DEVELOPMENT OF 3D FILAMENT EXTRUDER FOR PLASTIC WASTE AND FABRICATION OF 3D PRINTED PRODUCTS

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ABSTRACT

Recycled plastic waste can be transformed into 3D printer filament, offering a sustainable solution to plastic pollution. There is great potential to improve the environmental impact of waste plastic material by recycling into useful products. Presently only 4% to 7% of all plastic waste is currently recycled in Oman out of 2.3MT. The objective of this research is to develop a 3D filament extruded machine to create 3D filament from waste plastic PET bottles. To study the feasibility of recycling thermoplastic waste materials and the effects of mechanical properties were investigated. This work categories in three parts, in first part demonstrates the strip process using waste PET bottles, developed mechanical construction of extruder machine created 50% of them are 3D printed components. The second part describes an electrical and electronic system that regulates temperature, head cooling, filament winding speed, and heat block heating. The filament processing, 3D printing and testing are exhibited in the third section. Findings from research were compared with other commercially available filaments, shows that there is potential recycling of PET waste plastic as an alternative 3D filament. This research contributes to reducing plastic waste and encourages sustainable AM.

Keywords: plastic waste, extruder machine, 3D filament, 3D printing products, mechanical properties

INTRODUCTION.

SOURCE OF PLASTIC WASTE: Plastic items are part of modern life and would not be feasible without them. However, as the number of plastics manufactured rises, a massive amount of plastic waste is generated, beyond society's capacity for efficient management. Study shows[2][3] global source of plastic waste generation. From 2 MT in 1950 to over 454 MT in 2018, the world's production of plastic derived from fossil fuels increased dramatically. Between 1950 and 1980, almost 9.7 billion tones (BT) of plastics were produced; by 2025, that amount is expected to double, and by 2050, it is expected to quadruple. An estimated 343 MT of plastic waste are generated in one year.

The only way to protect humans from this threat is by recycling the waste plastics. In Oman according to the study only 4% -5% of 420,000 MT post-consumer plastic waste is now recycled, with the remaining 85% being disposed of in landfills. This means that Oman has a chance to recycle an additional 40,000 MT of plastic waste when compared to the 15% recycling rate of the European Union. In terms of value creation and retention, job growth, financial diversification, and environmental protection. This might significantly benefit Oman’s economy.

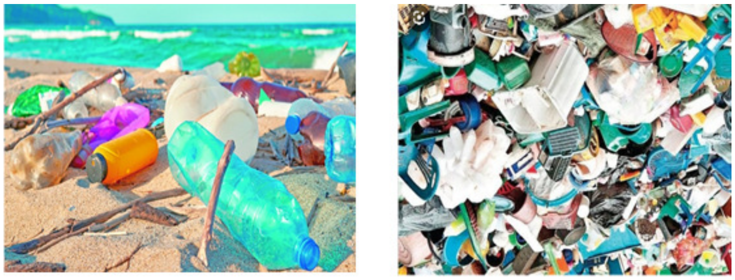

Fig 1 Waste plastic PET, HDPE & PP collection

RECYCLE PLASTIC WASTE: Recycling any material is important for the environment, moreover, recycling plastic provide certain advantages over other materials. Plastic takes up landfill space and pollutes the environment for a longer period because it can take hundreds of years, even up to one thousand years, for it to biodegrade.

PROCESSING OF WASTE PLASTIC

Fig 2 Processing of waste plastic [12]

FEASIBILITY STUDY

A feasibility study aims to identify the advantages and disadvantages of the current business or planned endeavor, environmental opportunities and threats, necessary resources, and, ultimately, the likelihood of success logically and objectively. The feasibility study aims to determine available resources.[21]

- Economic Feasibility The suggested project is considerably less expensive, that is, it will cost 75% less than the current model or machine because it has less mechanical structure and electronic kits. As a result, the suggested model will be less expensive and easier to implement.
- Operational Feasibility As the project simply requires additional programming to be installed on the Arduino, there isn't any complicated procedure involved in the process. An extruder operation happens by manual intervention. Unskilled labor can do this process very efficiently, only at the

beginning care should be taken about the nozzle temperature, speed and diameter of the filament and its quality.

Technical Feasibility Technical success of the system relies upon the work expected from the mechanical and electrical parts. The fabrication of the extruder machine is simple, it contains mechanical structure. The integration of the sensors and other electronic components are simpler and easier to operate.

REUSE WASTE PLASTIC MATERIALS FOR 3D PRINTING FILAMENT [1]

The reuse of waste plastic materials for 3D printing filament, explored increasingly since the early 2010s, has been gaining attention as a sustainable recycling practice. By 2023, the process, which involves converting plastics like PET, HDPE, and LDPE into 3D printing filament, has been refined to produce materials with properties nearing those of virgin plastics. The environmental and economic benefits, such as waste reduction and cost savings, have been key drivers of this research. This area remains under active study with a focus on improving the efficiency and quality of recycled filament.

