Measurement comparison between 3D model of the promotional school windmill shaft and two different prototypes made on a 3D printer Ender 3 S1 Plus

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Abstract: *Parents bought me a 3D printer three years ago. Many products have already been made on it, for friends and even a teacher who came up with the idea of making a promotional school windmill. A few of our classmates got together to cooperate on this project. Our task was to follow the demanding construction process, from planning to concepts, detailing, planning and production of technical documentation. In this article, I would like to present my work and the knowledge I have acquired through a school project: from conceptualization in the SolidWorks, to the production of a prototype on an Ender 3 S1 Plus machine. The 3D printer will produce the component with two different additive thermoplastic materials, PLA and PETG. If there is any significant difference in the accuracy of manufacturing the component with different materials will be shown by measuring on the Atos Q scanner.*
Keywords*: RAPID PROTOTYPING, ENDER 3 S1 PLUS, THERMPLASTICS, ATOS Q MEASUREMENT*

1. Introduction

The first step for faster product development was computer-aided design (CAD) software system that makes engineers more productive. The product CAD data was so effective, that the system was expanded throughout the enterprise connecting everyone involved in designing and building products. Design review meetings and communication are critical to the success of any product development project.

For design engineering, rapid prototyping is a most powerful tool for conceptualization, form and fit review, functional analysis, and pattern generation. These applications are also relevant to the manufacturing process. Prototypes are often used to answer two types of questions: "Will it work?" and "How well does it meet the customer needs?" When used to answer such questions, prototypes serve as learning tools.

Result of two different rapid prototyping techniques is shown in Fig. 1.

Fig. 1 *Result of Rapid Prototyping for learning and communication purpose. Exhaust and foot holder BMW motorcycle component made with DMLS (left side) and with CNC rapid prototyping technology (right side od Fig.) [1]*

2. From idea to modeling of windmill components

One way to think about the development process is as the initial creation of a wide set of alternative product concepts and then the subsequent narrowing of alternatives and increasing specification of the product until the product can be reliably and repeatably produced by the production system.

The conceptual design phase includes the definition of the product architecture and the decomposition of the product into subsystems and components. The final assembly scheme for the production system is usually defined during this phase as well. The output of this phase usually includes a geometric layout of the product, a functional specification of each of the product's subsystems, and a preliminary process flow diagram for the final assembly process.

We all have ideas. And so, in our class, with the support of our teacher-mentor, we set ourselves a development challenge: to make a prototype of a windmill that would serve to promote the school. First, a concept was created, based on the sketch presented in Figure 2.

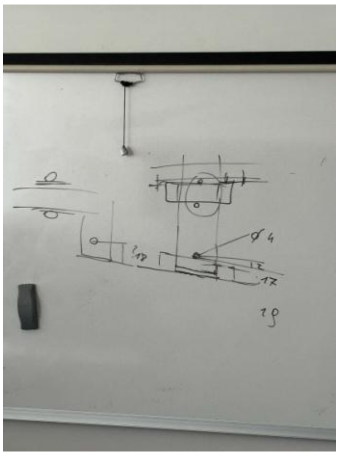


Fig. 2 *Sketch of our final concept, made on a school blackboard.*

Each of us students in the group took charge of one component of the assembled windmill. Each of us had to make a 3D model of the component in the SolidWorks program, draw a workshop drawing of the component and make a prototype. My mentor assigned me to make the component – the windmill shaft.

The Solidworks software we learned to use in our Technical school. SolidWorks is a software for solid modeling computer-aided design (CAD), computer-aided engineering (CAE). The complete software includes also tools for analyses and simulations, such as Finite Element Analysis, which supports modeling, design, and collaborative work. Figure 3 shows a 3D model of the shaft.

