions of 3D printer	400×400×500 [mm]
3D printer weight	16 [kg]
Print speed	80 [mm·s^{-1}]
Power supply/ input power	24V / 180W
Maximum temperature	280 °C

ity and quickly way. The benefits of printer are handling, stability and reliability. For production of all components of the printer are used aluminium alloys and steel [2]. Construction of printer with description of individual parts is shown in Figure 2. In Table 1 all important parameters of the printer are lists.

3D printer is able to print with a filament of of 1.75 mm thickness from ABS or PLA material. Depending on bore diameter of a nozzle can be used the thicknesses of layer 0.08 mm, 0.125 mm or 0.25 mm. Extruder head is equipped with stepper motor, which ensures uniformity of material dosage. Accurate and reliable positioning of a movement in the Z axis is achieved using dual fusing on linear ball bearing. The printer is controlled by G3DMaker software that is supplied with the 3D printer. It is user friendly and intuitive software. The user can load and prepare the model for printing directly in the visual environment. A model can be moved and rotate in x, y and z axis. It is also possible to load several models and change their size. The supported formats for this software are STL and 3DS. The generated G-code determines the approximate time of printing and also consumption of material [2, 6].

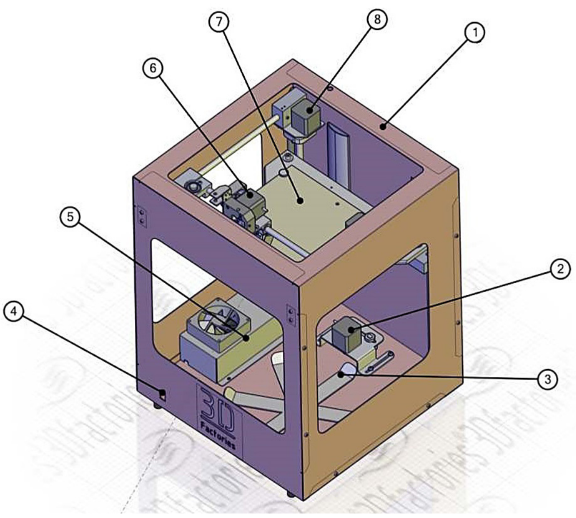


Fig. 2. Construction of 3D printer Easy3DMaker: 1 – outer casing, 2 – z-axis servomotor, 3 – material holder, 4 – power switch, 5 – control electronics, 6 – extrusion head, 7 – build platform, 8 – y-axis servomotor [2]

METHODOLOGY OF PRINTING

Exploring the best conditions for 3D printing was based on following points:

- used printer Easy3DMaker,
- used materials ABS Printplus and PLA Printplus (suitable for used printer),
- defined shape and dimensions of test sample,
- under conditions of printing more testing samples in less time was selected hexagonal shape with different sizes of rounded edges and internal bore to print accuracy,
- used nozzle: 5 mm, 3 mm and 2 mm, in experiments with the sequence of largest to smallest nozzle,
- constant parameters:
  – temperature of print table, PLA = 50 °C,
  – filling form: honeycomb,
  – filing density: 50%,
  – defaultcooling parameters (for each material),
- use of external cooling fans for shortening the cooling of pad.

TEST SAMPLE FOR 3D PRINT

The defined methodology of work shows that the experimental sample must be simple. Components with various shapes and difficult construction are unsuitable for the purpose of determining printing conditions [10]. The model of experimental component is shown in Figure 3. It is a simple component with hexagonal shape with different rounded edges. The inner hole has a shape of tear. Different rounded corners are used for detection of printing precision. Dimensions of experimental component are 26×24×15 mm. These dimensions were chosen for shortening time and possibility of printing a larger number of test samples. This allowed detailed analysis of printing conditions.

