Filament for a 3D Printer from Pet Bottles-Simple Machine

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***Abstract*—The first part of the article shows the process of preparation of the material from bottles, also mechanical construction created mostly from 3D printed parts. The second part of the article shows an electrical and electronic system, that is responsible for temperature controlling, filament winding speed control, head cooling and heating. The third part of the article shows the filament creation process and machine operation. The last part of the paper shows experimental results, comparison of features and parameters, for example, temperature resistance, tensile strength test or physical structure with popular filaments available on the market.**

***Index Terms*—3D printing, filament, recycling, PET bottles, machine**

I. Introduction

In nowadays, 3D printing is a very popular way of fast prototyping, making fully usable models and whole projects [1], [2]. In our University of Technology, we are using 3D printing in every project, a lot of parts are small, but we require them to be durable, for example, gears, clutches, motor mountings [3]-[7]. Researchers are even searching for means of improving mechanical properties of prints as so creating composite filaments [8]. The possibilities that 3D gives for us are irreplaceable, very low cost, speedy stage of computer model conversion into a real object, what's more, 3D printing allows us to make elements that are unreachable by other methods. During the prototyping, a lot of material and parts are discarded as waste as unsuccessful prints, poorly designed models, or poor print optimization. Creating a fully satisfying part brings a lot of unused material that goes into the bin. Living in an age where tons of garbage are produced, including large quantities of PET bottles so that we can connect this wasting procedure with our passion and work. Similar to other researchers, we aim to reduce our environmental impact and look for means of reusing materials for 3D printing [9]-[11]. This article is about a simple machine that allows us to transform unused PET bottles into the 3D printer filament. There are many materials available on the market, also PET filament, which is very durable, chemically and temperature resistant, flexible and easy for printing.

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II. The Process of Preparation of the Material from Pet Bottles

A. Cutting the Bottles

First of all, the most ordinary empty water or another drink bottle is needed. It should be cleaned from dust, labels, glue. The top of the bottle is trimmed [Fig. 1].

Figure 1. Bottle cutter.

A long 10mm width strip is made by using the specially designed cutter [Fig. 2]. The strip width can be regulated depending on the thickness of the material.

Figure 2. A strap created from a bottle.

The created strip is approximately 10m long. On the picture below [Fig. 3], we can see finished BPET compared with a raw strip.

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Figure 3. Finished BPET and raw strip.

The next step is to wind the plastic string on the bobbin [Fig. 4]. The loose end of the strip should be stenosed, making it easier to insert it into the heating block channel.

Figure 4. Strip winded on the bobbin.

III. The Process of Creating

A. Construction of the Machine

The machine is made of 80% from 3D printed parts. The specially designed casing has a modular structure, so every part of the machine is fully changeable. Every part is mounted to the machine by screws in properly designed places. Dimensions and designed model of the machine are shown in the picture below [Fig. 5].

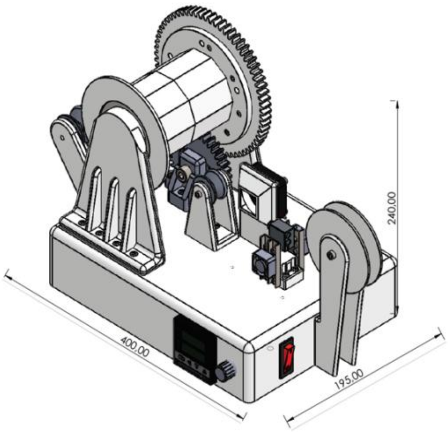

Figure 5. The project of the machine.

The model was designed in SolidWorks modelling program. The material used to create parts is PLA (polylactide), it has no contraction during printing, and it's easy to use because desirable dimensions of designed parts are different. In fact, so the designer must correct and optimize all dimensions so that this difference is as small as possible. PLA material is easy to make it. For example, 3mm hole in real print has ~2.9mm, so designer should change dimension in modelling program to 3.1mm and the printed part will match the assumed dimensions. In the picture below the real model of machine is shown [Fig. 6].