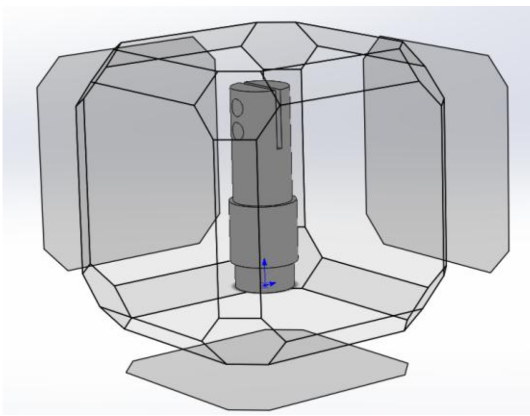


Fig. 3 *3D model of windmill shaft in SolidWorks program..*

The SolidWorks user base ranges from individuals to large corporations and covers a wide cross-section of manufacturing market segments. Its core industries include industrial equipment, high-tech, life sciences, home and lifestyle, architecture, engineering, and construction. Figure 4 shows a drawing of the shaft.

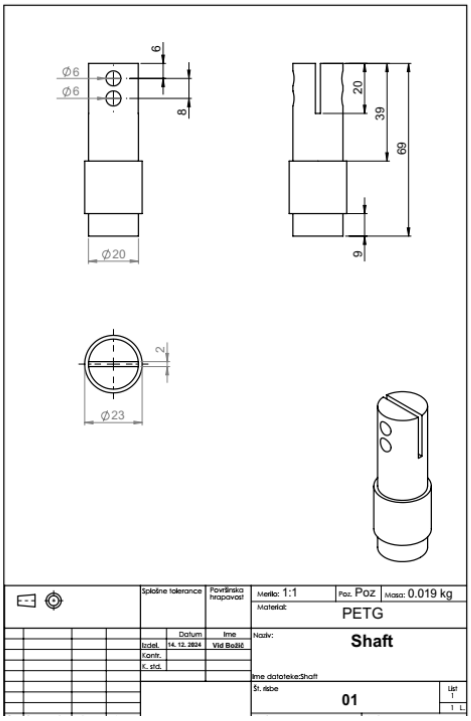


Fig. 4: Technical drawing of windmill shaft.

Rapid prototyping and 3D printer: Ender-3 S1 Plus

The next stage was the production of the shaft using rapid prototyping technology. If you own a 3D printer, software matters. That is why Cura is an open source slicing application for 3D printers. It was created by David Braam who was later employed by Ultimaker, a 3D printer manufacturing company, to maintain the software.

Ultimaker Cura is used by over one million users worldwide and handles 1.4 million print jobs per week. It is the preferred 3D printing software for Ultimaker 3D printers, but it can be used with other printers as well. It works by slicing the user’s model file into layers and generating a printer-specific g-code. Once finished, the g-code can be sent to the printer for the manufacture of the physical object. The open source software, compatible with most desktop 3D printers, can work with files in the most common 3D formats such as STL, OBJ, X3D, 3MF.

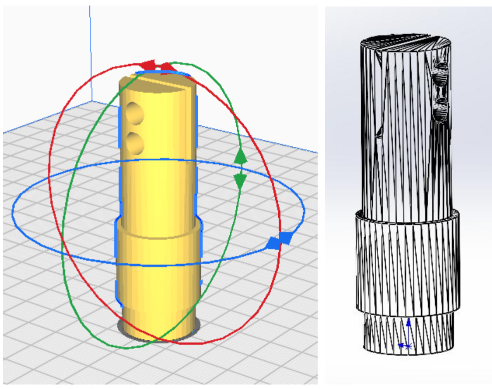


Fig. 5: 3D model in Ultimaker Cura program.

The Ender-3 S1 Plus resembles any number of open-frame 3D printers, including close to a dozen in Creality's Ender-3 stable alone. The printer is made up of a handful of essential parts. The base, measuring about 33 by 38 by 5 centimeters, houses the printer's electronics, power supply, and ports (a USB-C port and an SD card slot).

The mentioned printer is suitable for beginners who are still learning about the 3D printing process. This is my first 3D printer, and while it's very easy to set up and start printing, it does take some time and research for the user to get the hang of it. Most prints took anywhere from 1 to 5 hours or even more depending on the size and level of quality detail.

