ZESZYTY NAUKOWE WYŻSZEJ SZKOŁY ZARZĄDZANIA OCHRONĄ PRACY W KATOWICACH
Nr 1(14)/2018, s. 79-93 *ISSN-1895-3794*
eISSN-2300-0376

Jan Krmela
Vladimíra Krmelová
Alexander Dubček University of Trenčín, Faculty of Industrial Technologies
I. Krasku 491/30, 020 01 Púchov, Slovak Republic

DOI: 10.32039/WSZOP/1895-3794-2018-08

The safety during 3D printing of technical objects

Bezpieczeństwo podczas wydruku 3D obiektów technicznych

Abstract

The paper deals with 3D printing of technical objects at 3D printer GERMAN RepRap X400. This printer is designed for large format industrial 3D printing. The paper focuses on technology of 3D printing, preparing of geometrical 3D model for printing with use freeware Repetier Host and commercial software Simplify, comparing these programs, setting the parameters for 3D printing from the perspective of quality of printed objects and 3D printer control from afar with using software Repetier Server or other freeware. It is possible printing with different materials, not only standard ABS and PLA. The printer has DD3 Dual extruder. The extruders can be heated to 290°C. Maximum temperature of heated bed is 120°C. Printing Plate Carbon is used for 3D printing or other preparing pad.

This paper also includes verification of correct temperature distribution of heated bed by thermal imaging camera. On the basic experiments by thermal imaging camera, it was found the fact that the temperature difference of actual and set temperatures of a heated bed are increasing with increasing temperature. If the bed temperature is to be at real 60°C, then setting must be approx. 6°C higher, so the set temperature must be 66°C. In contrast, the control of the extruder nozzles confirmed that the actual temperature is nearly such as the set temperature.

Keywords: *3D printing, safety, PLA, temperature, settings, control*

Streszczenie

Artykuł dotyczy druku 3D obiektów technicznych w drukarce 3D GERMAN RepRap X400. Ta drukarka jest przeznaczona do przemysłowego druku 3D w dużym formacie. Artykuł koncentruje się na technologii druku 3D, przygotowaniu geometrycznego modelu 3D do druku z wykorzystaniem darmowego oprogramowania Repecier Host i komercyjnego oprogramowania Simplify, porównując te programy, ustawiając parametry druku 3D z perspektywy jakości drukowanych obiektów i sterowania drukarką 3D z daleka przy użyciu oprogramowania Repetier Server lub innego bezpłatnego oprogramowania. Możliwe jest drukowanie przy użyciu różnych materiałów, nie tylko standardowych ABS i PLA. Drukarka ma podwójną wytłaczarkę DD3. Wytłaczarki można ogrzać do 290°C. Maksymalna temperatura podgrzewanego złoża wynosi 120°C. Printing Plate Carbon służy do drukowania 3D lub innych podkładek przygotowawczych.

Artykuł zawiera również weryfikację prawidłowego rozkładu temperatury ogrzewanego złoża za pomocą kamery termowizyjnej. Na podstawie podstawowych eksperymentów przeprowadzonych za pomocą kamery termowizyjnej stwierdzono, że wraz ze wzrostem temperatury wzrasta różnica temperatury rzeczywistych i ustawionych temperatur podgrzewanego złoża. Jeżeli temperatura złoża ma wynosić rzeczywiście 60°C, ustawienie musi wynosić ok. 6°C wyżej, więc ustawiona temperatura musi wynosić 66°C. Natomiast sterowanie dyszami wytłaczarki potwierdziło, że rzeczywista temperatura jest prawie taka jak temperatura zadana.

Słowa kluczowe: *drukowanie 3D, PLA, temperatura, ustawienia, sterowanie*

1. Introduction

At present, the rapid advances in technology and, in particular, their use in a wide range of industries. One of the modern methods is 3D printing, in which the virtual model is printed in its real form using various 3D printing technologies. 3D models can be printed from different types of materials such as thermoplastics, metals, glass, elastomers, ceramics, etc. 3D printing is becoming increasingly popular in areas such as engineering, construction, automotive, medicine, electronics, science, research. The Faculty of Industrial Technologies in Púchov has since 2016 a new 3D printer GERMAN REPRAP X400, namely the version Pro Pro V3 (Figure 1), which is based on the Fused Deposition Modeling (FDM) method (sometimes the abbreviation FFF is used).

