Processing System for Plastic Bottle to Obtain Polyethylene Terephthalate Filament in 3D Printers

RICARDO YAURI[1,2], HILCAR BERMEO[2], ALEJANDRO LEÓN[2], OSCAR LLERENA[3]
[1]Facultad de Ingeniería,
Universidad Tecnológica del Perú,
Lima,
PERU

[2]Universidad Nacional Mayor de San Marcos,
Lima,
PERU

[3]Seoul National University of Science and Technology,
Seoul,
SOUTH KOREA

Abstract: - Plastic has become one of the most used materials in the world for many uses, especially PET plastic (polyethylene terephthalate) which is used to make plastic containers and bottles. In addition, in recent years there has been an increase in pollution due to its waste, which affects the terrestrial, marine, and climatic ecosystems. Since 2018, in Peru, thousands of tons of PET containers have been produced, of which only 21.9% was recycled. This generates great contamination of waste by plastic bottles that are produced annually. Therefore, it is important to carry out recycling processes to avoid contamination by PET bottles, which take more than 500 years to degrade. Therefore, new recycling processes are sought in areas of interest such as 3D printing technologies. For this reason, the objective of this paper is to implement a system that performs the recycling of PET bottles for use in 3D printing and thus contributes to reducing pollution. As a result, an electronic card was obtained for the automation of the foundry machine, cutting processes, casting, extrusion, and collection of filaments. In addition, a programming algorithm was developed to monitor and display the temperature based on a closed-loop system and thus obtain a higher performance and quality of PET filament.

Key-Words: - Plastic bottles, system processing, 3D printer, Polyethylene Terephthalate, recycling.

Received: February 21, 2023. Revised: November 22, 2023. Accepted: December 11, 2023. Published: January 17, 2024

1 Introduction

Since plastic was invented, it has become one of the most used materials in the world since it has many uses, such as the generation of PET plastic (polyethylene terephthalate) that is used to manufacture plastic containers and especially plastic bottles, [1]. Currently, the production of plastic bottles has continued to increase since 2018, when the production of plastics has reached 360 million tons, [2]. This increases the contamination by its residues which affects the terrestrial ecosystem, marine environment, and climate change. In addition, it has been estimated that in 2015 plastics were related to the production of CO2 and it is projected that, this will increase to approximately 6.5 gigatons, [3].

Plastic pollution is a serious environmental problem, as most plastics are single-use and can remain in the environment for centuries before breaking down, [4]. This indicates the great contamination by waste from plastic bottles that are produced annually in Peruvian territory. In addition, in 2016, the Algalita Foundation (USA) announced that off the coast of Peru and Chile, there is a large island made of plastic, of which 25% corresponds mostly to plastic bottles, [5].

For this reason, it is important to take recycling actions to combat contamination by PET bottles, since immense amounts of this material are produced every day. The main problem that arises is that it needs more than 500 years to degrade, [6]. it cannot be eliminated so easily, and it continues to accumulate in different environments, and ecosystems, among others.

Considering the above, it is necessary to recycle plastic bottles in technological areas related to 3D printing, [7], using filaments based on thermoplastic polymers as raw material. This is a field that is evolving due to its usefulness in various fields such as manufacturing, health, education, etc., [8], [9], and it has gained relevance, where it is commonly used to manufacture products and prototypes, in the manufacture of toys or educational material, and other areas, [10], integrating embedded intelligence in hardware systems to improve their tasks, [11].

Based on the above, the following research question is proposed: How is it possible to carry out the processing of plastic bottles to obtain low-cost PET filament? Therefore, the objective of the research is to implement a recycling system for PET bottles for 3D printing. PET thermoplastic is used for the majority of plastic bottles used in water containers, [12], so this research adds value in the context of reducing plastic bottle pollution. For this reason, the importance of recycling bottles to produce filaments in 3D printers is shown, having as specific objectives we have: Design and implement a low-cost printed circuit board to automate the plastic bottle processing system; Develop a programming algorithm for the printed circuit board; Design and manufacture the mechanical and structural parts of the system; Evaluate and analyze the operation of the system.

This paper has multiple sections which are organized as follows: Section 2 shows related works. On the other hand, section 3 describes the concepts and technologies used in plastic processing systems. Section 4 describes the implementation of the system. Finally, the results are shown in section 5, and the conclusions in section 6.