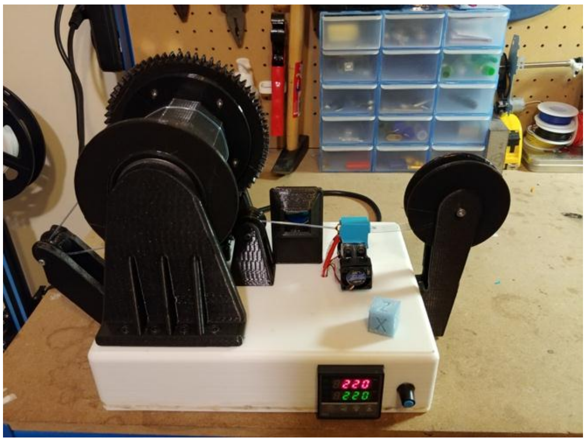

Figure 6. The real model of machine.

B. Construction of the Control Panel

The operator panel consists of REX C-100 temperature PID controller powered by 240v, that is controlling the temperature of the head [Fig. 7]. Temperature data is provided by thermocouple K placed in the head. The heater of power 40W is connected to this device and powered by 12V. This allows reaching temperature up to 260 ℃. On the right side, we can see PWM controller with built-in on/off switch, that is responsible for controlling big bobbin rotation speed.

Figure 7. Machine control panel.

C. Construction of the Big Bobbin

The big bobbin is set in motion by two-stage gear transmission with 1:10 gear ratio powered by DC motor [Fig. 8]. The motor has 12V and torque of 2Nm, and the rotational speed is 30 rpm/min.After taking the losses into account, we have 18Nm and 0.5-3 rpm/min on the bobbin. This amount of torque is necessary for the machine to work properly because pulling the filament requires very high force. Big bobbin and gears are bearing, which significantly reduces friction and increases the efficiency of the entire transmission.

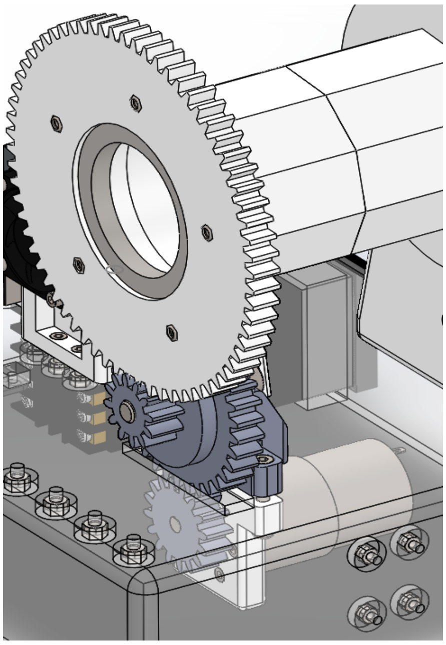

Figure 8. Gear transmission of the bobbin.

D. Design of the Heating Block

The heating block [Fig. 9] is made of regular 3D printing heating block, specially drilled nozzle allows extrusion of filaments with a diameter of 1.75mm. A plastic string passes through the heating block, which is plasticized and then formed by a nozzle into a filament.

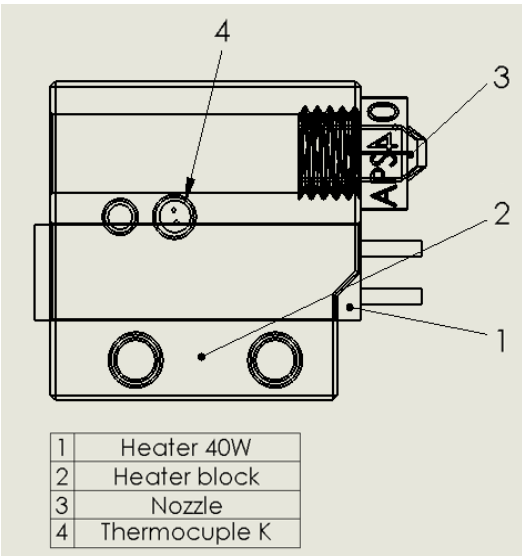

Figure 9. Heating block scheme.