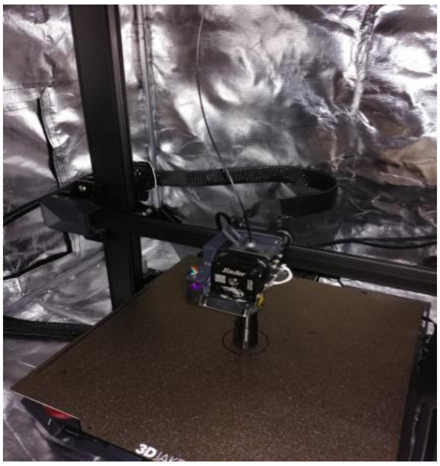


Fig. 6: My first 3D printer.

Basic printer Ender-3 S1 Plus specifications:
Print size: 300 x 300 x 300 mm
Print speed: 100 mm/s
Filament: 1.75 mm PLA, PETG
Working mode: online or SD offline
File format: STL, OBJ, G-code
Net Weight: 6.7 kg
Layer Thickness: 0.1-0.4 mm
Nozzle Diameter: 0.4 mm
Printing accuracy: ± 0.1 mm
Nozzle temperature: 255 °C
Heater temperature: 110 °C

The printer, as I mentioned, works with a process called fused deposition modeling (FDM). It works as follows:

- Filament: The printing material is available in spools of thin plastic filament, similar to a thick string.
- Heating and Extruding: The printer heats the filament until it melts. The molten plastic is then extruded through a nozzle.
- Layer by layer: The nozzle moves precisely, depositing layer by layer onto the build platform, slowly building a 3D object.

Filament PLA and PETG

Many materials are used as filament on 3D printer machines. I decided to compare two different materials: PLA and PETG.

Thermoplastic polymers such as PLA (polylactide), PETG (glycol-modified polyethylene terephthalate) and other types of plastics are usually obtained from natural sources such as corn, sugar cane, potatoes or petroleum, depending on the base material component. PLA is the most widely used plastic filament material in FDM 3D printing due to its low melting point, high strength, low thermal expansion and good layer adhesion, although it has poor heat resistance unless annealed.

PETG delivers significant chemical resistance, durability, and formability for manufacturing. PETG has good strength and durability, as well as being more impact resistant and better suited to higher temperatures. It is also widely used in 3D printing since the glycol prevents the problems such as overheating and becoming cloudy and fragile. With good adhesion between layers, minimal deformation during printing, good resistance in low temperature environments, chemical resistance against bases and acids, PETG is becoming the favored material for 3D printing.

I got the best visual results from both PLA and PETG prototypes after a week of testing, varying the printing parameters. The best PLA prototype was made with the following parameters:

Print nozzle temperature: 200 °C

I used this temperature for final PLA prototype. This temperature enables optimal melting of the material, as it is the highest limit that still ensures good adhesion and prevents problems such as clogging of the nozzle and uneven extrusion of the material.

Printing substrate temperature: 70 °C

This temperature is recommended for materials such as PLA due to the good adhesion of the first layer. The stability of the first layer is critical to a successful print finish, as irregularities in the initial layers can cause problems throughout the process.

Print speed: 50 mm/s

Reducing speed did increase the print time, but I expected the quality of the final product to be much better, as printing slower reduces defects such as uneven surfaces, excessive layer overlap or edge irregularities.

Speed of filling (Infill): 50 mm/s

This speed was chosen as a compromise between the printing speed of the inner layers and the quality of the structure.

External wall printing speed: 25 mm/s

To print the outer walls, I reduced the speed too, as I assumed that this would improve the quality of the outer surfaces and increase the smoothness of the edges.

Extruder movement speed: 100 mm/s

I significantly reduced the speed of the extruder movement to 100 mm/s as I assumed this would improve the quality of the model.

Response time: 20 mm/s

For the response time, I reduced the value to 20 mm/s to increase the accuracy when applying the material, especially during fast movements of the print head.