M. Juraschek et al. (2020)[27], Closed-loop manufacturing enables the integration of waste material and end-of-life products into the manufacturing processes of new products. As additive manufacturing in the form of filament-based 3D printing is becoming more frequently used, this process can be utilized to create a closed-loop process chain for the recycling of plastic waste material. Within the 3-CYLCE project, a modular process chainwasdevelopedfortreatingend-of-lifeproductsandextrudingprintable filament out of shredded waste material. This filament can then be utilized to create new products with 3D printers substituting virgin material[15]12. The implementation of the process chain in learning environments is discussed and the possible learning content presented.

METHODOLOGY: To create sustainable fabrication of 3d printing filament from waste plastic PET plastic, step by step methodology is carried as shown in fig 3.

Fig 3.Methodology Steps

Materials Selection:

The following thermoplastic waste were selected they are non-toxic such as Polyethylene Terephthalate (PET), Polypropylene (PP), and High-Density Polyethylene (HDPE) to recycle into useful 3D filament which in turn used in 3d printer to produce 3d printed products. The PET, HDPE &PP waste plastic products were collected from ISUP -Smail Industrial Area from Sultanate of Oman.

Subsequently the material collection, sorting, and cleaning, processing 3d filaments, preparing 3d printed specimen then characterization and optimization of parameters for 3D printing were performed as shown in fig 4.1.[17] and 4.2

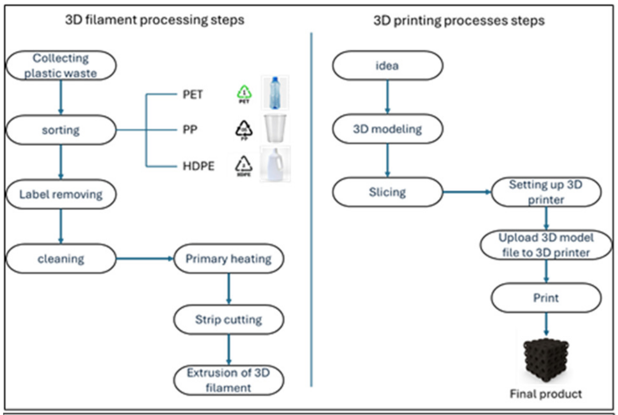

Fig 4.1: schematic representation of extrusion process of 3D filament and the 3D printing procedure.

Fig 4.2: Types of recycling

Development of strip using strip cutter:

A bottle cutter is developed for cutting plastic bottles into an even-width continuous smooth strip of flexible width as shown in fig 5. The following parts are required and assembled. Namely (a) Cutter base (b) bottle guider (c) steel blade (d) washers (e) external load

Fig 5. Methodology Steps

Mechanical Construction of extruder machine-2 Modified version:

The primary purpose of fabricating 3D filament extruding machines was to recycle plastic waste. The first step is to rebuild a or modified previous filament extruder machine is to take its design into consideration

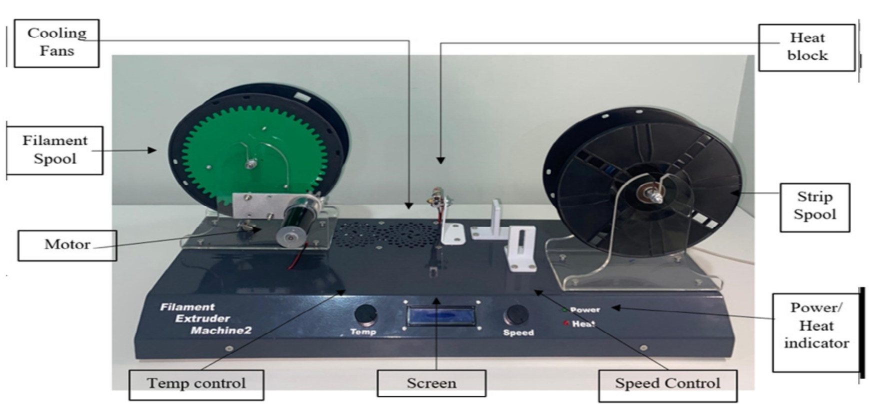

Fig 6: Developed 3D filament extruder machine -2 modified

to get its optimal condition

This extruder machine consists of mechanical components and electronic & control parts.

The following parts such as gear support, nozzle support, nozzle, hot end, filament and strip spools, mother board, temperature and speed controller, LED screen ,motor, frame are assembled with the help of threaded fasteners as shown in Fig 4.9

Electronic and Control Machine:

The 3D filament extrusion machine was automated and simplified. The components are DC brushless motor, LCD screen can display 2 lines, and 1 heater or heat block. The used motherboard is the Arduino uno AT Mega2560. The controlled inputs of the machine are the Potentiometer, who's responsible for controlling the speed, and the Rotary encoder is used to Control the temperature of the heat block.