FDM technology is currently the most used technology for 3D printing. Data obtained from a 3D design of the stl format (e.g. 3D object, which created by SolidWorks or Rhinoceros or other programs, is export as stl format) is imported into program such as Kisslicer, in which parameters such as selected of support type, type of device, model fill method, layer thickness, or model orientation in the printer's workspace are setting. The output from the program is special file G-code format for 3D printer.

It uses thermoplastic material (ABS, polycarbonate, elastomer, wax, etc.) in the shape of a filament that is unwound from the storage coil. In the nozzle, the building material is heated to the desired temperature and the molten material is passed through the nozzle opening. This system is set to a temperature slightly higher than the melting temperature of the thermoplastic material. From the nozzle outgoing material are combine to form the desired thin layer which quickly solidifies.

The nozzle moves in the coordinate axes X and Y and applies the individual layers. After applying one layer, the heated bed position drops by a value equal to the layer thickness of the model. Sometimes a support material is required for the model.

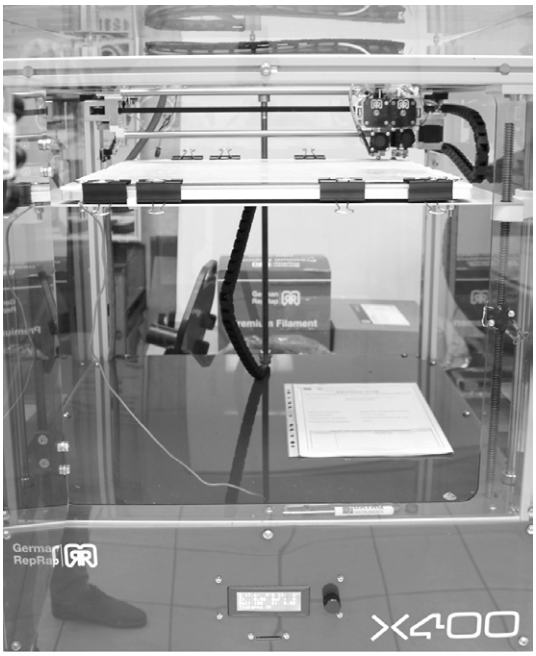


Fig. 1. 3D printer German RepRap X400
Rys. 1. Niemiecka drukarka 3D RepRap X400

Source: own.
Źródło: własne.

FDM benefits include lower operating costs and the cost of models, the possibility of using a large number of materials. Extruded models are characterized by good strength and shape-stable construction, which is suitable for mechanical use of models. The disadvantages of FDM are slower production of full parts of the model (print time is in hours) and less accuracy which is limited by the shape and diameter of the nozzle. Selected FDM 3D printing materials are shown in Figure 2. The choice of material depends on the use of the printed object. Each material has different mechanical properties (tensile strength, bending strength).

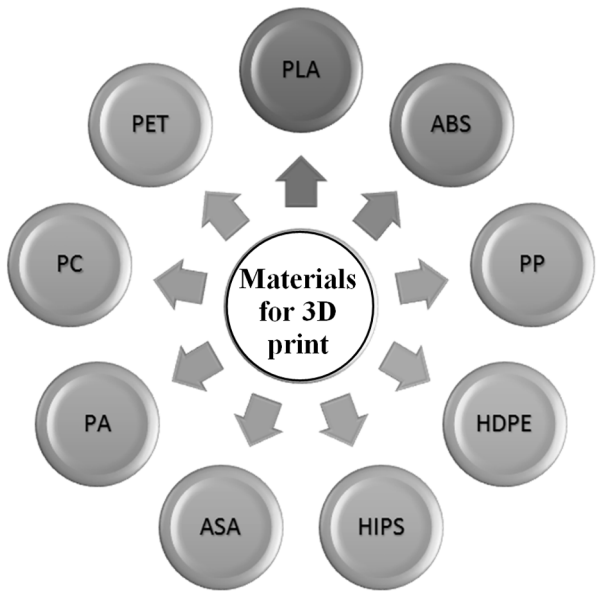


Fig. 2. Materials for 3D print (ASA – acrylonitrile styrene acrylate, PA – polyamide, PC – polycarbonate, PET – polyethylene terephthalate, PLA – polylactic acid, ABS – acrylonitrile butadiene styrene, PP – polypropylene, HDPE – high density polyethylene, HIPS – high-impact polystyrene)

Rys. 2. Materiały do druku 3D (ASA – akrylonitryl akrylan styrenowy, PA – poliamid, PC – poliwęglan, PET - politereftalan etylenu, PLA – kwas polimlekowy, ABS – akrylonitryl-butadien-styren, PP - polipropylen, HDPE – polietylen wysokiej gęstości, HIPS – wysokoudarowy polistyren)

Source: own research.
Źródło: opracowanie własne.