2 Literature Review

Plastic bottle processing systems have been studied in many investigations. Therefore, this section describes some of the relevant papers on this topic.

There is a need to educate the consumer about the importance of recycling plastic bottles and show how it is used for 3D printing, [13]. The authors propose the reprocessing and recyclability of PET from discarded bottles. The solution begins with the collection of plastic bottles subjected to a process of washing, cutting, crushing (PET_B) and finally being extruded in the form of a thin wire, called "PET SC" or "PET RC" (depending on whether the wire passed through slow or fast cooling respectively). The authors used the product of this process as raw material to 3D print some test pieces, calling the result PET_3D. All these PET samples went through several quality tests, including a mechanical characterization test.

A similar research is carried out in, [14], where a mechanical process for recycling and large-scale treatment of plastic water bottles to obtain 3D printing filaments is shown. Before starting with the mechanical process (Extrusion of material), the authors followed some previous steps to condition the plastic bottles. The collection, washing, drying, and grinding of the PET bottles with a 12-blade grinding machine were the steps to obtain the material to be extruded. For the extrusion process, an industrial machine was used, and 2 different diameters of 3D filaments (2.85, 2, and 1.75 mm) were obtained.

Another similar scientific paper is described in, [15]. The authors implement a machine capable of recycling PET plastic bottles to obtain filaments for 3D printers. To do this, they designed the mechanical parts, most of which were 3D printed. This system is made up of an extrusion nozzle, a ceramic heating element, a thermocouple, and a controller to regulate the temperature. The authors made a comparison based on 2 experimental tests to verify the quality of PET compared to other commercial filaments. It was observed that the PET was slightly more resistant than the PETG.

The paper developed in, [16], describes the use of material extrusion (MEX) for additive manufacturing (AM). However, this process involves the processing of new plastics using PET materials that offer high recyclability potential. The paper reviews how the process of extrusion and recycling of bottles to obtain PET is based on MEX processes with tensile tests. In addition, a complementary thermal and mechanical characterization of the recycled resin is performed to provide a comparison with polyethylene glycol-modified (PETG) material. Their results show the importance of the drying parameters, which are adequate for the extrusion and the sensitivity of the material.

In another paper, [17], the quality control of products and its importance in food industries are described, where additional safety standards are required. Many production processes can be controlled completely contact-free using machine vision cameras and advanced imaging. The advantages of these techniques are fast performance and robustness in complicated classification applications. This paper shows a novel data preprocessing method using a convolutional neural network (CNN) for quality control of polyethylene terephthalate (PET) products in bottle caps. In the results, a five-fold reduction in the prediction and training time is obtained in comparison.

In the context of recycling, there are papers, [18], [19], where it is stated that microplastic particles, produced by non-degradable waste from plastic bottles, have an impact on the environment. In this paper, a multi-scale feature fusion method for hyperspectral imaging is shown by segmenting objects by location, using sensor fusion to identify transparent polyethylene terephthalate (PET). A near-infrared (NIR) hyperspectral camera is used to obtain RGB and hyperspectral images. In addition, a band selection stage that reduces dimensionality is implemented, ensuring that the proposed fusion method improves the precision in the classification of plastic bottles.

On the other hand, due to the importance of the implementation of printed circuit boards (PCBs), it contributes to carrying out the integration process with electronic circuits for temperature, humidity, and lighting monitoring functions as described in [20]. The paper discloses the development of a prototype temperature meter and 2 other environmental conditions. For this, the authors designed the schematic of an electronic circuit that can carry out the census functions of some environmental conditions with an Arduino microcontroller that serves as a data processor.

In contrast, the main contribution of this research, the previously mentioned articles highlight the importance of educating consumers about recycling plastic bottles for 3D printing, incorporating methods such as washing, cutting, shredding, and extrusion processes to produce PET filaments. In addition, they present the development of extrusion machines that emphasize the remarkable robustness of PET-based filaments. In contrast, this research provides a comprehensive low-cost plastic bottle processing system focused on obtaining polyethylene terephthalate filaments for application in 3D printers, highlighting the original procedures and process optimization.