At the exit of the heating block, there is an airflow that cools and cures the newly formed filament. What's more, there is also blue silicone insulatorwhich increases the efficiency of heating. Because of that, all parts are made of plastic which is not resistant to high temperatures. The heating block has two small fans which cool the metal adapter connecting the plastic case to the hot block [Fig. 10].

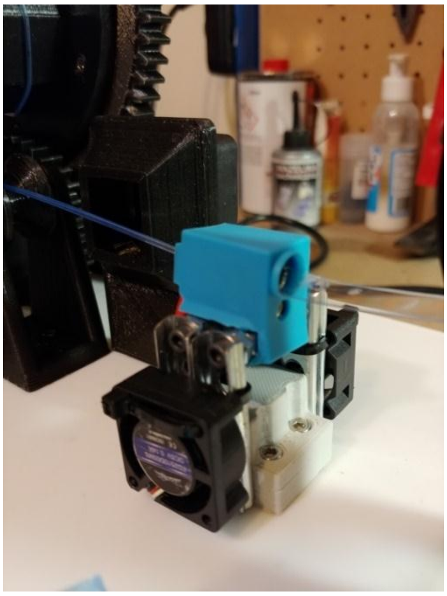

Figure 10. Heating block.

E. The Filament Creation Process and Machine Operation

At the beginning, a narrowed plastic string should be inserted through the cold nozzle power supply, which will greatly facilitate the initial extrusion of the filament through the nozzle, the next step is connecting the power supply. After that, the switch on the side of the case should be switched on. Activated controller REX c-100 is now heating block to set temperature 220 ℃ [Fig. 11], and this temperature was chosen experimentally. When the heating block reaches set temperature, the plastic string should be drawn manually until you can attach it to the bobbin. Now by switching on and regulating rotation of bobbin, the molten plastic is forced through the hothead, then cooled and hardened, and then wound on a bobbin.

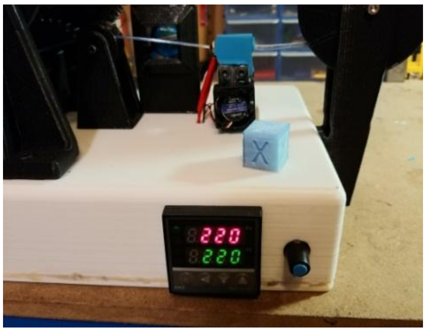

Figure 11. Machine operation.

Blocks placed on the path of the filament helps in guiding it and winding it on the drum [Fig. 12].

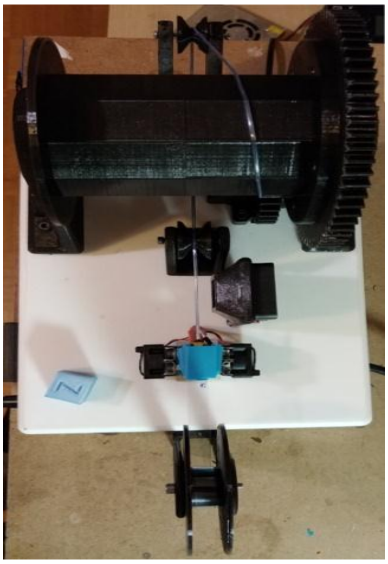

Figure 12. Filament creation process.

F. *Example Print with BPET*

Calibration cubes were printed of BPET filament, some of the calibrations of the 3D printer are needed, but satisfactory results were achieved at a temperature of as much as 256 ℃, bed temperature 80 ℃ and printing speed 35mm/s. The printing process is shown in the picture below [Fig. 13].