2. Parameters of 3D printer

Filament with a diameter of 1.75 mm is used for 3D printing. The build platform is 390 x 400 x 326 mm. The printer has DD3 Dual extruder (Figure 3). The DD3 extruder developed by German RepRap features two print heads, thus allowing printing in two colors or with water soluble support material such as PVA (polyvinyl alcohol) for PLA or HIPS for ABS parts. Exchangeable nozzles with diameters of 0.25; 0.40; 0.45; 0.60 and 0.80 mm are used. The nozzle with diameter 0.40 mm is most used. The 3D printer can be operated via an LCD display [1] with an SD card reader (Figure 4). The 3D printer includes electronic board Arduino Mega 2560 with Ramp 1.4.2 inside. The change of all parameters is possible via open Adurino by notebook.

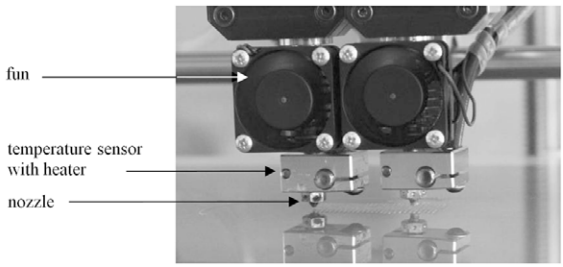


Fig. 3. Dual extruders (2 nozzles)
Rys. 3. Podwójne wytłaczarki (2 dysze)

Source: own research.
Źródło: własne.

Fig. 4. LCD display of 3D printer with displaying of actual nozzle temperature values (marked as E1 and E2) and heated bed temperature value (marked as B)

Rys. 4. Wyświetlacz LCD drukarki 3D z wyświetlaniem rzeczywistych wartości temperatury dysz (oznaczonych jako E1 i E2) oraz wartości temperatury podgrzewanego złoża (oznaczonych jako B)

Source: own research.
Źródło: opracowanie własne.

The other important technical parameters of 3D printer GERMAN REPRAP X400 are shown in Table 1.

Table 1. Technical parameters of 3D printer [2]
Tabela 1. Parametry techniczne drukarki 3D [2]

Distance between nozzles	29.95 mm
Minimum layer height	0.1 mm
Print speed	10-150 mm/s
Travel speed	10-300 mm/s
Dimensions	700 x 700 x 770 mm (height)
Weight	55 kg

Source: X400 PRO 3D printer [online]. Available on: https://www.germanreprap.com/en/products/3d-printer/x400-pro-3d-printer/

Print filaments are currently available from these materials: PLA, ABS, Timberfill, ASA and flexible filament Flexfill 98A (each material in at least two color shades) and as support materials HIPS and PVA. Timberfill is made of biodegradable wood-based material. A carbon pad is used for printing. If PLA is used for printing, then nozzle temperature is 210°C and heated bed temperature is 60°C according to the data by producer of specific PLA material.

The nozzles have high temperature. During filament exchange, you have to wait for nozzle cooling, but sometimes it needs immediate action and therefore, the fingers can be burned by really hot nozzle.

Similarly, heated bed temperature approx. 110°C (e.g. for ABS material) may be used. Ensure increased safety during 3D printing. There is a risk of injury by moving parts, on which extruders are of 3D printer. During printing, the heated bed moves down (axis z) with the rotating lead screws using. The door of cover 3D during print job can be open. Therefore, long hair or loose clothing could get caught up in rotating lead screws. The operator has to be very careful during the printing process.

2. Process for data preparing for printing

The geometry of the 3D models is to be exported to the stl format. Consequently, a so-called "slicing" process must be performed, which means that 3D model in stl format will be divided by the horizontal cuts that are needed to generate the code for the extruder moves. Various programs can be used for slicing (such as Cura, Kisslicer, Slic3r, Repetier-Host, Simlify3D), which can be connected to your computer printer via the USB interface to control the printer directly. Simplify3D (commercial version) and Repetier-Host (free open source program) were tested from the list of programs.

Repetier-Host (with modified printer parameter setting by the printer manufacturer) includes almost all of the features available in other programs. It includes „slicers" as well as control tools for 3D printer (Figure 5). It can also be used for both extruders. Its advantage is the disposition of the English, Poland, Czech and other translation. On the other hand Simplify3D is in English only (Figure 6 is view on slicing geometry). Both programs complement each other with print settings. Repetier-host includes Slic3r [3] for generating G-code file for 3D printer. The change parameters with change height are possible by other slicing program. Slicing by Simplify is faster as Repetier-Host.

