Preparation Of 3D Printing Filament Using Waste Plastic Bottle

Aniket Walimbe, Rutik Wadhvinde, Omkar Walimbe.

[1]*Department of Mechanical Engineering, Alamuri Ratnamala Institute of Engineering and Technology, Shahapur*

---***---

Abstract- The escalating environmental crisis driven by plastic pollution is one of the most pressing issues of our time. Plastic, a material once celebrated for its durability and versatility, has become a persistent and toxic waste, littering our landscapes and oceans. This project, entitled "Transformation of Waste Plastic Bottles into 3D Printing Filament," offers an innovative solution to this problem by repurposing plastic waste into a valuable resource for the growing 3D printing industry. 3D printing technology has revolutionized various sectors, from manufacturing to healthcare, by enabling the creation of complex structures with high precision.

However, the materials commonly used for 3D printing, known as filaments, are often derived from non-renewable resources, exacerbating the environmental burden. This project proposes an alternative approach by producing 3D printing filaments from recycled plastic bottles, thus transforming a pervasive environmental pollutant into a useful commodity. Our methodology involves collecting discarded plastic bottles, primarily composed of polyethylene terephthalate (PET), a type of polymer widely used in packaging. These bottles are cleaned, shredded, and subjected to a controlled heating process using advanced nozzle technology. The molten plastic is then extruded into thin strands, cooled, and wound onto spools to create 3D printing filaments. This process not only diverts plastic waste from landfills but also reduces the demand for virgin plastic production, contributing to a circular economy. The project also explores the properties and performance of recycled filaments in 3D printing applications. Preliminary results indicate that the recycled filaments exhibit comparable quality to commercially available filaments, demonstrating the feasibility of this approach.

Furthermore, the project underscores the potential for localised filament production, reducing transportation emissions and fostering self-sufficiency in 3D printing materials. In conclusion, this project embodies a paradigm shift in waste management and material production, turning the problem of plastic waste into a solution for sustainable manufacturing. By transforming discarded plastic bottles into 3D printing filaments, we mitigate the adverse environmental impacts of plastic waste and contribute to the advancement of sustainable manufacturing practices. This initiative serves as a testament to human ingenuity in the face of ecological challenges and underscores the potential of innovative technologies in driving sustainable development. This project is a step towards a future where waste is not an end product but a resource, where recycling is not just an afterthought but an integral part of the production cycle. It is a future where sustainability is a goal and a way of life. Through this project, we hope to inspire others to view waste not as a problem but as an opportunity for innovation and sustainability.

1. INTRODUCTION

The world is grappling with an environmental crisis of unprecedented proportions, largely driven by the pervasive use of plastic. This synthetic material, celebrated for its durability and versatility, has become a double-edged sword. While it has undoubtedly revolutionized various sectors, from packaging to healthcare, its non-biodegradable nature has led to an accumulation of plastic waste that is overwhelming our landfills, oceans, and ecosystems. Traditional recycling methods have proven insufficient in addressing this issue, necessitating the exploration of innovative approaches to repurpose plastic waste. This project, titled “Transformation of Waste Plastic Bottles into 3D Printing Filament,” presents one such pioneering initiative.

The project aims to alleviate the harmful impact of plastic pollution and redefine sustainable manufacturing practices. It proposes the use of plastic bottle strips, a by-product of the recycling process often overlooked due to their perceived limited utility, as a raw material for producing 3D printing filament. This innovative approach aligns with the principles of a circular economy, where waste materials are not discarded but transformed into valuable resources. It holds promise for ushering in a new era of eco-friendly additive manufacturing, reducing the environmental footprint of plastic waste, and creating a more sustainable and responsible future.

The core concept of this initiative involves repurposing plastic bottle strips, typically disregarded in the recycling process, into a valuable resource for 3D printing. The process begins with the collection of discarded plastic bottles, which are then cleaned and shredded into strips.

These strips are subjected to a controlled heating process using advanced technology, transforming them into a molten state. The molten plastic is then extruded through a nozzle toform thin strands, which are cooled and wound onto spools to create 3D printing filaments.

This project represents a paradigm shift in the conventional approach to plastic recycling. Integrating plastic bottle strips into the production of 3D printing filament addresses both the plastic waste crisis and the demand for eco-friendly alternatives in manufacturing. It disrupts the linear "take, make, dispose" model that has fuelled the global waste crisis, replacing it with a circular approach where waste materials are transformed into valuable resources.

The project also explores the performance of recycled filaments in 3D printing applications. Preliminary results indicate that the recycled filaments exhibit comparable quality to commercially available filaments, demonstrating the feasibility of this approach.

Furthermore, the project underscores the potential for localised filament production, reducing transportation emissions and fostering self-sufficiency in 3D printing materials.