3 Polymers and Plastic Melters

3.1 Thermoplastic Polymers

A polymer is a large molecule made up of repetitive chains of simple chemical units such as monomers (Carbon atom as the fundamental element). Normally these polymers are made up of thousands of monomers to form plastic materials or tissues of living beings, [21]. Table 1 shows some examples of polymers with their respective monomer with which it was formed.

Thermoplastic polymers are a type of plastic that can be molded at high temperatures and solidified when cooled. In addition, due to its interaction with heat, it is easier to be recycled, [22].Thermoplastics chemically deteriorate if they are heated and cooled continuously since the polymers, which make up the thermoplastic, are susceptible to thermal aging, [21]. In industry worldwide, thermoplastics replace materials such as metals and glass due to the versatility and ease with which they can be manufactured. Among the types of polymers, we have:

- Polylactic Acid (PLA). It is characterized by being biodegradable since it comes from renewable organic sources (corn starch, sugar cane). These are produced from a lower consumption of fossil resources unlike other polymers, [23].
- Acrylonitrile Butadiene Styrene (ABS). Made up of monomers and have better mechanical and thermal properties than others, [24].
- Polyethylene terephthalate (PET). It is a polymer that belongs to the family of polyesters and is derived from petroleum raw materials. It is a material like glass and the materials obtained with PET are characterized by being hard but the resistance to bending decreases with increasing temperature.

3.2 Plastic Melting System

A plastic melting system is a set of processes and equipment that melts and mixes plastic materials into a molten state, used in applications such as injection molding, extrusion, and 3D printing. Through heat and pressure, plastics become malleable and can be molded into different shapes and final products according to specific techniques such as injection molding, extrusion, and 3D printing.

i) Thermoplastic casting. There are different types of processes for obtaining plastics such as extrusion, coating, injection molding, thermoforming, and casting, among others. These processes have great commercial and technological importance due to the materials that are obtained as a product. In the last 50 years, the applications of plastics have increased considerably and an example of this is the replacement of glass containers with plastic containers or bottles, [21]. There are several reasons why plastic-obtaining processes are carried out: Ease that polymers must obtain an immense number of plastic parts, Less energy is required to produce products from plastics compared to metals, and plastic-obtaining processes are one-step operations.

ii) Temperature control. There are several units for a temperature control system and among them we have: the power supply unit (system power), sensor unit (detects the temperature), display unit (shows the temperature status), and control unit. control. This last unit processes the information so that the system produces an action either to increase or decrease the temperature, [25]. Among some control methods, we have thermostats (Figure 1), thermistors, and PID control.

Fig. 1: bimetal thermostat, [26]

iii) Plastic Extrusion. Is one of the many basic processes for the formation of different types of materials (metallic or ceramic such as polymers). In general, extrusion compresses a material, in which the result flows through an orifice, producing a product whose size depends on the shape of the orifice, [27]. Figure 2 shows the extrusion process of a solid-state polymer with a specific thickness.

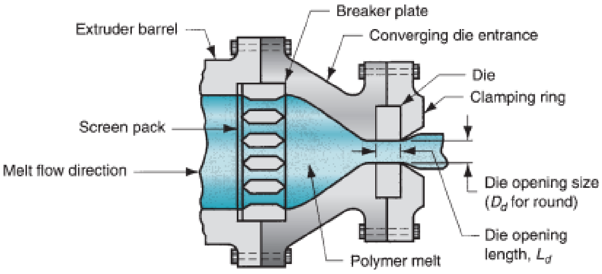

Fig. 2: Extrusion process for polymers, [27]

4 Proposed System

The methodological research process for the development of the system is innovative because it presents a proposed system to transform plastic bottles into PET filaments for 3D printing, focusing on automation through a PCB that controls sensors, actuators, and low cost. The distinctive feature lies in the integration of a structural design that houses the electronics and mechanical parts to coordinate the collection of material.

Its main base is the development of a printed circuit board (PCB). This PCB will oversee automating the process for obtaining the filament and this will be achieved thanks to the control of sensors, actuators, and peripherals. To contain all the electronics, the design of structural parts that build the body of the machine is carried out, and mechanical parts are designed that work together with the peripherals that carry out the filament collection process.