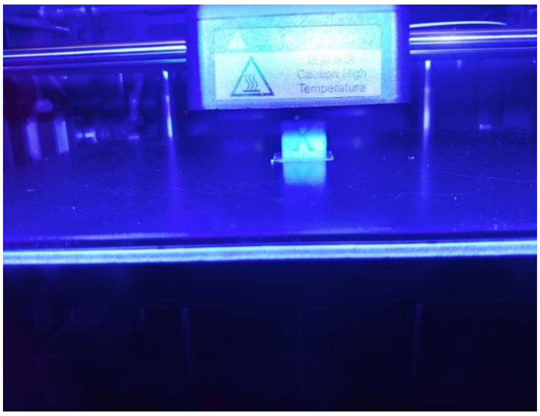

Figure 13. Printing process of BPET filament.

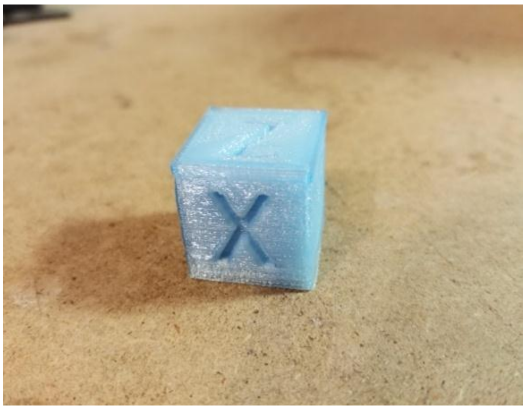

Figure 14. Calibration cube made of BPET.

The hardness of the obtained material is very high compared to other materials, and the structure is shiny. In the finished element, you can see a few dirt not removed when the filament was prepared, due to the irregular width of the cut strip, we also see the resulting bumps [Fig. 14].

IV. Experiments and Results

Numerous papers focus on mechanical properties of filaments and 3D prints based on a set of experiments [10], [12], [13]. We decided to test the most crucial parameters of filaments and prints, using methods available to us.

A. *Introduction*

The most popular materials used in 3D printing will be used in experiments such as PET-G, ABS, PLA. I called my recycled filament BPET (BottlePET). All print parameters of individual materials were selected to obtain the best print quality [Table I]. Printing speed, infill and nozzle size were the same for each print. All BPET prints were made from the same sample of the BPET.

TABLE I. Printing Parameters of Individual Materials

Material	3D printer head temperature [℃]	3D printer bed temperature [℃]	Printing speed [mm/s]	Nozzle size [mm]	Infill [%]
PET-G	250	70	30	0.2	100
ABS	255	100	30	0.2	100
PLA	202	55	30	0.2	100
BPET	256	85	30	0.2	100

B. *Microscope Examination of Filament*

Samples of an ordinary PETG filament from market and BPET filament were created [Fig. 15]. Transparency of both filaments was essential to make observation using an available microscope.

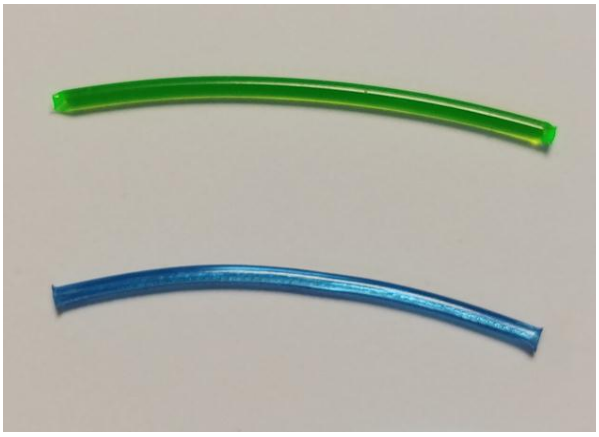

Figure 15. Samples.

