Recycling the PET plastic bottle waste accumulated during the Arabian Pilgrimage into 3D printing filament to print durable material models and use them in designs that support the eternal memory

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Abstract

Designing a system for recycling plastic bottles in our research enabled us to address the problem of plastic waste accumulating during the Arbaeen pilgrimage due to the large number of visitors. There are numerous ways to recycle materials, including manufacturing suitable materials at a low cost by recycling plastics with good mechanical properties to manufacture spare parts using 3D printing. PET was used for plastic bottles by recycling it into filaments with specific specifications and thicknesses, as determined by the system designed during the research. A 3D printer was then used to print the filaments after shaping them and printing a new material with new specifications. These filaments were used as raw material, and a 3D printer (Ender 3 S1 Pro) was used to produce a material with better strength and hardness specifications for the filling ratios during printing with best30% infill ratio. This allows for the printing of models and designs that can serve to commemorate the anniversary.

Keywords: Recycling plastics, 3D printer, Creative designs .

INTRODUCTION

The demand for plastic materials has skyrocketed worldwide across a number of industrial sectors, posing serious waste management difficulties (Obande, 2021, 108771).

The intrinsic toxicity of plastic materials Alabi, (2019,1–13). poses a serious threat to human health, the environment, and marine life, making them an important worldwide environmental problem. According to information from researchers PET or PETE is a polyester produced by the reaction of terephthalic acid and ethylene glycol, and is produced by mixing the two materials in the required molar amounts and renewing the reduced water with a successful efficiency of 99% Van Sebille, 2019,1–13

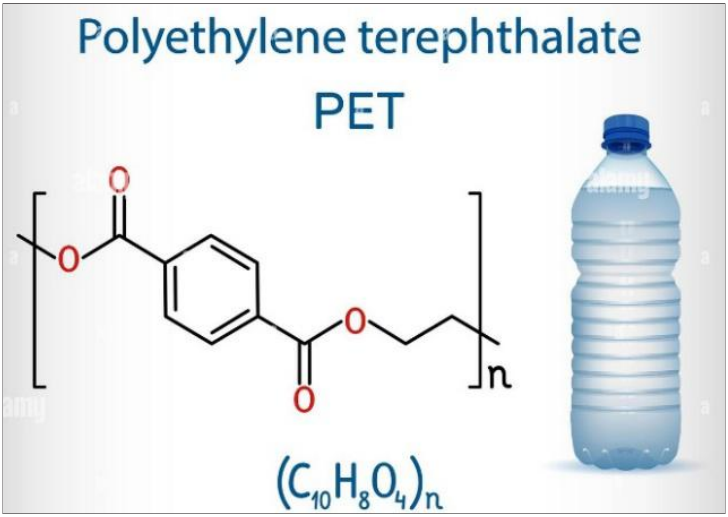
the Japanese Japanese melt crystallizes after solidification, which can be obtained as partially crystalline or amorphous products according to the request. The partially crystalline product is characterized by high strength and hardness to friction and to dilute acids and oils and their conversion, but it is sensitive to heat (Ghosh, 1986, 2551–2560).

About 70 million tons are manufactured from it, representing 20% of the production of the plastics industry sector and partially crystalline polyester is used in electronics, limbs and screws, seat belts and car covers, and is also used in the medical field in implanting artificial organs and in artificial networks and in microvascular(Dhaka, V, 2022,1777–1800). Amorphous polyester is less durable, but more resistant to impact. Because it is transparent and lighter than glass, it is used in packaging such as drinking bottles, food containers, and cosmetics. It is also used in electronics in magnetic tape holders, fig(1).

Fig(1): Polyethylene terephthalate (PET or PETE)

Chemical composition of Polyethylene terephthalate (PET or PETE)

Polyethylene terephthalate (PET) is a polymer belonging to the polyester family, composed of repeating units of ethylene glycol and terephthalic acid. The general chemical formula for PET is $(C_{10}H_8O_4)_n$ (Ghosh,1986, 2551–2560) where «n» refers to the number of repeating units in the polymer chain,fig(2).