4.1 Stages of System

The proposed system is composed of the following stages (Figure 3):

- First stage: Cutting and Segmentation of plastic bottles. Plastic bottles can be cut manually or with assistance.
- Second stage: Casting and Extrusion. oversees the casting and extrusion of the plastic threads obtained from the previous stage.
- Third stage: Filament collection. It consists of the extraction of the material both to be cut and to be extruded. This stage is also responsible for storing the filaments for 3D printing. For this, a NEMA17-1.5 A stepper motor (PAP) is used, due to the precision for positioning and speed control, the torque with which it works, the weight, dimensions, and the price (Table 1).

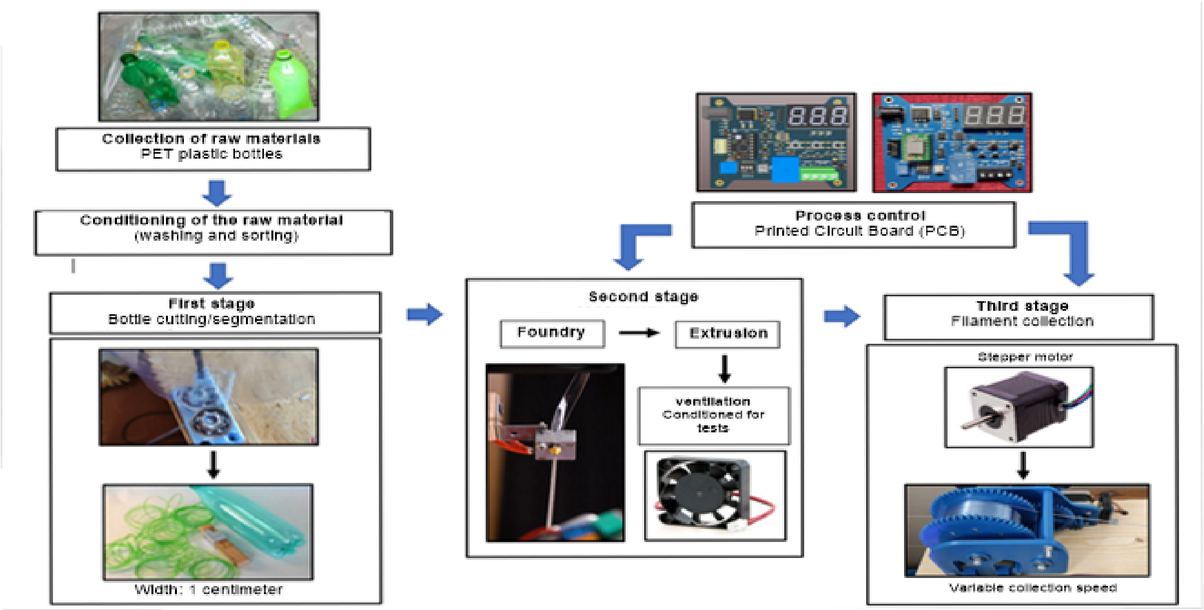

Fig. 3: Block diagram for the system

Table 1. Comparison of three PAP engines

	Motor PAP stepper NEMA 17 1.5 A	Motor PAP stepper NEMA 23 1.5A	Motor Johnson Electric, 12 V,
Cost	S/. 25	S/. 100	S/. 65
Nominal voltage	4.8 V	4.8 V	12 v
Nominal current	1.5 A	1.5 A	Not indicate
Torque	0.55 N.m	0.7 N.m	0.05 N.m
Weight	350 grams	700 grams	25 grams

4.2 Process Control

The machine to be implemented contains 3 stages (cutting, casting, and harvesting). A process control is carried out for monitoring, temperature control, and the PAP motor. This integrates all the electronic components, microcontrollers, and drivers necessary for the control of the necessary processes of the stages:

- Electronic card design. Controls the foundry stage and the collection of the designed machine. It is made up of: Power supply. Engine control phase. Finally, the temperature control phase of the casting
- Processing with a microcontroller (Figure 4).
- Calculations of the track widths of the PCB. Techniques applied for thermal relief.
- Techniques applied for thermal relief in the PCB.
- Implementation and integration of the PCB. Using Altium Designer software. Figure 5 shows a 3D view of the integrated PCB with all the electronic components.

Figure 6 represents the physical part of the PCB with the necessary symbols to position the electronic components in the correct place.