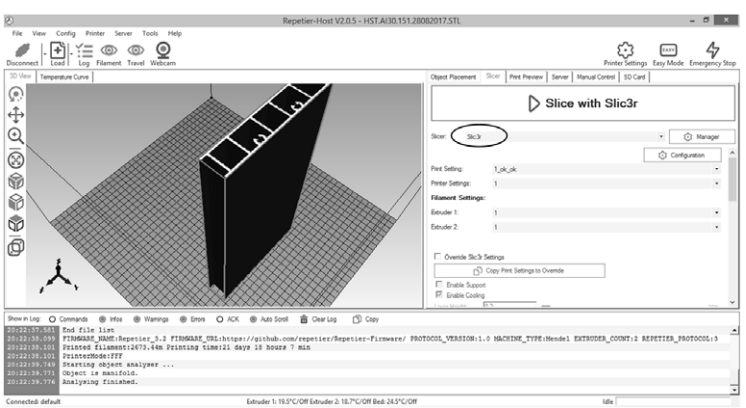


Fig. 5. Repetier-Host with slice parameters
Source: own research.

Before generating of G-code the price of print per hour and price of material give to setting for obtaining of final price of printed part. Also sometimes the repairs of geometry of 3D object for printing had to use. The program Netfabb Basic is very simply and quickly program for repair of geometry. Also the setting of parameters such as extrusion width, retraction speed, layer height, infill, nozzle temperature, heated bed and other important parameters are necessary choose appropriately (Figure 7). E.g. the extrusion width is 0.35 mm for nozzle with diameter 0.40 mm for specific material.

After generating of G-code the information about print time, volume of materials, weight and namely price for material are obtained, see Figure 8.

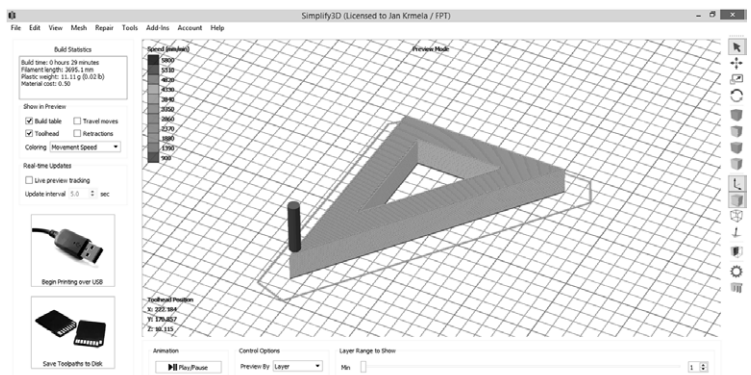


Fig. 6. Simplify3D environment
Rys. 6. Środowisko Simplify3D

Source: own research.
Źródło: badania własne.

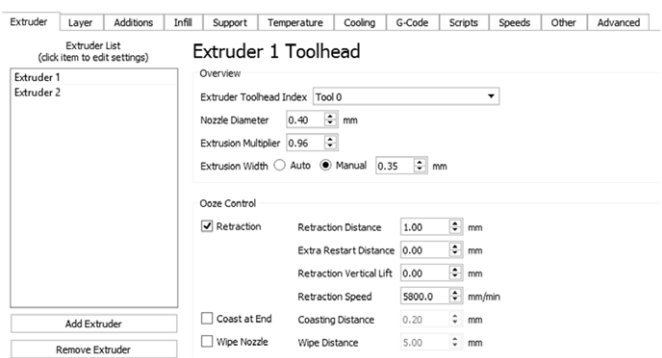


Fig. 7. Setting of printing parameters by Simplify3D
Rys. 7. Ustawienia parametrów drukowania Simplify3D.

Source: own research.
Źródło: badania własne.