The best PETG prototype was made with the following parameters:

Print nozzle temperature: 235 °C
Printing substrate temperature: 85 °C
Print speed: 50 mm/s
Speed of filling (Infill): 50 mm/s
External wall printing speed: 25 mm/s
Extruder movement speed: 100 mm/s
Response time: 20 mm/s

Measurement of two prototypes and comparison with 3D model

The company Merilna tehnika s.p. has its laboratory in Unec, close to Postojna. The director of the company is Mr. Samo Strle. Samo has many years of experience in the field of measurement and quality. He just had some time to show me the measuring instruments and machines that he has in his premises. I learned a lot about contourograph, roughness meter, altimeter, optical meter and two 3D measuring machines: Zeiss and Dea.

We decided to measure both prototypes and compare them with the 3D model on the ATOS Q 3D scanner. ATOS Q is an industrial 3D scanner that can be used in a variety of applications due to its wide range of measuring areas. In addition to incorporating many of the features of our high-end automated systems, ATOS Q's lightweight design makes it easy to transport from one location to another, providing users with added convenience and flexibility. One of the major advantages is that with ATOS, the entire part's surface is captured. ATOS blue light 3D scanners help alleviate this challenge by picking up every visible area. This results in incredibly detailed, accurate data full of millions of XYZ points that create a geometric part in minutes.

These scanners register the surface information of an object with the help of reflected light from its surface. 3D scanning spray is an evaporating solution that works to matt out reflective and transparent surfaces. With a dedicated spray, we prepared both prototypes for measurement, to ensures much more efficient 3D scanning and complete scan results. Nejc, an employee of company, introduced me to the machine and measurement with ATOS Q. Figure 7 shows the measurement process - scanning the PLA prototype and blue light for high-quality measurement capture.

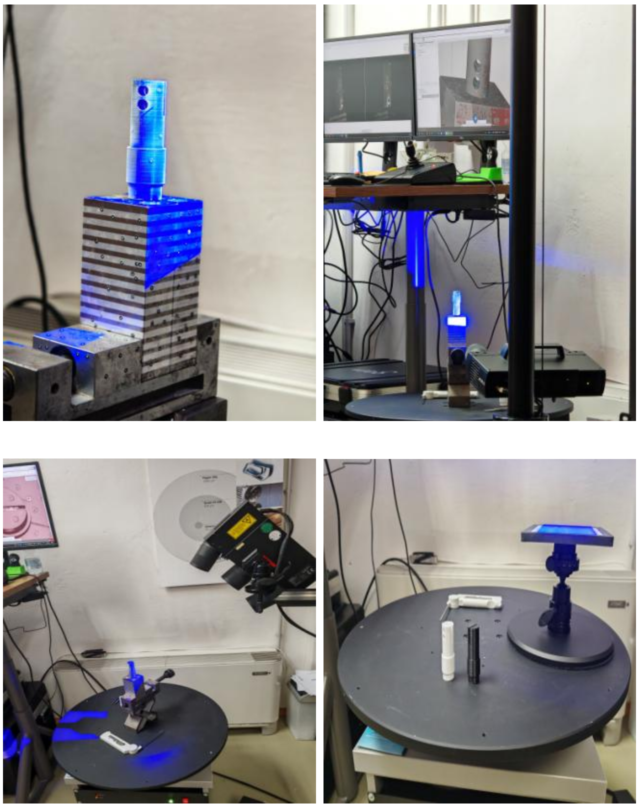
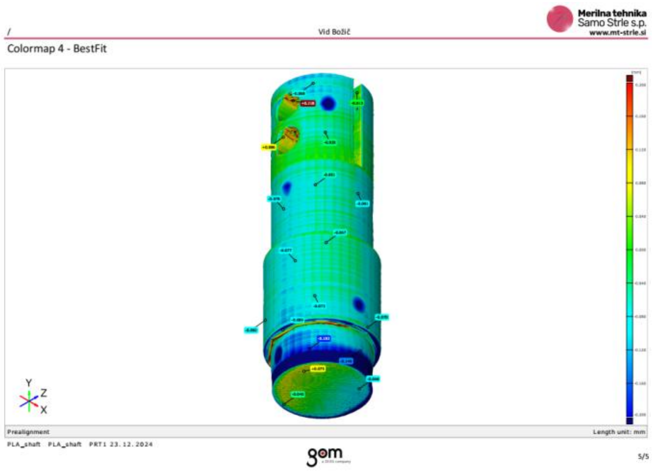