In conclusion, this project embodies a paradigm shift in waste management and material production, turning the problem of plastic waste into a solution for sustainable manufacturing. By transforming discarded plastic bottles into 3D printing filaments, we mitigate the adverse environmental impacts of plastic waste and contribute to the advancement of sustainable manufacturing practices. This initiative serves as a testament to human ingenuity in the face of ecological challenges and underscores the potential of innovative technologies in driving sustainable development.

This project is a step towards a future where waste is not an end product but a resource, where recycling is not just an afterthought but an integral part of the production cycle. It is a future where sustainability is a goal and a way of life. Through this project, we hope to inspire others to view waste not as a problem but as an opportunity for innovation and sustainability. We believe that the "Transformation of Waste Plastic Bottles into 3D Printing Filament" can serve as a blueprint for sustainable manufacturing practices, paving the way for a greener and more sustainable future.

PROBLEM STATEMENT

The world is currently facing an environmental crisis of unprecedented proportions, largely driven by the pervasive use of plastic. This synthetic material, celebrated for its durability and versatility, has become a double-edged sword. While it has undoubtedly revolutionized various sectors, from packaging to healthcare, its non-biodegradable nature has led to an accumulation of plastic waste that is overwhelming our landfills, oceans, and ecosystems.

Plastic waste, particularly in the form of plastic bottles, is one of the most significant contributors to this crisis. Globally, millions of plastic bottles are produced every minute, and a significant proportion of these end up as waste. Despite recycling efforts, a large amount of waste is not effectively processed, leading to environmental pollution and resource wastage.

Fig No.1: Waste Plastic Bottle Pollution

Moreover, the 3D printing industry, a rapidly growing sector, is heavily reliant on plastic filaments. These filaments are often made from virgin plastic materials, contributing to the demand for plastic production and exacerbating the environmental burden. There is a pressing need for more sustainable alternatives in this industry.

The problem, therefore, lies in the intersection of these two issues - the accumulation of plastic bottle waste and the demand for plastic filaments in the 3D printing industry. The challenge is to find a way to repurpose plastic bottle waste into a valuable resource for 3D printing, thereby addressing both the plastic waste crisis and the need for sustainable materials in 3D printing.

This project, titled "Transformation of Waste Plastic Bottles into 3D Printing Filament," aims to tackle this problem. The goal is to develop a process that can convert waste plastic bottles into high-quality 3D printing filaments. This not only provides a solution for managing plastic bottle waste but also offers a sustainable alternative for 3D printing materials.

However, several challenges need to be addressed to realize this goal. These include developing a cost effective and efficient process for converting plastic bottles into filaments, ensuring the quality and performance of the recycled filaments, and scaling up the process for mass production. In conclusion, the problem this project seeks to address is both complex and multifaceted, involving issues of waste management, resource utilization, and sustainable manufacturing. By transforming waste plastic bottles into 3D printing filaments, this project aims to contribute to the solution of these problems, paving the way for a more sustainable and responsible future.

2. LITERATURE REVIEW

Introduction

According to the literature review there is very little study has been done on reutilization of 3D printed waste material so this is the one of the major problems we are facing that 3D printed material having lot of (troubleshoot) problems which cause lot of waste of filament. This is very harmful for earth because plastic waste causes lot of pollution.

Circular economy (CE) concept is a response to environmental and social problems, being a replacement for the previously used linear concept based on the "take–make–dispose" model.

Population growth, intensive use of resources, and uncontrolled environmental pollution forced the implementation of another economic closed-loop system, based on the principles of 3Rs: Reduce, Reuse, and Recycle. The broader methodology (6R, Fig.1) includes additional three approaches: Recover, Redesign, and Remanufacture (Jawahir and Bradley 2016). [1]

Circular economy goals were set for Europe in Circular Economy Package on 2 December 2015 ("EUR-Lex-52015DC0614-EN-EUR-Lex," accessed 2020.04.09). The CE package lists five priority fields requiring specific action: plastics, wastes from demolition and construction, critical raw materials, food waste, bio products and biomass. This plan considers specific key targets, including recycling of municipal wastes at the level of 65% until 2030, recycling of packaging waste at the level of 75% until 2030, and reduction of landfilling to a maximum of 10% until 2030. CE is designed to be a restorative and regenerative system, beneficial to society and economy, allowing for the reduction of natural resources, and waste and environmental pollution minimization, as well as for the recovery of materials and energy (Fig. 2) (Kaur et al. 2018). [2]

Recycling is recognized as the most preferred option of waste management for reuse of the materials in order to manufacture new products (Mwanza and Mbohwa 2017). [3]. Such practices decrease waste generation and enable material recovery as long as possible. One of the main wastes, which is currently a serious environmental problem, is plastic. The aim of this work was to review the possibility of reusing polymeric materials for 3D printing. The this work was to review the possibility of reusing polymeric materials for 3D printing. The attention

was paid to the recycling potential, existing commercial solutions, and programs related to the promotion of the idea of reuse of waste materials. The work also included possible changes in the polymer material, which may occur during subsequent extrusions.