PRINT SETTINGS

All settings related to printing are in G3D-Maker represented with print profiles. The main

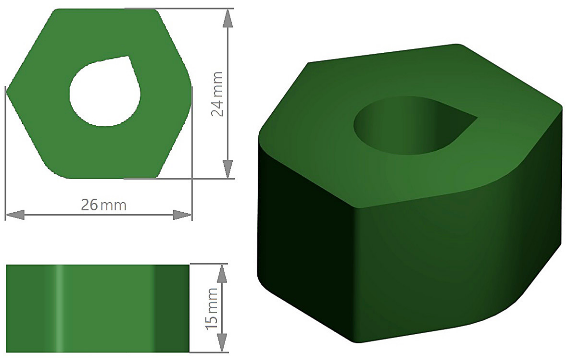


Fig. 3. Model of test sample

parts of the print profile are common settings, cooling, speed and advanced settings. In common settings user define the accuracy, retract, print settings and the skirt. Accuracy defines the height of the first layer and the number of layers to be filled. A retract adjust the speed of pull, length of the pulled material and the number of print table decreases during retract. Print settings contain several important parameters which substantially affect the quality of surface and internal structure of the produced components. This is particularly solid layers parameter that show a number of horizontal layers on the base and the top of the model, fill pattern that offer different types of the internal structure. The solid pattern is used to select the shape of the outer layer. Skirt is used to launch extrusion before printing. Cooling allows to set cooling fan parameters for proper component cooling. It is possible to start cooling under specified conditions or cooled constantly during the entire period of the press. Print speed parameters have substantially affect the quality and accuracy of the printed parts. In this section are defined speeds of printing perimeters – v_p, small perimeters – v_{sp}, infill – v_i, solid infill – v_{si}, top solid infill – v_{tsi}, bridges – v_b and external perimeter speed – v_{ep}. An important parameter in an advanced setting is extrusion width – e_w. This is a theoretical value which indicates the width of the printed material. It is necessary for a proper calculation of the extruder path. An advanced setting allows also to set parameters for a support material.

DETERMINE THE PARAMETERS FOR PLA PRINTPLUS

This section describes production of components using polymer PLA Printplus material and nozzles with bore diameter – n_d, about a size: n_d = 0.5 mm, n_d = 0.3 mm and n_d = 0.2 mm.

The nozzle 0.5

The first test sample PLA1 was printed with the random printing parameters.This setting was based on the user's manual for the used printer. We started with maximum layer thickness l_t = 0.25 mm. The printed component has a high peripheral inequality. The top solid layer and covering layer insufficiently overlap the internal structure. On the second test sample PLA2 thickness of the extruded layer was reduced to l_t = 0.125 mm. It was found that this parameter has a large impact to print quality. The surface around the perimeter of the component is softer and the layers have better fitting. Top covering layer also have less rough surface. The internal

Table 2. Appropriate printing conditions for PLA Printplus

PLA Printplus			
Parameters for printing / Nozzle bore diameter – n_d	0.5 mm	0.3 mm	0.2 mm
Thickness of layer – l_t [mm]	0.125	0.125	0.08
Temperature of nozzle – t_n [°C]	205	205	205
Temperature of build platform – t_{bp} [°C]	50	50	50
Solid (horizontal) layers [–]	4	6	8
Type of infill [–]	Honeycomb	Honeycomb	Honeycomb
With of extrusion – e_w [mm]	0.5	0.27	0.25
Speed of retract – v_r [$mm\cdot s^{-1}$]	400	400	400
Perimeter speed – v_p [$mm\cdot s^{-1}$]	50	35	30
Print speed of infill – v_{pi} [$mm\cdot s^{-1}$]	45	35	30
Print speed of solid infill – v_{si} [$mm\cdot s^{-1}$]	40	30	30
Print speed of covering layer – v_{cl} [$mm\cdot s^{-1}$]	35	30	30
Time of print – t_p [min]	65	92	155