Processing of 3d Filament using extruded Machine:

When producing filament for 3D printing machines, there are a few factors to consider: (1) Nozzle size of the diameter, (2) the filament structure should not have any internal bubbles, and (3) filament diameter 1.75mm, this size as commercially available filament size and compatible to 3D printer (4) controlled Temperature such that filament should not burn as a result. At the beginning, a narrowed plastic strip of width 8 -9mm range inserted through the cold nozzle which was drilled taper sunk slightly larger than the strip width and the taper will help gently fold the edges until reach the nozzle diameter. The next step is connecting the power supply, activate controller Arduino Nano - Rotary Encoder is now heating block to set temperature 175-180°C for PET water bottle, When the heating block reaches set temperature, The filament would be formed by extruding through hot nozzle and the process of cooling the filament with the help of air cooling can be done with of fan. This makes the molten plastic filament cool down to avoid extra shrinking of the plastic filament. Initial filament will be drawn manually until it can attach to the spool and continue to roll the filament till the end of the strip. To get the ideal of motor speed, it has been studied by trial and error on machine. In result, the speed of motor is 90 RPM and the extrusion speed is 13- 15 RPM as per calculation. The tests have been carried out many times to get the best parameter such as nozzle temperature and spool speed to produce smooth, continuous uniform long filament of diameter 1.75mm+/- 0.03 as shown in Fig 7. Filament extrusion parameters data shown in table 1 and 2.

Investigation of 3D printed Samples from waste plastic (PET) 3d filaments:

PET filament calibration samples were printed. While some 3D printer calibrations are required, satisfactory results were obtained at a temperature of 280°C, a bed temperature of 90°C, printing speed of 40mm/s and the flow of filament increased to 130%. Its density 1.27g/cc.

The following Stages of Improvement mentioned below on 3D printed samples from 3D waste plastic filament by varying print parameters as shown in Fig 8.

Fig 7. Quality smooth 3D filament hollow c/s from recycled PET plastic waste.

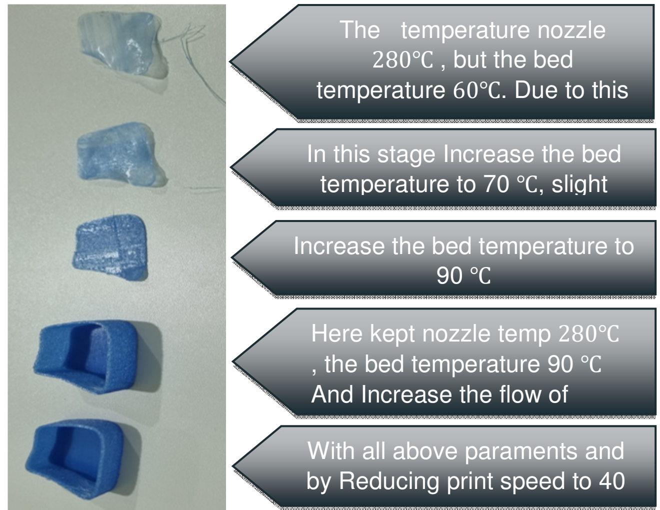

Fig 8. Stages of Improvement on 3D printed samples by

Tensile Test Setup

Tensile test specimens from the laminates were prepared as per ASTM D638 standard for testing the tensile properties such as tensile strength, tensile modulus, % elongation and failure strain of rectangular cross section of the specimen. Four to five specimens were tested at room temperature $23^0 C \pm 2$ with a controlled room humidity. Tensile test was performed at a speed of 10mm/min using H25KT-Universal Testing Machine shown in Fig 9 , before and after fracture test specimen as shown in fig 10. average values of the results recorded and shown in the table (3).

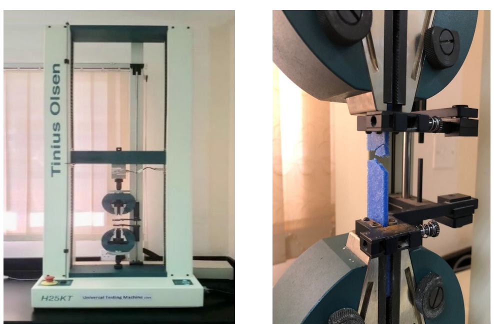

Fig 9. Tensile Test Setup

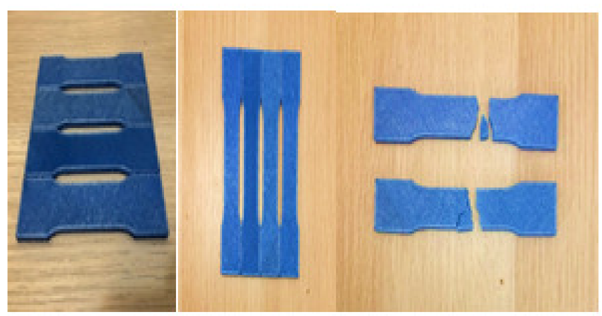

Fig 10. Tensile Test specimen before and after fracture

RESULTS & DISCUSSION

Table 1: 3D filament extrusion and properties, Motor speed 90rpm.