4.3 Development of the Pieces

The design and obtaining of the mechanical and structural parts are shown. To do this, the following steps are performed:

- 3D design of the pieces. Structural pieces, which support and coverage to the different sections of the machine. Figure 7 shows the part called the Main Base, which contains all the electronics and devices inside. The front section of this piece is where printed buttons were placed to be able to configure and display the information.
- 3D printing and post-processing. All the designs were exported in STL format to be able to proceed with the 3D printing of the pieces.

4.4 Assembly and Integration

- After 3D printing and post-processing of all the parts, the assembly, and integration of devices were carried out to complete the development of the foundry machine. In Figure 8, you can see all the 3D-printed parts and accessories (screws, filming, metal supports, etc.). While in Figure 9, the total of all the electronics used (PCB, sensors, and actuators) is presented.

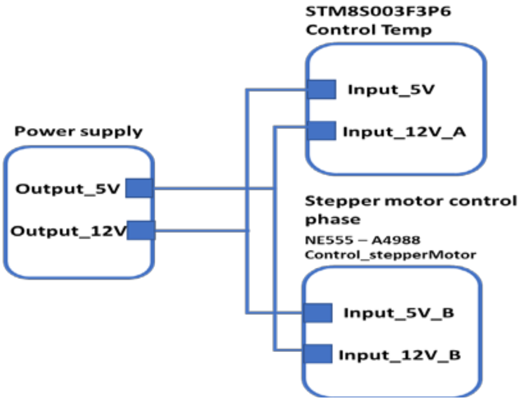

Fig. 4: Design stages

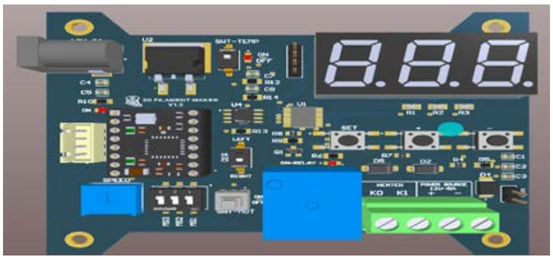

Fig. 5: 3D simulation view of the PCB

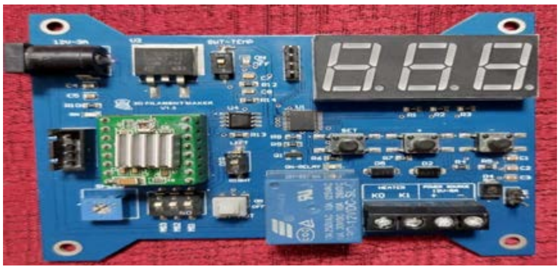

Fig. 6: Implementation of the PCB

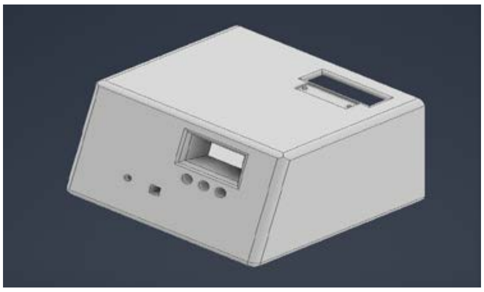

Fig. 7: Main base

Fig. 8: 3D printed parts and accessories of the foundry machine

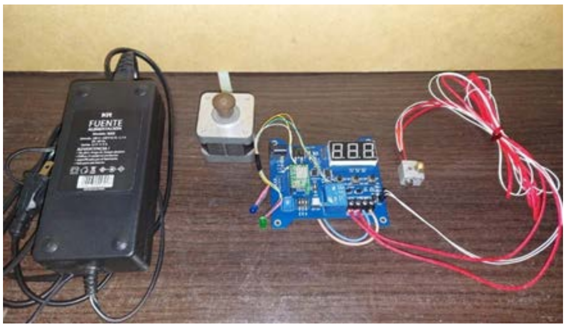

Fig. 9: Electronics used in the foundry machine

With the electronics assembled, the filament collection system is placed. Subsequently, the gears are placed, both the Pinion and the gear (Figure 10). The view of the foundry machine has the piece Belt Aligner on the left side.

