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SMART DEVICE FOR PET RECYCLING

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Abstract :. PET (polyethylene terephthalate) is a common plastic substance used to make water bottles, carbonated drinks, juices and others. PET is durable and easy to transport, but can be difficult to degrade in nature. If not recycled, PET can remain in the environment for hundreds of years, polluting the sea and other environmental areas.
The work presents the creation of an smart device, which can easily, with low costs, be transformed in laboratory conditions, respecting the steps of the industrial technological process, of polyethylene terephthalate (PET) into recycled PET. The final goal is to research the mechanical characteristics of recycled PET. The method used is *Computer Assisted Thermoplastic Extrusion*, the main parameters of the entire technological process being permanently monitored. The results of mechanical and thermal tests were demonstrated that recycled PET can be transformed into filament for 3D printing of finished products that have properties similar to those obtained industrially.
Key words : Device, polyethylene terephthalate (PET), parameter, extrusion, mechanical characteristics.

1. INTRODUCTION

In the world of plastics there are different types of synthetic materials. One of them is PET (polyethylene terephthalate). It belongs to the polyester group and is a type of plastic raw material derived from petroleum. Many people do not know what PET is. It was discovered by British scientists Winfield and Dickson in 1941, who patented it as a fibre-making polymer. It is very useful today. [1]. It is a semi-crystalline thermoplastic material created by the condensation of terephthalic acid and ethylene glycol. This material can be found like: semi-crystalline PET, amorphous PET and glycol modified PET with higher impact resistance. PET is durable and easy to transport, but can be difficult to degrade in nature. If not recycled, PET can remain in the environment for hundreds of years, polluting the sea and other environmental areas [1].

Recycling PET reduces the amount of waste that ends up in the environment and saves natural resources by reducing the need to extract new raw materials to make new bottles. In addition, PET recycling can reduce greenhouse gas emissions and the energy required to manufacture new plastic products. PET is a difficult material to extrude due hygroscopic tendencies and for this reason, PET should be extruded with a moisture. During 4 hours the drying temperatures are in the range 120 …150^0 C. After drying, the PET needs to be processed immediately because can result many degradations in structure of material. PET material must dried in air for 25 hours at about 130^0 C, when can have a mass loss after only few minutes during a degradation test in air at 270…280^0 C. For a vacuum-dried material with the same parameters, no loss of material is recorded [2]-[7].

Temperature and pressure play an important role in the processes of obtaining PET filament because thermal and thermo-oxidative processes of degradation of the material occur [10]-[12].

There are several methods to recycle PET bottles, including washing and sorting the bottles, which are then turned into recycled materials for use in making new products such as clothes, car mats or even other bottles [4], [6]. This process can save energy and reduce greenhouse gas emissions.

PET has the following characteristics:process able by blowing, injection, extrusion; excellent mechanical properties; bio-orientable;cost / performance; first place in recycling.

Like all materials, there are some disadvantages to PET. Drying is one of its main disadvantages. All polyester must be dried to avoid loss of properties. The moisture content of the polymer upon entering the process must be a maximum of 0.005% [2].

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In this paper, will be presented an smart automatic device, which can used to transformed into PET flakes and finally, into products.

2. GENERAL INFORMATION ABOUT PRODUCTION LINE FROM OTHER DEVICES FOR PET RECYCLING

2.1 The disadvantages of PET recycling:

Equipment cost is a disadvantage for PET, as is temperature [2]. Bio-oriented injection moulding equipment is a good reward based on mass production. In blow moulding and extrusion, conventional PVC equipment can be used, which has more versatility to produce different sizes and shapes.

When the temperature exceeds 70 degrees, polyester cannot maintain good performance. Improvements were made by modifying the equipment to allow hot filling. Crystalline (opaque) PET has good temperature resistance, up to 230 °C [2]. Not recommended for permanent outdoor use.

2.2 The benefits of PET recycling:

We have unique properties, good availability and excellent recycling. Among its good properties we have clarity, gloss, transparency, gas or flavour barrier properties, impact strength, thermoform ability, easy to print with ink, allowing microwave cooking [2], [3].