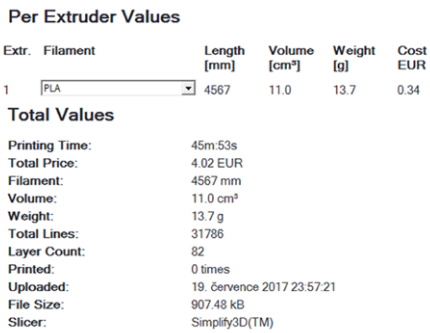


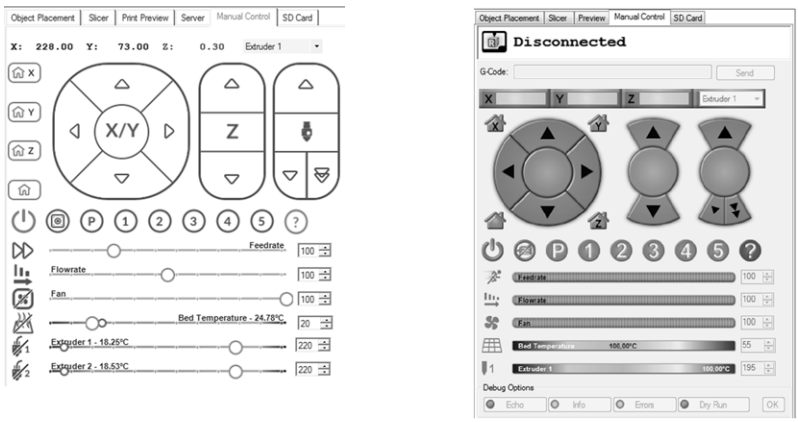
Fig. 8. Information about technical object for 3D printing from Repetier-host
Rys. 8. Informacja o technicznych parametrach druku 3D z Repetier-host.

Source: own research.
Źródło: opracowanie własne.

4. Control of 3D printer

The 3D printer GERMAN REPRAP X400 is equipped with a SD memory card slot with full print process control over the LCD and LCD output control parameters in the English or other languages such as Czech. The generated G-code can then be uploaded to a memory card and the print process can be started without the need for computer using.

An optional network connection via Ethernet and Wifi as well as browser-based control and print monitoring via webcam are possible by 3DPrintBox which on the base Raspberry Pi with operating software from producer of 3D printer. Raspberry Pi runs on AstroPrint or Octoprint which were use for comparison too. Thus, in on-line mode on a computer, for example, in the office or at home (observation from long-distance), it is possible to check the whole process of printing and watch printing by camera. 3D printer panel control from afar with using software Repetier-Host via software Repetier-Server is on the Figure 9.



a) b)

Fig. 9. On-line control panel in Repetier-Host – a) new of program and b) old version
Rys. 9. Kontrolny panel on-line w Repetier-Host - a) nowyprogram i b) stara wersja

Source: own research.
Źródło: badania własne.

5. Thermal measurement to verify the heated bed temperature

The 3D printer has a pad that can be heated while printing 3D models. Heating the pad to the desired temperature is very important when using thermoplastics that tend to peel away from the pad. Temperatures for selected materials for 3D printing are in Table 2.

Table 2. Temperatures for selected materials for 3D printing
Tabela 2. Temperatury dla wybranych materiałów do drukowania 3D

Material	Temperature of nozzle [°C]	Heated bed temeperature [°C]
ABS	220-240 (245*)	80-100 (115*)
PLA	190-210	60 (65*)
Flexifill 98A	200-220	30-50 (70*)
Timberfill	170-185 (195*)	40-50 (65*)

** Temperature change of the washer based on the test print for specific materials*
Source: own research.

When printing with ABS, the temperature difference of 1°C may also have a significant effect on the correct model printing. A thermal imaging camera was used to verify the temperature of the heated bed temperature. Heated bed temperature measurements were made at 60, 80, 100 and 120°C. These temperatures were set directly on the 3D printer. E.g. at 120°C, the difference between the actual and the set temperature was up to 9°C [4], see thermogram on the Figure 10. The temperature difference from the center of the heated bed to the edges was approximately 8°C, see Figure 11. As well as controlling the heated bed temperature, control of the extruder nozzle temperature was performed.

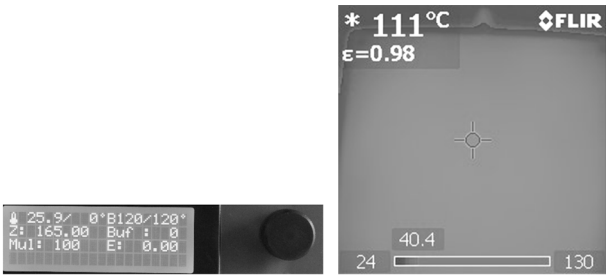


Fig. 10. Heated bed temperature – comparison between temperatures set to 120°C at display and real state on heated bed (thermogram on the right)

Source: Pajtáš M.: 3D printing for technical applications and design software extension for the PRINTER GERMAN RepRap X400 (3D tlač pre technické aplikácie a návrhy softwarového rozšírenia pre tlačiareň German RepRap X400), Bachelor work, supervisor: Krmela J., Púchov: Alexander Dubček University of Trenčín, Faculty of Industrial Technologies, 2016, 62 p., in Slovak.