Fig(2): Chemical composition of PET

Advantages of Polyethylene Terephthalate

1. Polyethylene terephthalate (PET) is a thermoplastic polymer commonly used in various fields, such as packaging and synthetic fibers. PET has the following properties(Ragaert, K., 2017, 24–58)(Singh, N.,2017, 409–422).
2. High Tensile Strength: PET has excellent tensile strength, making it suitable for applications requiring high durability.
3. Good Chemical Resistance: PET exhibits good resistance to many chemicals, making it suitable for packaging.
4. Transparency: PET can be transparent, making it ideal for applications requiring optical clarity.
5. Abrasion and Crease Resistance: The stiffness of PET fibers gives it high resistance to creases and abrasion, making it suitable for use in fabrics and clothing.
6. Good Barrier Properties: PET provides an effective barrier against carbon dioxide and moisture, making it suitable for packaging soft drinks and food products.

Plastic

Plastic is a polymeric material widely used in a variety of applications due to its diverse properties, such as lightness, durability, and formability. However, its widespread use has led to the accumulation of massive amounts of plastic waste, posing a significant environmental challenge (Singh, N.,2017, 409–422) Plastic recycling is an important solution to reduce this waste and conserve natural resources.

Types of plastic recycling:

A. Mechanical Recycling:

This involves converting plastic into new products without changing its chemical composition(Geyer, R.,2017, 1700782). This is the most common method shown in fig(3).

Fig(3): Mechanical plastic recycling

B. Chemical Recycling:

This involves breaking down plastic into its basic chemical components to produce new materials, allowing for the recycling of low-quality plastics and improving process efficiency(Ghosh, 1986, 2551–2560).

Mechanical properties of plastics (Geyer, R.,2017, 1700782) :

1. Tensile strength.
2. Compressive strength.
3. Elasticity.
4. Elongation at break.

5. Impact resistance.
6. Shear strength.
7. Hardness.
8. Fracture resistance.

Shore Hardness Test

The Shore Hardness Test is an important mechanical test used to assess the resistance of ductile materials (such as rubber and plastic) to deformation under a specific load. This test is widely used in various industries, including prosthetics, where hardness is a critical indicator of a material›s quality and durability,The Shore hardness test measures a material›s resistance to penetration by a needle or a specially shaped point under a specified load, and gives results on a scale of 0 to 100, with higher values indicating harder materials (Khalid R., 2014, 547-553) (Pedrosa Rebouças Filho, P.,2010,1520).

Types of shore scale:

A. Shore:

Used to measure the hardness of soft materials such as natural rubber and soft plastics.

B. Shore:

Used for harder materials such as rigid plastics (e.g., PET, ABS, Nylon).

3D Printer

3D printing fig(4) is a technology that produces three-dimensional objects by adding material layer by layer according to a digital model, unlike traditional manufacturing that removes material (Reazul Haq Abdul,2019,102-108).

Fig(4): 3D Printer

Advantages of 3D Printing

A. Custom Manufacturing:

Suitable for designing parts tailored to the user›s body, especially in medicine.

B. Reduced Waste:

Material is added only where needed, reducing waste.

C. Rapid Design Modification:

The model can be modified and reprinted instantly without the cost of upfront tooling.

Materials and Method

Table (1): Materials and equipment used

Device name	Usage
Pellet Dryer	Drying the pellets from moisture before extrusion.
Hopper	Feeds the pellets to the extruder evenly.
Extruder	Melts the pellets and pushes them out using an internal screw.
Heated Barrel	Heats the barrel to the melting point of the plastic.
Nozzle/Die	Forms the output filament to the desired diameter (e.g., 1.75mm).
Cooling System	Cools the filament immediately upon exit using a fan or water bath.
Laser Gauge	Measures the filament diameter and automatically controls quality.
Puller	Pulls the filament from the nozzle at a set speed after cooling.
Spool Winder	Winds the filament onto the spool evenly and tangle-free
Control Panel	Sets temperature, speed, diameter, and electronically monitors the line.
3D printer Bambu lab p1s Ender3 S1 pro	Used to print plastic filaments to form PET samples.
Digital Microscopes	Used to view the filling percentage of PET samples.
UTM	Used for tensile testing
HARTIP 3000	Used for hardness testing
Thread manufacturing system	Used to make plastic threads

Samples materials Preparation Method

First step: manufacturing plastic filament:

The process of manufacturing plastic filament begins with wooden or metal parts and involves building the structure of the filament extruder. Fig(5) The extrusion cylinder is then mounted at a suitable angle to allow gravity to assist the material›s passage through it. A DC motor or stepper motor is mounted on the structure, and its rotation drives a screw (drill) inside the extrusion cylinder to force the hot plastic through. The motor is then connected to a power source. Stainless steel tubes are used to melt the plastic. A temperature sensor and heating element are used to achieve temperatures between 200 and 250°C. A hopper or simple container with a feed tube is then used to load the scrap plastic or filament. A spool is then used to draw out the plastic. A metal tube with a small opening (about 1.75 mm in diameter) is used for the 3D printing filament. After the plastic is extruded from the mold, it must be rapidly cooled using a cooling fan to form a durable filament. After the filament is extruded and cooled, it must be wound onto a spool. You can use an old spool, such as a sewing thread spool.