5 Results

5.1 Foundry Machine

To conduct the tests, the machine is first prepared, connecting the power supply to the machine. The plastic tape was prepared by feeding it through the tape aligner piece. Once the connections were made, the machine was turned on. A green LED is the indicator that the machine is on and working properly. Values are shown on the 7-segment display, as can be seen in Figure 11.

5.2 Performance Evaluation

For the evaluation of performance, an exhaustive analysis of each of the three fundamental stages of the casting process of the machine is carried out. This verification was carried out through a series of meticulous specific evaluations at each stage of the casting machine process. Multiple replicate tests were performed under controlled conditions to ensure consistency and reliability of results. In addition, through visual observations, the filaments produced in each stage were evaluated.

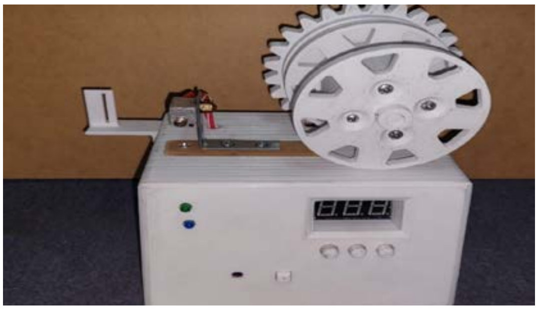

Fig. 10: Assembled foundry machine

Fig. 11: Starting the casting machine

Each of the 3 stages of the foundry machine is analyzed. To do this, at each stage an evaluation of its operation is carried out to analyze its behavior as described below:

- First stage: The system uses a wound tape obtained from the bottle (Figure 12).
- Evaluation of the Second stage: foundry and Extrusion. A temperature value close to the melting point of the PETG material (265°) was entered (Figure 13).
- Evaluation of the Third stage: Collection of filaments. A section of the material is placed at the tip of the spool, which will collect the filament.

5.3 Analysis of the Filament Obtained

The shape of the filament and its consistency were verified. The filament obtained maintains a cylindrical shape, while the consistency is resistant and flexible. These characteristics have been equated to a commercial filament (Figure 14) where, on the left side, there is commercial filament while on the right side is the filament obtained by the foundry machine. The diameter of the material was measured with a digital vernier. The diameter obtained is 1.7mm, although this is an approximate value because the instrument only has 1 decimal place. The value of the diameter is related to the speed of extraction of the filament from the machine and the faster this action is performed; the filament tends to be thinner.

In addition to shape and diameter, Figure 14 reveals other key aspects of the filament produced by the casting machine. The robust and flexible consistency of the filament is evident in the image, suggesting adequate homogeneity in the distribution of the molten material during the extrusion process. A uniform surface free of irregularities in the filament is also observed, indicating a coherent extrusion and an effective control of the process conditions.

Fig. 12: Collection of the tape obtained

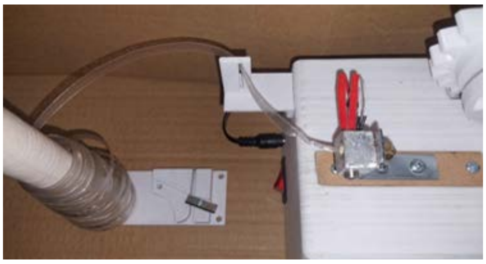

Fig. 13: Filament foundry process

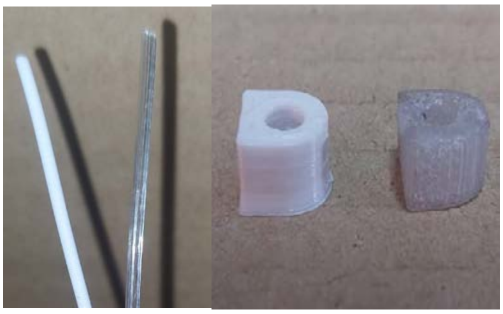

Fig. 14: Comparison of shape and consistency with a commercial filament

6 Conclusions

An essential achievement of the system lies in the incorporation of a sophisticated electronic card, meticulously designed for the integral automation of all the stages and operations related to the casting machine. The careful planning of the phases of cutting, casting, extrusion, and collection of filaments by segments generates an advanced level of specialization and optimization of their respective functions.