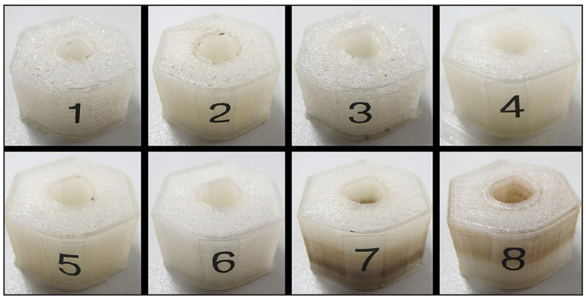


Fig. 4. The PLA test samples printed with nozzle bore diameter 0.5 mm

structure is printed more accurately, which contributes to higher strength of the finished part. On test samples PLA3 and PLA4 the impact of travel speed was examined. A significant change of value had no impact on print quality. At the test sample PLA5 the value of a perimeter speed was changed to v_p = 40 mm/s. A small variation of this parameter does not cause visible changes on the surface of part. test sample PLA6 has a similar look, where the speed of covering layer was changed to value v_{cl} = 35 mm/s. The internal structure of the component is not completely covered because it was set at high speed of the top infill printing. Setting of appropriate temperature for printing was verified at the test sample PLA7. The temperature was increased from t_e = 205°C to t_e = 215°C. By observation, it was found that the temperature is too high and leads to overburning the materialas there were visible dark material layers on the parts. Test sample PLA8 was printed with higher number of solid layers. This slightly lengthens the time of production. Pictures of the printed samples are presented in Figure 4.

The nozzle 0.3

The use of nozzle with smaller diameter does not mean that the printed product will have automatically better quality. Test samples from PLA9 to PLA16 are produced under the same conditions as the first 8 test samples. The surface quality of these samples is very similar to the test samples extruded with nozzle n_d = 0.5 mm. For enhanced quality, it is necessary to amend the previous print settings. A very important parameter which largely influences the print is the width of extruded material. When we use a nozzle with diameter n_d = 0.3 mm, it is appropriate to set this parameter at value e_w = 0.27. In case of badly chosen value caused that component is produced with many errors. In addition to reducing the value of extruded material it was also necessary to reduce the speed of layering. Lower speeds caused thinner fiber of material was better caught to previous layer. The surface of a part is softer to touch. The test sample PLA26 was printed after finding all suitable conditions for nozzle with bore diameter n_d = 0.3 mm. Fibers on covering layer are more linked and cause better covering of the infill. The black spot on the top of component is due to inclusion. See Figure 5.

The nozzle 0.2

By using a nozzle with bore dimension n_d = 0.2 mm we are able to make components with high quality. It was necessary to set thickness of extruded layer to the value l_t = 0.125 mm or lt = 0.08 mm. The parts printed at the lowest thickness are characterized by top quality of surface and internal structure. Test samples from PLA 17 to PLA24 were used to find the best conditions for printing with nozzle bore diameter n_d = 0.2 mm. Using the most appropriate conditions for printing form PLA material the test sample PLA27 was printed. A large share to quality of its surface had a low speed of layering. also width of extrusion was changed to value e_w = 0.2 mm. The resulting surface of part is smooth. Compared to other samples, the test sample PLA27 is the best printed test sample from PLA.