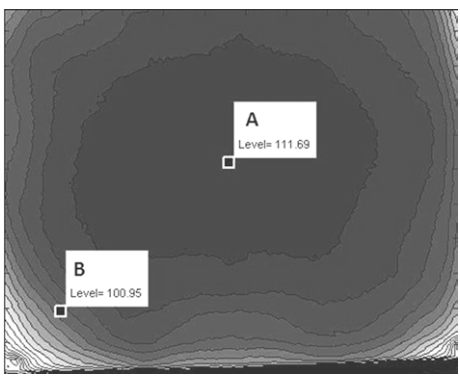


Fig. 11. Heated bed – isothermal areas for temperatures set to 120°C

Source: Pajtáš M.: 3D printing for technical applications and design software extension for the PRINTER GERMAN RepRap X400 (3D tlač pre technické aplikácie a návrhy softwarového rozšírenia pre tlačiareň German RepRap X400), Bachelor work, supervisor: Krmela J., Púchov: Alexander Dubček University of Trenčín, Faculty of Industrial Technologies, 2016, 62 p., in Slovak.

On the basic experiments by thermal imaging camera, it has been found that the difference with actual and adjusted temperatures increases with increasing temperature. If the bed temperature is to be at real 60°C, then setting must be approx. 6°C higher, so the set temperature must be 66°C. It is therefore advisable to use heated bed temperature 62°C for PLA, and a minimum heated bed temperature about 109°C for the ABS, which actually corresponds to only 100°C. In contrast, verify of the extruder nozzles temperature confirmed that the actual temperature corresponds to the set temperature with maximum difference 5°C.

The printing temperature was verified of special G-code (from producer of printing), which has layers with different temperatures (change nozzle temperature setting during printing), see Figure 12.

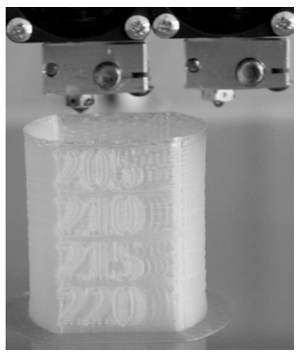
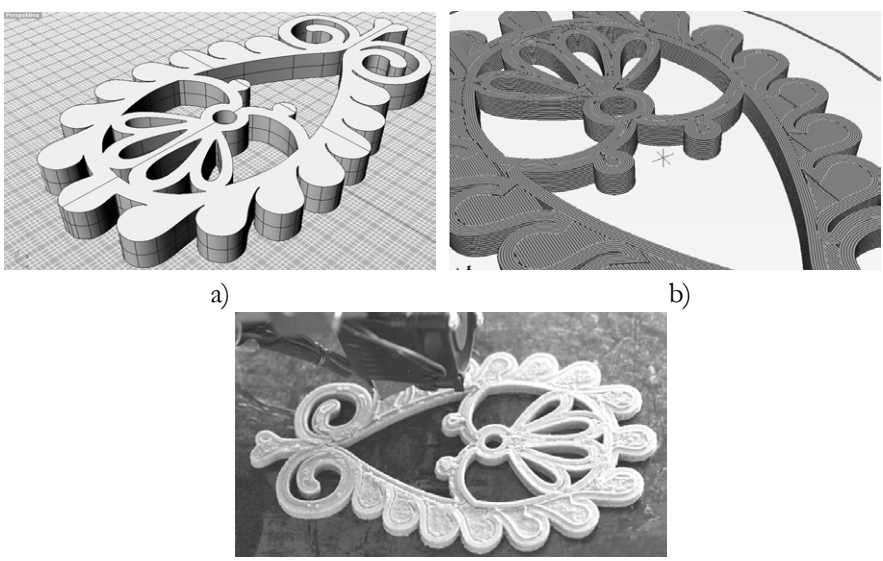


Fig. 12. Layers with different temperatures
Rys. 12. Warstwy o różnych temperaturach

Source: own research.
Źródło: opracowanie własne.

6. Final 3D printed technical objects

As samples of final 3D printed technical objects are the earrings and ring for model collection on the Figures 13 and 14. Print time of selected one earring on the Figure 13 was about 4 hours [5].



a) b)

c)

Fig. 13. From design to printing of earrings (material Timberfill) – a) design in Rhinoceros, b) slicing, c) printing of final layer
Rys. 13. Od projektu do druku kolczyków (materiał Timberfill) – a) wzór w Rhinoceros, b) krojenie, c) druk końcowej warstwy

Source: own research.
Źródło: opracowanie własne.