Highlighting the electronics, it displays its functionality by processing the temperature data captured by the sensors in real-time, exercising crucial control over the quality of the PET filaments obtained in the casting process. The execution of control algorithms allows the supervision, regulation, and display of the temperature. This control, anchored in a closed-loop system, culminates in an amplified level of performance and quality.

The design and manufacture of mechanical and structural parts are integrated into the process of generating PET filaments from plastic bottles, which provide protection, support, and structuring of the different stages of the machine. The quality of these filaments was verified by comparing them with another commercial filament through 3D printing of the same piece. The results show a visual understanding of filament quality, supported by precise measurements, thus cementing the effectiveness and viability of the casting system in producing high-quality filament.

In future research, new process control and monitoring strategies could be explored, such as more advanced programming algorithms for the closed-loop system, which allow more precise control of temperature and other parameters. These improvements would contribute to the reduction of contamination by PET plastic bottles.

References:

[1] X. Xu *et al.*, "Chemical upcycling of waste PET into sustainable asphalt pavement containing recycled concrete aggregates: Insight into moisture-induced damage," *Constr. Build. Mater.*, vol. 360, Dec. 2022, doi: 10.1016/J.CONBUILDMAT.2022.129632.

[2] P. Europe, "Plastics - the Facts 2019," *plasticseurope*, 2019. https://plasticseurope.org/wp-content/uploads/2021/10/2019-Plastics-the-facts.pdf (Accessed Date: August 7, 2023).

[3] T. D. Moshood, G. Nawanir, F. Mahmud, F. Mohamad, M. H. Ahmad, and A. AbdulGhani, "Sustainability of biodegradable plastics: New problem or solution to solve the global plastic pollution?," *Curr. Res. Green Sustain. Chem.*, vol. 5, p. 100273, Jan. 2022, doi: 10.1016/J.CRGSC.2022.100273.

[4] O. Poma, B. Ricce, J. Beraún, J. E. Perez Carpio, H. Fernandez, and J. Soria, "Biodegradation of Low-Density Polyethylene—LDPE by the Lepidopteran Galleria Mellonella Reusing Beekeeping Waste," *Front. Bioeng. Biotechnol.*, vol. 10, Sep. 2022, doi: 10.3389/FBIOE.2022.915331.

[5] Michael Niaounakis, *Polymers Used in Flexible Packaging*. Elsevier, Inc, 2020.

[6] J. Vaucher, A. Demongeot, V. Michaud, and Y. Leterrier, "Recycling of Bottle Grade PET: Influence of HDPE Contamination on the Microstructure and Mechanical Performance of 3D Printed Parts," *Polym. 2022, Vol. 14, Page 5507*, vol. 14, no. 24, p. 5507, Dec. 2022, doi: 10.3390/POLYM14245507.

[7] L. E. Ruiz, A. C. Pinho, and D. N. Resende, "3D Printing as a Disruptive Technology for the Circular Economy of Plastic Components of End-of-Life Vehicles: A Systematic Review," *Sustain.*, vol. 14, no. 20, Oct. 2022, doi: 10.3390/SU142013256.

[8] W. Liu, H. Huang, L. Zhu, and Z. Liu, "Integrating carbon fiber reclamation and additive manufacturing for recycling CFRP waste," *Compos. Part B Eng.*, vol. 215, Jun. 2021, doi: 10.1016/J.COMPOSITESB.2021.108808.

[9] J. Casado, O. Konuray, A. Roig, X. Fernández-Francos, and X. Ramis, "3D printable hybrid acrylate-epoxy dynamic networks," *Eur. Polym. J.*, vol. 173, Jun. 2022, doi: 10.1016/J.EURPOLYMJ.2022.111256.

[10] J. Herzberger, J. M. Sirrine, C. B. Williams, and T. E. Long, "Polymer Design for 3D Printing Elastomers: Recent Advances in Structure, Properties, and Printing," *Prog. Polym. Sci.*, vol. 97, p. 101144, Oct. 2019, doi: 10.1016/J.PROGPOLYMSCI.2019.101144.

[11] R. Yauri and R. Espino, "Edge device for movement pattern classification using neural network algorithms," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 30, no. 1, pp. 229–236, Apr. 2023, doi: 10.11591/IJEECS.V30.I1.PP229-236.