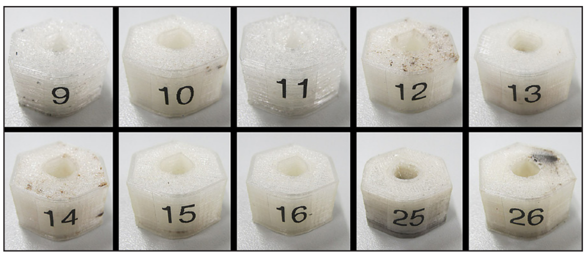


Fig. 5. The PLA test samples printed with nozzle bore diameter 0.3 mm

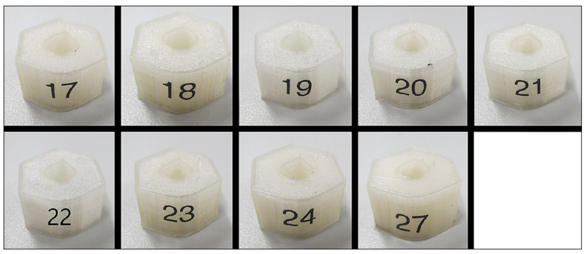


Fig. 6. The PLA test samples printed with nozzle bore diameter 0.2 mm

Table 3. Appropriate printing conditions for ABS Printplus

ABS Printplus			
Parameters for printing / Nozzle bore diameter – n_d	0.5 mm	0.3 mm	0.2 mm
Thickness of layer – l_t [mm]	0.125	0.125	0.08
Temperature of nozzle – t_n [°C]	225	255	255
Temperature of build platform – t_{bp} [°C]	65	65	80
Solid (horizontal) layers [–]	6	6	8
Type of infill [–]	Honeycomb	Honeycomb	Honeycomb
With of extrusion – e_w [mm]	0.5	0.27	0.25
Speed of retract – v_r [mm·s^{-1}]	400	400	400
Perimeter speed – v_p [mm·s^{-1}]	45	40	35
Print speed of infill – v_{pi} [mm·s^{-1}]	40	35	35
Print speed of solid infill – v_{si} [mm·s^{-1}]	40	30	30
Print speed of covering layer – v_{cl} [mm·s^{-1}]	35	30	30
Time of print – t_p [min]	66	90	151

DETERMINE THE PARAMETERS FOR ABS PRINTPLUS

This section describes how to print test samples from ABS Printplus material with different nozzle bore diameter using a variety of print settings changes. The section also evaluates the impact of printed parameters to the quality of test samples.

The nozzle 0.5

The test sample ABS1 printed with values based on user's manual showed major deficiencies. The infill did not have desired shape because layers are not well connected to each other. The quality of surface was low. The external perimetric layers are shrunk and the base of component is not completely printed. On Test samples ABS2, ABS3 and ABS4 values of a retract are gradually changed. The surface of parts is similar to the first sample. The test sample ABS3 is the best made component form this group of test samples. According to the quality of a surface, we can divide thetest sample ABS3 it into two sides. The lower side is printed better, because the outer peripheral layers are adjected to each other. The quality of the printed edge around the base is also positive. The upper side is printed worse. The external perimetric layers are separated from each other. The covering layer is printed only on half of the surface. By change the thickness of extruded layer from value l_t = 0.25 mm to l_t = 0.125 mm the time doubles the production, whereas the surface of the component is softer. The component with serial number ABS7 has a complete base. The parameter which had influence on print base completeness was the speed of covering layer, which we set to v_{cl} = 35 mm/s. The combination of high speeds, greater thickness of extruded layers and low temperature on print table resulted in the poor quality of the printed component. It is represented by test sample ABS8. The test samples ABS9, ABS10 and ABS11 had a speed of covering layer set again to the optimum value v_{cl} = 35 mm/s. The best surface has a test sample ABS9. Sample ABS10 has a slightly concave base, which was caused by low temperature of print table (55°C).

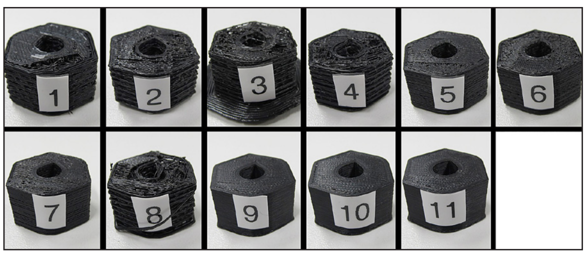


Fig. 7. The ABS test samples printed with nozzle bore diameter 0.5 mm

The nozzle 0.3

Change of the width of extruded material to value e_w = 0.27 increased spress time from t_p = 66 min. to t_p = 90 min. On sample ABS12 quality