Fig. 14. Final model collection – earrings and ring from filament Timberfill
Ryc. 14. Ostateczna kolekcja modeli – kolczyki i pierścionek z filamentu Timberfill
Source: Semanová A.: The effect of tradition folk culture for clothing creation (Vplyv tradičnej ľudovej kultúry na odevnú tvorbu), Bachelor work, supervisor: Krmelová V., Púchov: Alexander Dubček University of Trenčín, Faculty of Industrial Technologies, 2017, in Slovak.

Next sample is propeller of model (Figure 15) of watermill from ABS. The model consist only five layers in the narrowest place of propeller and heated bed temperature had to be suitably chosen to avoid deformation of the edges of propeller during printing.

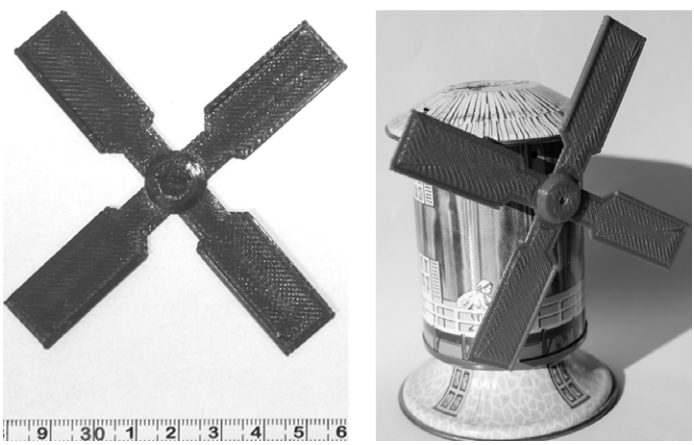


Fig. 15. Propeller of model of watermill from ABS (with tape measure in cm) with its use for kid stuff money-box (right)
Source: own research.

Miniature of specific tire model (see Figure 16) have also been printed from PLA for purpose as a teaching aid in selected technically subjects, which are oriented with oriented to composite objects and will also be used to plan experiments on static tire test equipment within the Slovak grant project No. KEGA 005TnUAD-4/2016.