2.3 Other solutions for automatic devices for PET recycling line:

Recycled PET may be used in a wide variety of final applications. As the quality of the collected PET bottles varies significantly from country to country, and even within the same country and as their conditions can be very bad, it is necessary to be continuously informed on the technologies and technical solutions of PET recycling line, in order to correctly process the most difficult and contaminated materials and reach the best final quality.[4]. Exist different plants for PET recycling, like: 500kg/h PET Cleaning and Recycling Production Line (China [4], 3000kg/h PET Bottle Recycling Line(India)[4], 5000kg/h PET Bottle Recycling Plant（UAE customer）[4], 6000kg/h PET Bottle Recycling Plant (America customer)[4], etc. All of these have: PET bottle washing and recycling machine, line for mixed soft and hard material washing and recycling machine, film washing and recycling machine, PET sheet extrusion line (Figure 1), (Table 1) [5], PET strap production line (Figure 2) [6], PET fibre production line (Figure 3)[7] .The flow of PET fibre production line is presented in Figure 4 [7].

Figure 1 Dryer-free PET Double Venting Sheet Line [5]

where exist a free of crystallization drying system with with the simple operation, low power cost, low production’s costs.

Table 1. Technical parameters for PET sheet extrusion line, [5]

Model	PET single layer	PET multilayer
Extruder Specification, diameter Φ [mm]	120/33	120/33, 65/33
Products Width, [mm]	500-1500	500-1200
Products Thickness, [mm]	0.20-1.5	0.20-1.5
Capacity(Max., kg/h)	450	500
Main Motor Power, [kW]	132	132/45
Design Production Speed, [m/min]	20	25

Figure 2 PET strap production line [6]

Figure 3 PET fiber production line [7]

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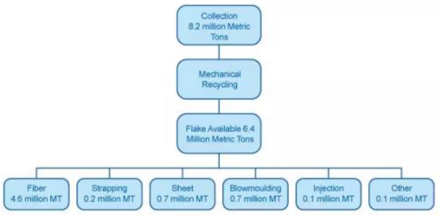

Figure 4 Flow chart of PET fibre production line [7]

Another PET recycling machines [8] has a complete line according to different customers needs (Figure 5).

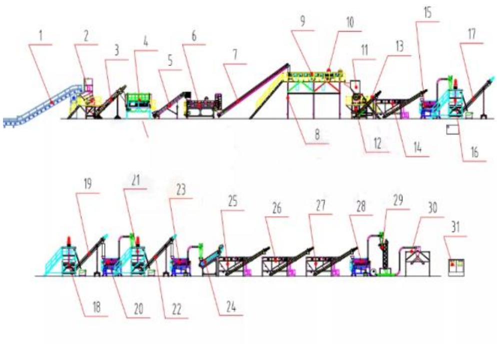

Figure 5 Main flow chart of complete PET recycling line [8]

where: 1-bale breaker; 2-elevated belt conveyor; 3-trommel; 4-belt conveyor; 5-mechanical label remover; 6- belt conveyor; 7-metal detector; 8-manual sorting table; 9- belt conveyor;10-crusher/granulator; 11-screw feeder; 12-float washing tank; 13- screw feeder; 14-hot washer; 15- screw feeder;16-horizontal friction water; 17-floating tanks; 18- screw feeder; 19-dewatering machine; 20-hot air pipeline drying system; 21-loosened label separator; 22-silo. Technical parameters of this line are only for reference (Table 2)[8]:

Table 2. Technical parameters for PET sheet extrusion line, [5]

Production capacity [kg/h]	Total installation power [kW]	Water consumption [m3 /h]	Line size [mm]
300-500	70-125	3-5	45x5x5
1000-1500	360	5-8	75x5x5
2000	450	8-10	106x6x6
3000	640	10-12	132x7x7

The final products humidity is below 1%, impurities 100ppm, the whole line capacity is about 300 ..2000 kg/h, flakes size 6 ..14 mm, transparency is 90%.

3. MATERIAL AND METHODS

The technologies used to identify and sort the waste are essential to obtain the best quality PET flakes, which later become raw material in other production processes.

3.1. Transforming PET into tape

The steps of a PET tape production technology are; sorting, milling, washing and packing [9].