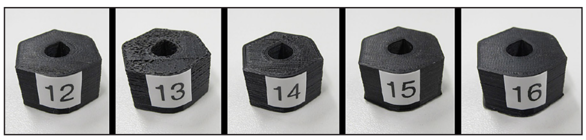


Fig. 8. The ABS test samples printed with nozzle bore diameter 0.5 mm

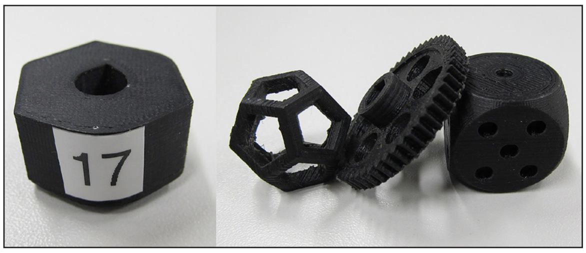


Fig. 9. The ABS test sample and experimental components printed with nozzle bore diameter 0.2 mm

and soft surface were achieved. The test sample ABS14 was printed with a width of extruded material set on the value e_w = 0.5 mm. It was found that changing bore diameter of nozzle without changing the width of extruded material value is not appropriate. This is because the extrusion head badly recalculates the route. On covering layer small gaps between fibers remained. The test sample ABS15 has softer surface and high quality of inner structure due to a slower speed.

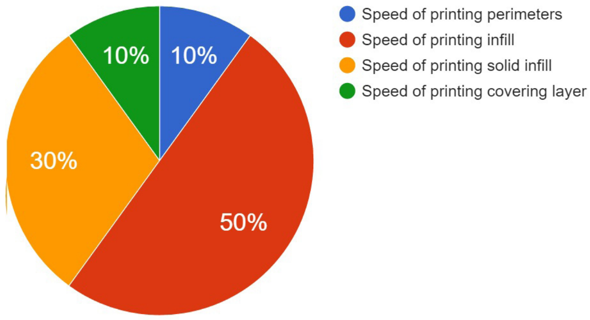
The nozzle 0.2

Components produced with nozzle bore diameter n_d = 0.2 mm has the highest quality surface. The reason was change of thickness of extruded layer to 0.08 mm, change of the width of extruded material to e_w = 0.25 mm and reduction of print speed.

EVALUATION OF RESULTS

A combination of two used materials (PLA, ABS), nozzles with bore diameter n_d = 0.5 mm, n_d = 0.3 mm and n_d = 0.2 mm and different parameters 44 test samples were printed. They were intended to evaluate the possibilities of printing with 3D printer Easy3DMaker. For the production of given components recommendations of appropriate printing conditions for print materials PLA Printplus (see Table 2) and ABS Printplus (see Table 3) were developed. Experiments have shown that the bore diameter of the nozzle has a major impact on the time of printing, but PLA and ABS materials shall not affect the time of printing. For production components with good surface to set proper values printing speed is required (see Fig. 10a). From these settings perimeter speed and speed of covering layer have large impact to surface quality. For production of quality internal structure print speed of solid infill is the most important parameter (see Fig. 10b). Suitable conditions for printing with ABS material were verified to other experimental components with various shapes. A gear, dice and dodekahedron were printed (see Fig. 9).

a)



b)

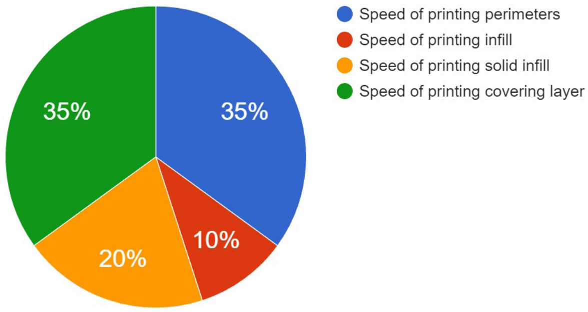


Fig. 10. Impact parameters: a) surface quality, b) quality of internal structure

CONCLUSION

This article describes a process of creating methodology to finding best conditions for 3D printing. It also describes printing process and the evaluation of finished components. We found that the use of appropriate printing conditions, allows us to print components from PLA Printplus in quality comparable to ABS Printplus. The best conditions for print components with small size provides the nozzle with bore diameter n_d = 0.2 mm. Larger nozzles shorten the production time to the detriment of quality. Printing speeds are among the most important print parameters. It was found that with the reduction of the diameter of nozzle and thickness of applied layer it is necessary to reduce the value of speeds. This observation holds true in both used materials. Found suitable conditions will serve as a basis for further experiments.

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