__Fig. 7:__ Measurement of PLA prototype with ATOS Q [2].

GOM Inspect is the comprehensive, user-centric 3D metrology software that tackles every challenge. It has one user interface that handles the entire workflow, which covers complex inspection tasks in different applications. With GOM [3] inspect software we can easily visualize surface inspections and generate reports of measuring results.

Figure 8 presents the results of measurements of the PLA prototype relative to the 3D model. A color gradient towards dark blue means a deviation of the prototype measurement relative to the 3D model in a negative direction, while a color gradient towards dark red means a deviation of the prototype measurement relative to the 3D model in a positive direction.



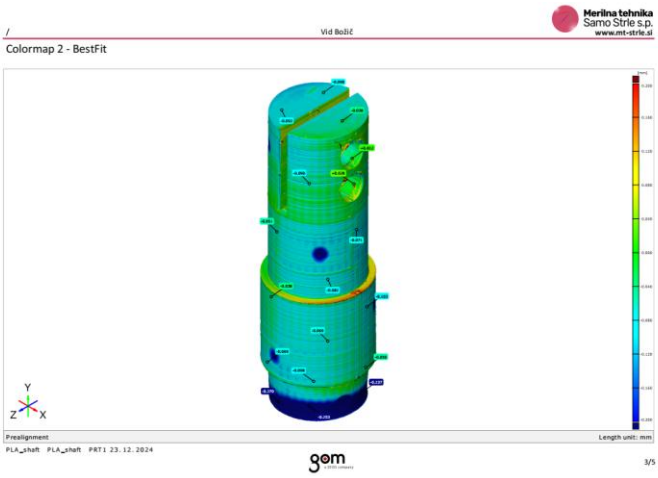


Fig. 8: *Results of measurement of PLA prototype with GOM software.*

The measurements surprised me greatly, as the results of the PLA prototype are extremely good: the largest deviation from the 3D model was at the shaft end: - 0.270 mm and in the upper hole: + 0.218 mm.

Figure 9 presents the results of measurements of the PETG prototype relative to the 3D model.