Name of material	Extrusion temp	Extrusion speed rpm	Extrusion rate mm/min	Weight of filament grams	Filament Dia (mm)
PET_R	185°C	14%	33.34	18	1.75
HDPE	200^0C	12%	34	24	1.75
PP	240^0C	10%	40	49	1.75

Motor speed 90rpm, For PET 14% extrusion speed means 14% of 90 is equal to 13rpm, it is same as calculated speed shown in equation number (3).

Table 2 : Comparison of various size of PET wastewater-bottle filament data

Size of PET bottle (lit)	Water bottle Weight (gram)	Weight strip (gram)	Width strip (mm)	strip thickness (mm)	Filament weight (gram)	Filament length (m)	Time taken (min)	utilization %
1.5	24	16	9	0.18	18	7	21	75
2	34	24	9	0.18	24	10.5	32	71
5	70	49	7.5	0.38	49	25	70	70

% Utilization of wastewater bottle 1.5 liters = (output weight / input weight) x100

= (18 grams/ 24grams) x 100 = 75%

Time taken to produce for one-meter-long filament = 3minutes,

Length of the filament an average 333 mm / minute

Weight of the filament / minute = 1.34grms

Discharge speed of the filament mm/s = 6mm/s

Table 3: Comparison of Tensile test 3d printed filament PET_R, PLA, and ABS specimen (grid infill pattern)

Test Specimen	Infill density	Max Stress (MPa)	Break Stress (MPa)	Max Force (KN)	Elongation at Break (%)	Young's Modulus (MPa)
PET_R	**100%**	**41.52**	**7.01**	**3.25**	**10**	**1100**
PLA	100%	31.41	6.01	1.55	5.3	1080
ABS	100%	34	5.2	1.6	5.5	864
Annealed PET_R	**100%**	**45**	**21**	**3.5**	**11.1**	**1150**

Table 4: 3D printing Parameter comparison recycle PET_R with other 3D filaments.

Material	3D Printer Head Temperature (°C)	3D Printer Bed Temperature (°C)	Printing Speed (mm/s)	Nozzle Size (mm)	Infill (%)	Filament daimeter (mm)
PET_R	**280**	**90**	**40**	**0.4**	**100**	**1.75**
ABS	255	100	30	0.4	100	1.75
PLA	202	55	30	0.4	100	1.75
HDPE	220	50	50	0.4	100	1.75
PP	230	40	40	0.4	100	1.75

Conclusion:

1. Plastics are not susceptible to biological degradation and their degradation further pollutes the environment.
2. Recycling was found to be the most advantageous way to value consumer plastics, which is in line with the concept of a circular economy and environmental benefits.
3. Transform plastic waste into sustainable filament for 3D printing products that can be used in technology and education.

4. We also observed that there is lack of available infrastructure to recycle plastic waste in the country.
5. The filament extruder prototype for a 3D printer was developed successfully. This machine can produce filaments from the plastic wasted materials during the process. The entire setup is portable and can be adopted for small scale industries and educational institutions.
6. This extruder machine developed with low investment cost, it has less maintenance, and needs unskilled or semi-skilled labor to operate.
7. The process involves collection, sorting PET bottles, cutting them into strips, and extruding them to obtain 1.7±0.03 mm diameter filament compatible with 3D printers, contributing to environmental sustainability and economic growth.
8. To obtain smooth, continuous long filament best result at a temperature 185^0C and extrusion speed range 13- 15rpm for PET waste bottle, dependent on the width of the strip compatible to 3d printing.
9. From tensile test data shows that Fiber direction parallel to the pull direction results in high tensile strength,
10. Process parameters such as part infill pattern/ layer thickness/infill density/ nozzle diameter/ filament diameter/ smoothness of the filament, nozzle temperature and print bed temperature/ print speed, specimen thickness/ shell thickness will influence the mechanical properties.
11. The best quality print result shows from table 4, PET_R has the potential to make 3D printed components which gives second life to recycle waste plastic, can be used for engineering and education purpose.
12. PET_R shows better mechanical strength compared to commercially available PLA and ABS
13. PLA is difficult to recycle into usable 3D printing filament [29]

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