Sorting: The first step is breaking the bales and separating the bottles according to colour and type of material. By using a rotary sieve and ballistic system, impurities such as dust or sand particles are removed mechanically, and polymers other than PET, such as PE films, cardboard or papers are removed manually. Metal scraps found in the bales are automatically removed using a magnetic separator. Also, aluminium waste (beer cans, cans) is eliminated with the help of an automatic sorting system. In the last phase, the PET bottles are optically sorted by colour, after which they are transported and distributed to the feed mouths of the grinding mills.

Milling: PET plastic is ground into PET granules of 8 to 12 millimetres.

Washing: PET tapes are washed and separated using high precision equipment.

Packaging: PET tapes are packed in special big-bag covers, approx. 1 ton. The contents of each bag are tested in quality laboratories before being sent to the final processors.

3.2. Transformation of recycled PET into products

The phases of that technology are [10], [11]:

- *PET tape*: made from 100% recycled tapes, PET tape is a binding product of excellent strength and durability, used in the wood, metallurgical, textile or construction industries;

- *from PET filament to granules*: PET granules are obtained from 100% recycled PET and become raw material for the production of food and non-food packaging;

- *the application of ecological recycling technologies:* obtaining the filament for the 3D printer from PET tape.

On the industrial technological line, the aspects of reliability and intelligent operational control can be observed [9]-[11]: technology without pre-drying; efficient vacuum system with minor losses; optimized equipment design; accessible and efficient control on

4. RESULTS AND DISSCUTIONS

4.1 Industrial PET film production

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technological steps (Figure 6) [11].

Figure 6 PET sheet line control system [11]

In Fig.6 the maximum output production is 821 kg/h (power or motor of extruder is 160 kW, diameter of screw is 93 mm), minimum output production is 686.8 kg/h (power or motor of extruder is 110 kW, diameter of screw is 71.4 mm)[11]. Can work on different rotations (maximum 306.2 rpm; minimum 42.7 rpm)[11].

The steps of operational flux are [11]: loadering; transit silo; loss-in-weight feeding; twin screw compounding; cooling stack and edge cutting; thickness testing; corona treatment; silicon/anti-static coating and drying; protection film coating; haul-off; automatic wintering with accumulator.

PET can be extruded with single or twin-screw extruders. In the process with single screw extruder the screw speed is better controlled than in process with twin-screw extruders.

4.2 The automatic device for PET film

The study presents an automatic device, which was created in laboratory conditions. The purpose of creating this device in the laboratory was to give students the opportunity to train some practical skills, following the operational flow on a different scale, more economical in terms of costs.

The device consists of (Figure 7, Figure 8):

- 1-logic board based on a microprocessor Atmega 328;
- 2,3- two stepper motors Nema 17 Advance 1 and Advance 2;
- 4-an extruder with temperature sensor;
- 5- fan;.
- 6- LCD display 2004 Blue compatible I2C;
- 7-buttons control;
- 8- power supply 12V / 6A.

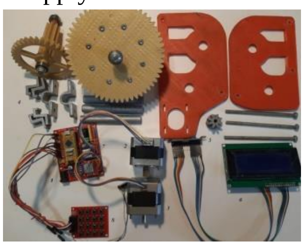

Figure 7 The components of device

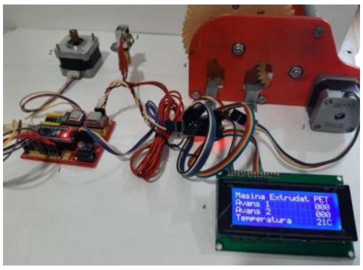

Figure 8 PET film ansambly

The working mode of this device is:
- the first stepper motor, called *Advance 1*, ensures a constant speed of the material (PET) at the entrance to the *Extruder*.
- when passing through the *Extruder* heated to 250^0C, the base material will be transformed from rectangular section into round section with a diameter of 1.75mm.
- after exiting the *Extruder*, the resulting material will be coiled on the roller driven by the second stepper motor *Advance 2*, during which the resulting material will also undergo a cooling operation by the *Fan* .
- the travel speeds of the PET material is adjusted using the *Control Buttons*.
- the advance speed of the two motors and the extruder temperature can be viewed in real time on the *LCD Display*. The flow chart of operation is shown in Figure 9:

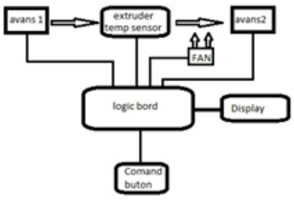

Figure 9 The flow chart of operation

All components are powered by a 12V DC power supply (8).