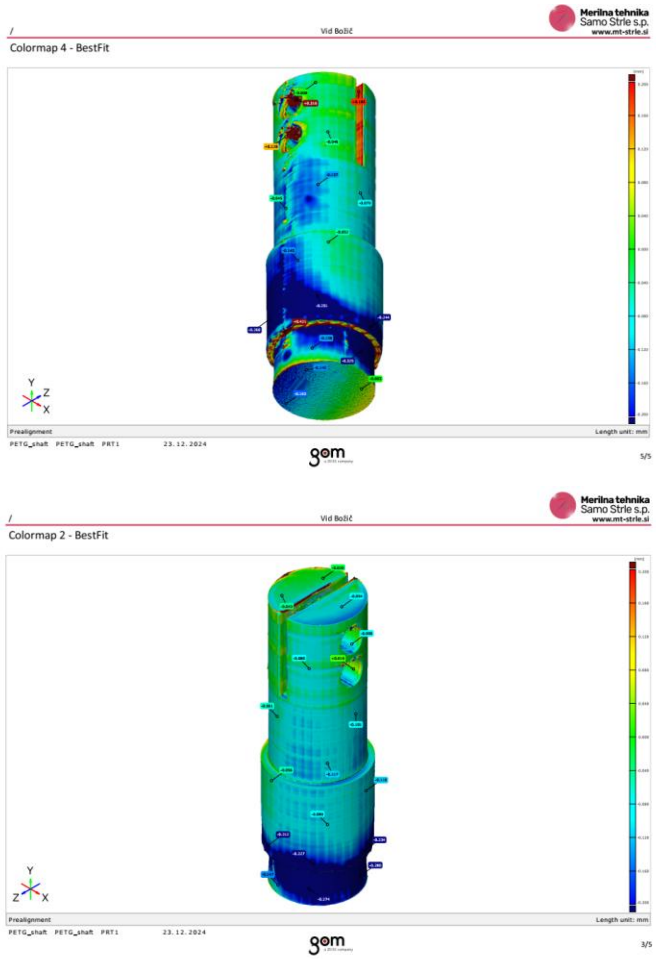


Fig. 9: *Results of measurement of PETG prototype with GOM software.*

A slightly larger deviation from the 3D model was measured in the PETG prototype. The largest deviation from the 3D model was at the shaft end: - 0.325 mm and in the upper hole: + 0.310 mm.

A comparison between the two prototypes is shown in the figure 10. The difference between them is greatest on the underside of the shaft and ranges from -0.405 mm to + 0.223 mm.

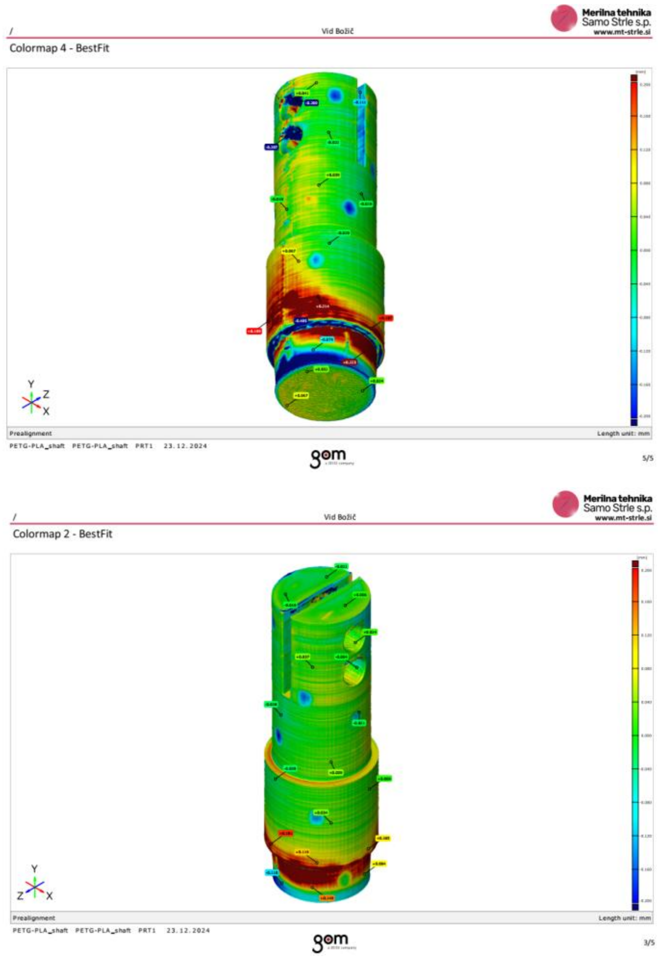


Fig. 10: *Comparison results of measurement of PLA and PETG prototype.*

Conclusions

Our project team is almost at the end of its concept. We have to combine, assemble all the prototype components into the final assembly and test our first windmill prototype on the planned object. I am satisfied with my work, acquired knowledge and experience. I used my previous knowledge in the field of 3D modeling and rapid prototyping technology. The results after measuring the two first prototypes surprised me. I expected greater deviations from the 3D model. We can achieve good results with a relatively cheap printer. The results of the prototypes could possibly be further improved by optimizing the settings of the machine's 3D printer. However, this task should wait for me, if the team agree on making a real functional prototype.

3. References

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2. Merilna tehnika company achive, *Dimensional report PLA and PETG shaft*, Zeiss GOM ATOS (23. 12. 2024)
3. https://www.zeiss.com/metrology/en/systems/optical-3d/3d-scanning/atos/atos-q.html