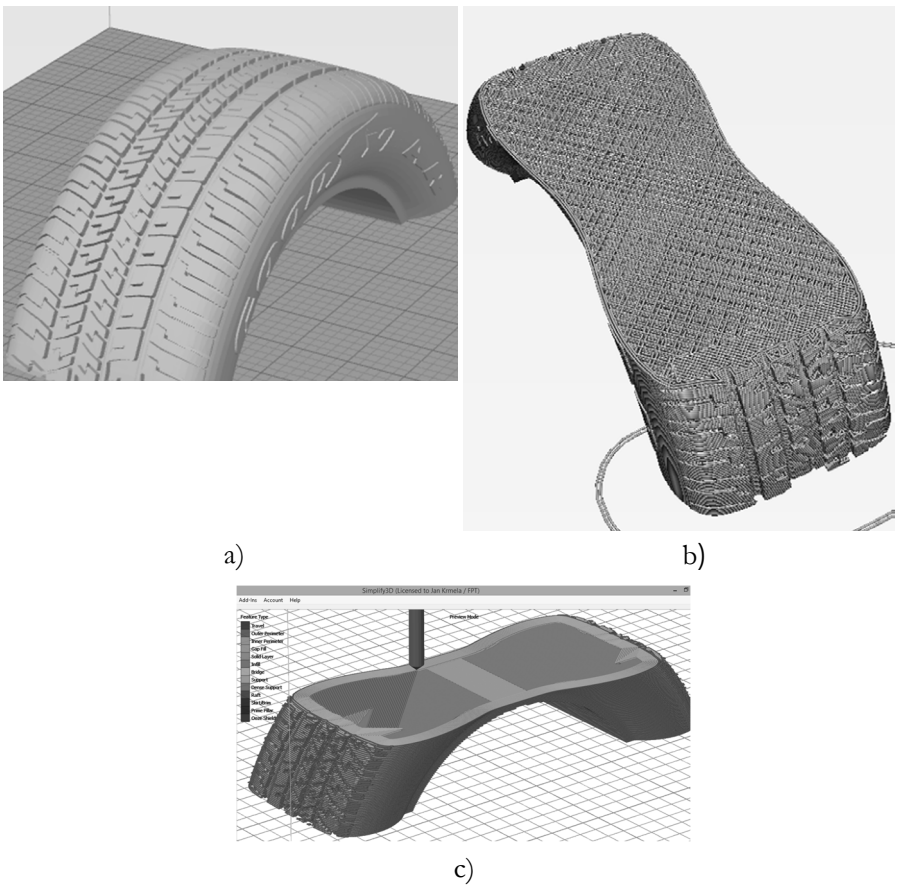


Fig. 16. Miniature of specific tire model from PLA – a) design 3D geometry model (was downloaded from internet), b) slicing model by Repetier-host, c) slicing model by Simplify3D

Source: own research.

By control programs the printing of some parts altogether but sequentially is possible. As sample the two same profiles on the Figure 17. As a first step, the entire one profile was printed, and as the second step after whole first profile printed the second profile was printed. Printing takes place as a single G-code file, but printing of the profiles takes place sequentially. The profiles have high of 200 mm. The G-code was optimized for obtaining of short print time and

good quality. The dimensional accuracy of the final object is ± 0.1 mm. The print time of these profiles was approx. 12 hours.

The other big profiles had high of 300 mm, almost the whole height of build platform is used. ;Sometimes the print time was over 50 hours per one profile only. 3D printing can sometimes be labeled as not quickly production but production requiring longer production times.

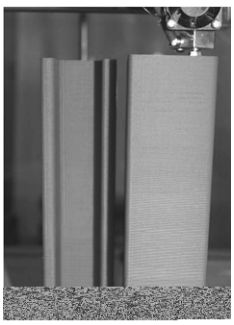


Figure 17. Profiles from PLA – printing of both parts altogether and sequentially
Source: own research.

6. Conclussion

If the heated bed temperature sets on 100°C for ABS, this temperature would be for ABS on that printer, as the actual measurement would be only 92°C.

The nozzles have high temperature. There is a risk of burns during the exchange of the filament. Similarly, heated bed temperature 120°C may be used.

Ensure increased safety during 3D printing. The nozzles of 3D printer have high temperature in range from 180 to 290°C during and after printing job before the nozzles cool. There is a risk of burns during the exchange of the filament. Similarly, the heated bed may have high temperature about 120°C. There is a risk of injury by moving parts, on which extruders are of 3D printer. Operator has to be very careful during the printing process.

In the future we plan printing with two materials simultaneously for purpose creating composites not only for educational process.

The optimum print settings (especially print speed, layer thickness, temperature) are needed to search to avoid defects and print errors.

Further, the 3D printing of two materials is contemplated in order to produce a part of the composite incorporating, for example, filament Carbon20.

The project was funded by the Cultural and Educational Grant Agency of the Slovak Republic (KEGA), grant No. KEGA 005TnUAD-4/2016 and the Slovak grant agency VEGA 1/0589/17 and the project „Centrum pre testovanie kvality

a diagnostiku materiálov“ ITMS code 26210120046 of the Operational Program Research and Development funded from European Fund of Regional Development.

BIBLIOGRAPHY

[1] LCD Controller Menu, German Reprap [online]. Available on: https://www.germanreprap.com/wp-content/uploads/2016/10/firmware_-_lcd_controller_menu-1-1.pdf

[2] X400 PRO 3D printer, German Reprap [online]. Available on: https://www.germanreprap.com/en/products/3d-printer/x400-pro-3d-printer/ and https://www.germanreprap.com/wp-content/uploads/2016/10/x400ce_3d_printer_manual-1.pdf

[3] Slic3r User Manual, German Reprap [online]. Available on: https://www.germanreprap.com/wp-content/uploads/ 2016/ 10/slic3r_user_manual-1.pdf

[4] Pajtáš M.: *3D printing for technical applications and design software extension for the PRINTER GERMAN RepRap X400 (3D tlač pre technické aplikácie a návrhy softwarového rozšírenia pre tlačiareň German RepRap X400)*, Bachelor work, supervisor: Krmela J., Púchov: Alexander Dubček University of Trenčín, Faculty of Industrial Technologies, 2016, 62 p., in Slovak.

[5] Semanová A.: *The effect of tradition folk culture for clothing creation (Vplyv tradičnej ľudovej kultúry na odevnú tvorbu)*, Bachelor work, supervisor: Krmelová V., Púchov: Alexander Dubček University of Trenčín, Faculty of Industrial Technologies, 2017, in Slovak.