2.1. Plastic waste management

Plastics have appeared in our daily lives around 100 years ago; still they are indispensable materials with various properties and applications used at home, at work, traveling, or in their

spare time. Plastics are extremely versatile materials, so that the possibilities of their application are virtually limitless. Their unquestionable advantage is the high mechanical strength, low density, low weight, easy processing, and low cost (Mwanza and Mbohwa 2017). Due to these features, plastics have been found applications in the production of packaging, automotive industry, electricity, construction, and transport, as well as in medicine, agriculture, or other areas. The ubiquitous plastic is a source of huge amounts of waste, the management of which is a serious problem. Global production of plastics in 2018 amounted to 359 million metric tons (in EU 61.8 million metric tons) (www.plasticeurope.org, accessed 2020.04.09). It is predicted that this number will double over the next 20 years. In many countries, plastic waste is not managed and goes to landfills. Landfill space is limited and the amount of plastic stored is growing rapidly every year.

Tighter regulations on waste management need to enforce recovery of materials and energy so as to meet the requirements of the circular economy project. In EU, 75.1% of plastic waste was processed (32.5% recycling and 42.6% energy recovery) while 24.9% still was landfilled (www.plasticeurope.org, accessed 2020.04.09). There are many methods to manage the growing amount of plastic waste, including primary recycling (re-extrusion), mechanical recycling, and chemical reuse or the use of thermal methods that generate energy (combustion, pyrolysis, gasification) (Al-Salem et al. 2009). [4]

Primary recycling allows the recovery of uncontaminated polymer residues with parameters corresponding to the starting material. It can be applied to residues that have not been used in the production process, e.g., in the extrusion, which is popular in most production centers the

production process, e.g., in the extrusion, which is popular in most production centers (Singh et al. 2017a).

Secondary recycling additionally uses materials that may contain contam- ination. These impurities are removed during conversion, after preliminary shredding. Such material is successively milled and granulated and becomes an input to plastic processing, but is usually of lower quality than that of primary recycling. Chemical recycling includes chemical processes that convert plastics into compounds that can be reused for production, mainly in de-polymerization processes (solvolysis) (Singh et al. 2017a). [5]

Methods of energy recovery from polymeric materials are the least environmentally beneficial option, but the energy content of plastics is significant; they are highly efficient energy sources with similar calorific value as fuel oil (average 42 MJ/kg) (Kumar et al. 2011). [6]. However, it is necessary to continuously monitor emissions from such processes, as they can generate many organic pollutants such as dioxins (Ragaert et al. 2017). [7].

Plastics generally cannot be decomposed by microorganisms because bacteria have not developed enzymes that enable the biological decomposition of these materials . However, biodegradable materials that degrade under the influence of the environment are designed, such as various types of polyesters, including polylactide (PLA) or polycaprolactone (PCL), which are used in the production of 3D printing filaments. (Shah et al. 2008). [8].

Environmental hazards resulting from the pyrolysis of plastics and the under-degradability of polymers force them to be processed. Landfilling is only a temporary solution. Given the continuous production of plastics and the very low degree of processing, a new solution is necessary. Of course, the best waste management strategy is to prevent their generation.

Unfortunately, many factors, such as convenience, consumer lifestyle, advantage of characteristics, and production costs over glass and metal packaging, make plastics abundant in the environment and persistent. A waste-free economy is only theory that waits to be implemented. Therefore, cost-effective plastic processing technologies are urgently needed. In addition to the available technologies, 3D printing using waste polymers is a new, potential solution with the highest possible degree of future implementation.

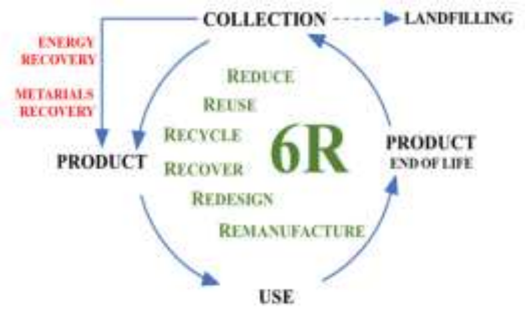


Fig No.2 Plastic waste Management

2.2. Commercial polymers for 3D printing

The filaments used in 3D printing are primarily thermoplastics. The most popular are acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) (Anderson 2017). The remaining group of materials are polycaprolactone (PCL), polycarbonate (PC), polystyrene (PS), polyetherimide (PEI), polyetheretherketone (PEEK), and various types of polyethylene (PE), including LDPE (low-density PE), LLDPE (linear low-density PE), and HDPE (high-density PE). These types of materials are commonly used to print automotive components, surgical instruments, prototypes, various types of packaging, small garden architecture, toys, and many other products that are in everyday use.