As we can see in the figure below [Fig. 16], the internal structure of the PETG filament is uniform and external structure without distortion.

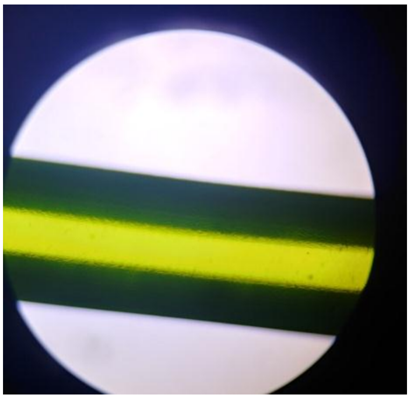

Figure 16. PETG microscope examination.

Unlike the previous filament, this one has visible defects in the internal structure, most likely, it is an empty space created in the processing process [Fig. 17]. The external structure is smooth.

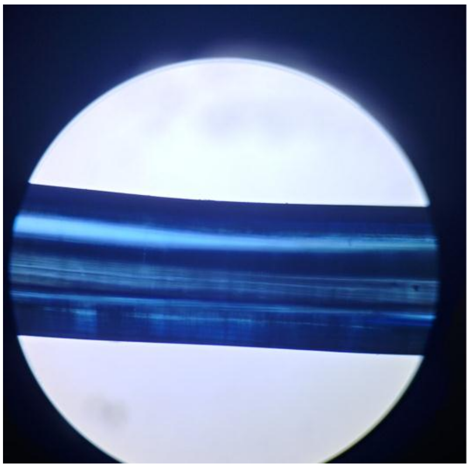

Figure 17. BPET microscope examination.

C. Temperature Resistance Test

Temperature test was conducted in the laboratory oven. The temperature range was 30-160 degrees, in steps of 5. Special samples were prepared. They were loaded with a steel nut that helped bent the sample. In the picture below [Fig. 18], particular materials and temperatures at which the sample began to change its shape are shown.

Figure 18. Samples at the initial stage of melting.

The temperature was consistently raised until the sample is completely melted. The temperatures and shape of the sample are shown in the picture below [Fig. 19].

Figure 19. Completely melted samples.

The ABS sample has withstood the temperature tests best. The BPET sample was slightly more resistant than ordinary PET-G filament. The test was repeated three times with similar effect.

D. Tensile Strengthtest

In the test was used ZWICK/ROELL Z010 tensile testing machine. The special sample was designed. Dimensions of the sample are shown in the figure below [Fig. 20].

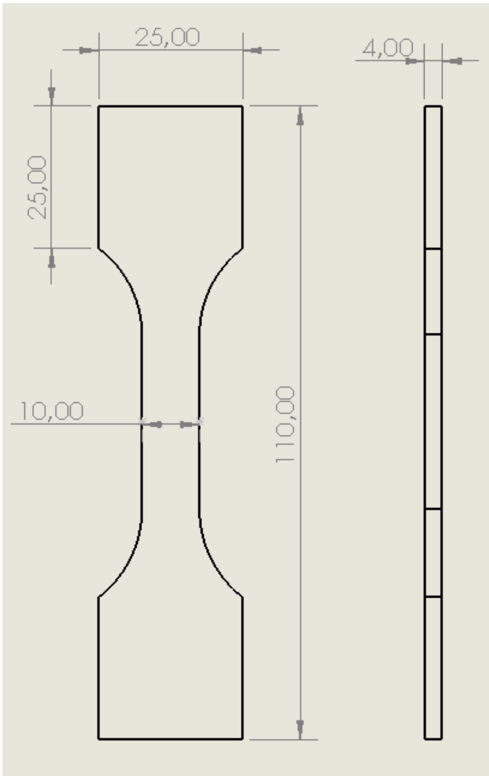

Figure 20. Sample dimensions.