[12] B. Jain, A. K. Singh, and M. A. B. H. Susan, "The World Around Bottled Water," *Bottled Packag. Water*, pp. 39–61, 2019, doi: 10.1016/b978-0-12-815272-0.00002-7.

[13] F. Ferrari, C. E. Corcione, F. Montagna, and A. Maffezzoli, "3D printing of polymer waste for improving people's awareness about marine litter," *Polymers (Basel).*, vol. 12, no. 8, 2020, doi: 10.3390/POLYM12081738.

[14] A. Oussai, L. Kátai, and Z. Bártfai, "Development of 3D printing raw materials from plastic waste," *Hungarian Agric. Eng.*, vol. 7410, no. 37, pp. 34–40, 2020, doi: 10.17676/hae.2020.37.34.

[15] I. Tylman and K. Dzierzek, "Filament for a 3D Printer from Pet Bottles-Simple Machine," *Int. J. Mech. Eng. Robot. Res.*, vol. 9, no. 10, pp. 1386–1392, 2020, doi: 10.18178/ijmerr.9.10.1386-1392.

[16] M. Bustos Seibert, G. A. Mazzei Capote, M.

Gruber, W. Volk, and T. A. Osswald, “Manufacturing of a PET Filament from Recycled Material for Material Extrusion (MEX),” *Recycling*, vol. 7, no. 5, Oct. 2022, doi: 10.3390/RECYCLING7050069.

[17] M. Malesa and P. Rajkiewicz, “Quality control of pet bottles caps with dedicated image calibration and deep neural networks,” *Sensors (Switzerland)*, vol. 21, no. 2, pp. 1–16, Jan. 2021, doi: 10.3390/S21020501.

[18] M. H. Tan, M. S. Chiong, Y. Y. Chun, K. Tsukahara, and K. Tahara, “An Analysis of Practices and Challenges for Plastic Recycling Industry in Malaysia,” *Int. J. Autom. Technol.*, vol. 16, no. 6, pp. 831–837, 2022, doi: 10.20965/IJAT.2022.P0831.

[19] Z. Cai, J. Yang, H. Fang, T. Ji, Y. Hu, and X. Wang, “Research on Waste Plastics Classification Method Based on Multi-Scale Feature Fusion,” *Sensors*, vol. 22, no. 20, Oct. 2022, doi: 10.3390/S22207974.

[20] M. Moise, P. Svasta, and A. Mazare, “Implementation of a prototype embedded system for in-car multipoint temperature measuring,” *22nd Eur. Microelectron. Packag. Conf. Exhib.*, pp. 7–10, 2019, doi: 10.23919/EMPC44848.2019.8951766.

[21] B. Björkner, *Plastic Materials*. Springer, Berlin, Heidelberg, 1995. doi: 10.1007/978-3-662-03104-9_28.

[22] J. Van Gisbergen and J. Den Doelder, “Processability predictions for mechanically recycled blends of linear polymers,” *J. Polym. Eng.*, vol. 40, no. 9, pp. 771–781, Oct. 2020, doi: 10.1515/POLYENG-2019-0224.

[23] E. Tuncer, “Basics of the polylactic acid,” *ResearchGate*, vol. 1, no. May, p. 10, 2020, doi: 10.13140/RG.2.2.10114.71362.

[24] D. Sy, “Material and Application Report 2015 Acrylonitrile Butadiene Styrene (ABS) and 3D Printer (2),” no. December 2015, 2015.

[25] E. Ogu, J. Ekundayo, and O. Oyetesu, “Temperature control system,” in *IEEE Central America and Panama Student Conference, CONESCAPAN*, 2011, vol. 1, p. 95. doi: 10.1109/CONESCAPAN.2017.8277609.

[26] R. E. Smith, *Electricity for refrigeration, heating, and air conditioning*. Delmar Cengage Learning, 2011.

[27] M. Groover, “Fundamentals of Modern Manufacturing: Materials,Processes,andSystems,” *Metall. Weld.*, p. 1025, 2010, doi: 10.1007/978-94-010-9506-8_6.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

All authors have contributed equally to the creation on this article.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The authors have no conflict of interest to declare.

Creative Commons Attribution License 4.0 (Attribution 4.0 International, CC BY 4.0)