Two Step: 3D printing:

After the printing filament is made from PET or PETG polymer, it must be dried at 70-80°C for 4-6 hours before use. The shape of the sample is then designed according to the required tensile strength and hardness. The model is then cut using a cutting software and printed on a 3D printer. It is essential to ensure that the printer surface is flat and that the filament is securely fastened to the inlet port. After printing is complete, the sample is allowed to cool, its edges are cleaned of excess material, Three samples were prepared: 1. PET sample, 20% print with infill 2. PET sample, 25% print with infill 3. PET sample, 30% print with infill.

Three samples were prepared:

1. PET sample, 20% print fill.
2. PET sample, 25% print fill.
3. PET sample, 30% print fill.

. Fig(5): plastic filament machine

Hardness Test

The hardness of the samples was measured with a (HARTIP 3000) device as shown in Fig (6) Hardness device

Fig(6): Hardness device

Digital Microscope

The samples were examined using a digital microscope as shown in Figure (7) of the microscope, Table (2) shows the characteristics of the microscope.

Fig(7): Digital Microscope

Table (2): Characteristics of the microscope

SPECIFICATION	DETAILS
IMAGE SENSOR	CMOS
MOBILE PHONE COMPATIBLE OS	Android
FOCUS RANGE	15mm-40mm
FRAME RATE	Up to 30 FPS
AVAILABLE IMAGE FORMAT	BMP/JPG
IMAGE RESOLUTION	Up to 640*480 - 1920*1440
ADJUSTABLE ILLUMINATION	8 Built-in LED Diodes
COMPATIBLE OS	Windows 7/Windows 10/Mac 10.13 and above
PC INTERFACE	USB 3.0/2.0/1.1
PC POWERED	5V Direct Current
AVAILABLE VIDEO FORMAT	AVI
PRODUCT COLOR	Black
DIMENSION	14.5cm x 10cm x 5cm
WEIGHT	About 200g

Result and Discussion

the results of 3D printing PET samples from plastic filaments. To study some of their mechanical properties, the samples were examined using the following tests: tensile testing and hardness testing.

Three PET samples were manufactured using FDM 3D printing technology, with all printing conditions fixed except for the infill density.

Hardness testing using a HARTIP 3000.

And Microscopic used to show infill printing shape.

Mechanical properties

PET sample:

This sample under a microscope shows that printing at a low 20% fill ratio produces a light, void-filled internal structure, making it more susceptible to premature fracture under load. It also results in poor mechanical properties and may only be suitable for cosmetic applications or non-load-bearing prototypes, as shown in the fig (8).

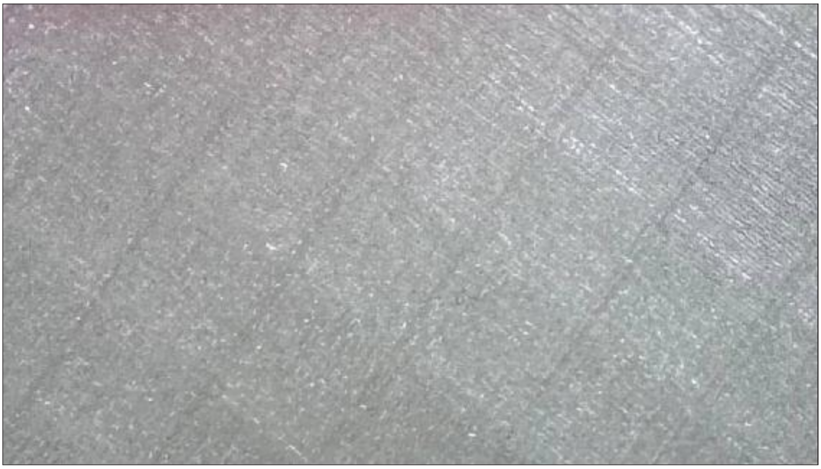


Fig (8): Microscopic image of the first model showing a 20% fill rate.

Under the microscope, this sample shows a significant improvement in mechanical properties without a significant increase in printing time or material consumption, making it a good choice for applications requiring moderate strength. Its internal structure is more cohesive, which helps it withstand higher stresses and delays fracture. Therefore, it performs better than the first sample, as shown in the fig(9).