Individual samples were made on 3D printer and signed [Fig. 21].

Figure 21. Samples.

Every individual sample was tested on the machine. Results are shown below [Table II].

TABLE II. TENSILE TEST RESULTS

Material	E_t MPa	σ_Y MPa	σ_M MPa	ε_M %	σ_B MPa	ε_B %	h mm	b mm	A_0 mm^2
PET-G	205	42,1	42,1	5,8	8,39	9,3	4	10,2	40,80
PLA	267	44,1	44,1	4,5	16,5	5,8	4	10,2	40,80
ABS	200	32,0	32,0	5,2	11,2	6,2	4	10,2	40,80
BPET	133	-	26,2	5,4	10,3	5,5	4	10,2	40,80

The graph shows that samples from PLA, ABS and BPET broke brittle, only the sample from PET-G broke tough. The results shown on the graph are typical for hard plastics [Fig. 22].

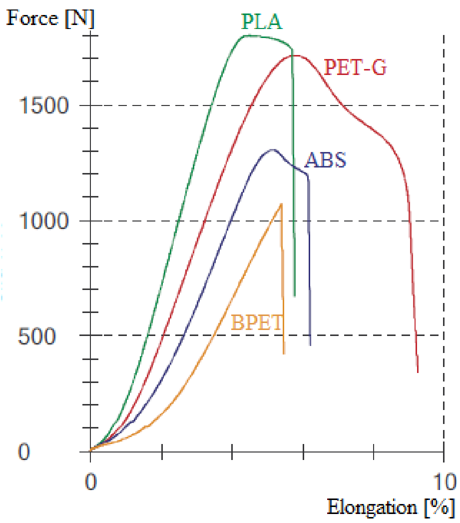

Figure 22. Tensile test graph.

On the figure below we can see that BPET, PLA and ABS brakes with small elongation compared with PET-G [Fig. 23]. BPET sample was the weakest one, compared with PLA sample it was two times weaker. The reason can be traced to the implementation of the filament, fine inclusions, moisture and air bubbles formed in the process of creating the filament significantly weaken its structure.

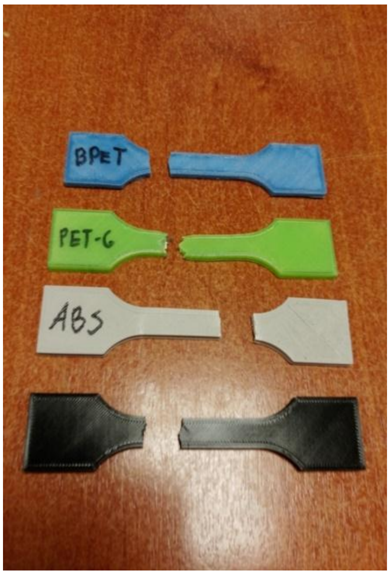

Figure 23. Samples after tensile test.

V. CONCLUSION

In this paper, we have introduced the design and model of a filament machine and proposed an alternative way to create ecological filament. We have tested the machine and filament comparing with generally available filaments in simple tests.It was a success to receive a filament that can be used in a regular 3D printer from ordinary plastic bottles.

The researchesshown in the article allowed the analysis of the created material that has a lot of potential, even in the promotion of waste recycling, and in the future, creating durable elements.

Creating and using BPET filamentwith printing parts on a 3D printer requires deeper and longer analysis. It is a prototype, and the machine has many drawbacks that need to be corrected.

There are several solution of similar machine avaiable. Presented method in the article is the least popular. The most popular way to create filament from plastic bottles or plastic waste is creating granules and then using those for processing, this is more complicated process and the machine is much bigger, not that compact size like machine presented in this article. Compared with another constructions machine showed in this article is made in 90% from 3D printed parts which affects the low price of the device.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

I. Tylman has developed the filament machine and conducted the experiments. All of the authors have participated in writing the paper, and all have approved the final version.

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