4.3 Experimental data

The final goal of this paper is to research the mechanical characteristics of recycled PET. The method used is *Computer Assisted Thermoplastic Extrusion*[12]-[14].

First, the samples are obtained from the recycled PET flakes during printing (Figure 10, Figure 11), from which, then, the final products will be obtained. (Figure 12, Figure 13).

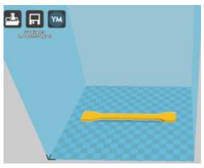

Figure 10 Design sample-horizontal print 36 minutes, 2.78m, 8 g.

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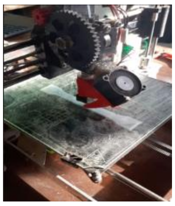
Figure 11 PET samples printing


Figure 12 Types of recycled PET samples


Figure 13 Products made from recycled PET

Filament printing conditions are : temperature of nozzle and for print bed, thickness of layer, printing speed and platform material (Table 3):

Table 3. Printing conditions

Data	Value
Temperature of nozzle (^{0}C)	268
Temperature for print bed (^{0}C)	88
Thickness of layer (mm)	0.15
Printing speed (mm/min)	1980
Material of platform	glass
Flow multiplier (-)	1

These products have the mechanical and thermal characteristics of the filament used in 3D printing (details will be presented in another work).
During the testing of the properties of the materials and the adhesion of the layers, the direction of the load is respected.
For *mechanical testing* of recycled materials the testing speed was 5 mm/min. Using an extensometer the share stresses were measured for materials of recycled PET and the average obtained data was compared with the values from specialized software [(Table 4, Figure 14).

Table 4. Mechanical testing -share stresses

Sample Material	rPET (MPa)	Soft r-PET
1	223	234
2	242	245
Average	232.5	239.5

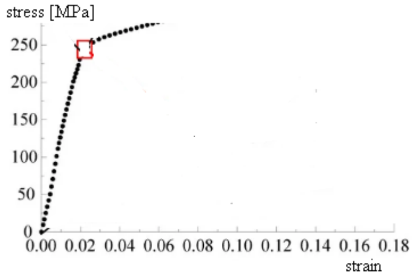

Figure 14 The diagram stress-strain

The values in the specialized literature indicate an average of 245 MPa [13], [14].

The values of elastic modulus E of the print samples for 0^0 and 90^0 bed orientation are shown in Table 5:

Table 5. Mechanical testing - elastic modulus E

Data	rPET (MPa)
E_o (MPa)	1595
E_{90} (MPa)	1995

For *thermal testing* were analysed the results of the heating and cooling cycle. During second heating cycle the results of measurements helped to establish the glass transition region-for rPET from 77^0C to 87^0C.
During the heating cycles can observed the lamellar thickness distribution of the crystallites (Table 6):

Table 6. Heating cycle results

Data	rPET
Fusion Heat (J/grd)	-37.80
Crystallinity (%)	26

After finished tests some samples presented elongations and ductile fractures in compared to others [15],[16].

5. CONCLUSIONS

After analysing the mechanical and thermal properties of the samples obtained from recycled PET we can conclude:
- media stress is about 232.5 MPa compared to the one obtained by software 239.5 MPa;
- the values of elastic modulus E is variable from 1595 MPa (on 0^0 bed orientation) to 1995 MPa (on 90^0 bed orientation);
- during thermal tests was observed that on a value of fusion heat about (-37.80)J/grd , appear lamellar thickness distribution of the crystallites (26% crystallinity).

The properties of the samples from which the finished products were made are close to those in the industry, so the process carried out with this device can be positively validated.

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Creativity starts from the students' laboratories and can lead to the certification of their results on an industrial scale.

6. ACKNOWLEDGMENTS

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