Fig (9): Microscopic image of the first model showing a 25% fill rate.

Under the microscope, this sample features a denser, more cohesive internal structure, reducing the likelihood of weak points forming between layers. It also boasts exemplary performance in terms of strength and stiffness, making it suitable for applications requiring high mechanical properties, such as functional parts or prosthetics that withstand constant stress(Dizon, J.R.C.,2018,44-67). This sample recorded the highest mechanical performance of the three samples, as shown in the fig (10)

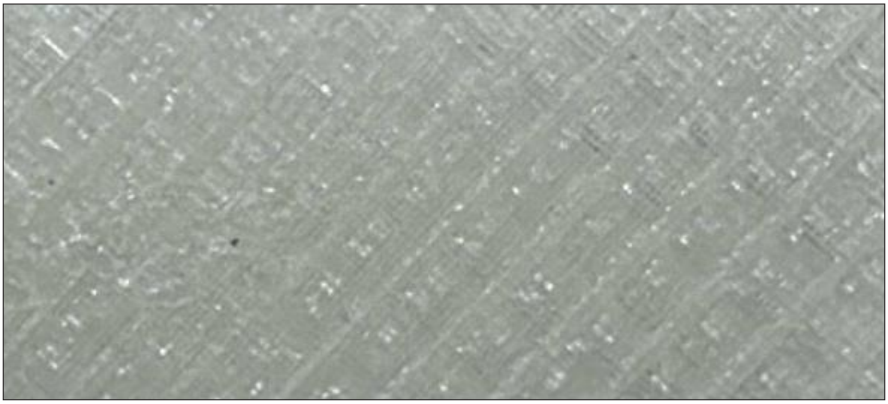


Fig (10): Microscopic image of the first model showing a 30% fill rate.

Hardness testing

Shore hardness test the specimen recorded the highest surface mechanical properties among the three specimens show in Fig(11) table (3).

The goal of several research projects has been to investigate the mechanical characteristics of 3D prints and filaments.

The mechanical characteristics of 3D prints and filaments have been used in these investigations as hardness (Woern, A.L., 2018, 1413) (Chadha, A., 2019, 550–559)(Suteja,T.,2020, 1569).

Table (3) Shore Hardness values

Shore Hardness					Average test values
infill 20%	46	51	53	48	49
infill 25%	52	58	61	56	56
infill 30%	64	61	69	59	63

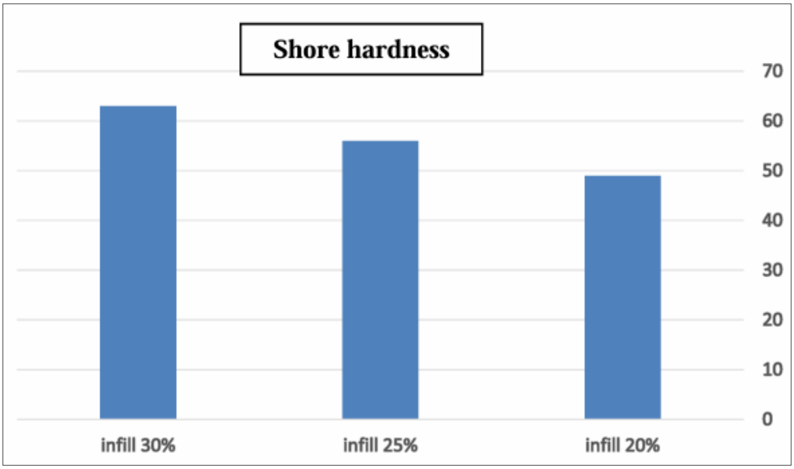


Fig (11): Shore hardness

Creative 3D printing designs

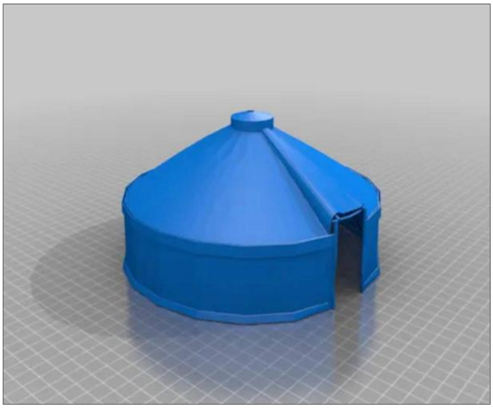


Fig (12): Some productions of 3D Printer

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