Despite the advantages, 3D printing generates large amounts of waste, which are the result of failed prints or rejected support structures. What is more, the ability to create components without machining or tools causes that many prints are used as disposable prototypes. The number of thermoplastic prints is constantly growing with the development of additive technology, so there is the problem of waste management. The solution may be filaments obtained from the recycling of plastics. Filaments used in 3D printing are most often formed in the extrusion process, by inserting a granulate or polymer powder into the extruder, which, under the influence of temperature, is transformed into a homogeneous material in the form of the line with defined parameters (standardized diameter, adapted to the size of the printer element). An increasing number of companies offer filaments from recycled PLA or ABS. Unfortunately, sofar there is not much information about the mechanical properties of recycled filaments. They have a crucial influence on print quality. Thus, investigating these properties of recycled filaments and comparing them with virgin material will provide the basic knowledge necessary for the further development of 3D printing technology (Anderson 2017) [9].

2.3. Recycled polymers for 3D printing

For this reason, environmental pollution associated with this type of waste is a serious problem. Data shows that up to 90% of plastics could be reused. Currently as much as 80% of plastic waste is in landfill and only a few percent is recycled. The biggest problem is plastics made from HDPE, LDPE, PP, and PVC, which are largely used by manufacturers and which are landfilled with greenhouse gas emissions (Aboulkas et al.2010). [10]

A much smaller global problem is PLA-related waste, Fig. 1 The basic concept of circular economy Environ Sci Pollut Res whose natural origin does not have such a strong impact on the environment. Unfortunately, goods made of this material are less durable mechanically, which in turn discourages potential manufacturers from using them more often. The main limitation related to the reuse of the material is the problem of losing the properties after recycling several times. Additionally, stability loss is observed, which in turn may adversely affect human health (Lithner et al. 2011). [11]

The 3D printing technology allows more possibilities to create complex structures on a small scale. The evolving technology also poses risks associated with the generation of more plastic. However, the data show that at present, 3D printing waste is not such a big problem and the technology itself can be used to combat the growing amount of post-production waste (Cruz Sanchez et al. 2017). [12]

The recycling process of polymeric materials for 3D printing is based on a number of activities such as selective material separation, decontamination and purification, grinding, re-melting, and extrusion. The main obstacles resulting from this process are logistical a economic aspects. The analysis shows no economic benefits from the recycling of materials, and the cost of the recycled product depends on the market price of the originally manufactured filament.

However, given the increasing environmental restrictions and recycling of plastic waste, this

could be a potential solution, despite the lack of clear Economic profitability (Hopewell et al. 2009). [13]

2.4. The impact of recycling on the material Properties-

Shear stress, temperature, and oxygen occurring during extrusion degrade polymers. The process takes place not only in polymers sensitive to these factors (PLA) but also in polymers that are relatively resistant (PE) (Anderson 2017). The change of the physical properties of the polymer significantly influences the obtaining of high-quality extrusion products. Multiple extrusion of polymers has a strong influence on their change in viscosity, molecular weight, and breaking strength. Changes in properties are generated by factors such as temperature, but also by the amount of extrusion of one material (Zenkiewicz et al. 2009). [14]

2.5. Mechanical properties

Polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS) are the most popular filament materials among the thermoplastics which are currently available for 3D printing. The costs of commercial filaments are up to 200 times higher than those of raw plastics, though their thermo-mechanical recycling would significantly contribute to the reduction of 3D printing cost. ABS is produced from oil and used for a variety of durable goods despite being toxic. In contrast, PLA is bio-based, biodegradable, and biocompatible polymer. (Cruz Sanchez et al. 2017). [15]

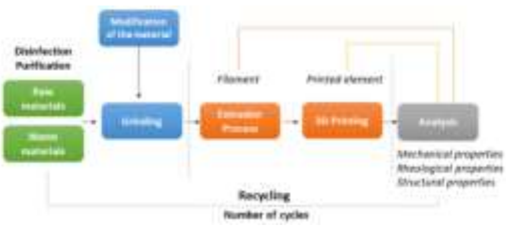


Chart No.2. Manufacture of filament from waste materials

The data obtained clearly identified that recycling reduces the mechanical strength of PLA. To overcome this problem, it is possible to coat the recycled polymer filament with a polydopamine (PDA). PDA adhesive aqueous solution is adsorbed on hydrophobic finger-like surface of PLA by development cohesive strength through self-polymerization. The PDA coated polymer is thermal-stable up to 200 °C. It possesses higher tensile strength and strain at break, and its surface exhibits higher adhesion than uncoated PLA (Zhao et al. 2018b) [16].

2.6. Additives manufacturing

To solve the problem of environmental pollution and to find the alternative for shrinking post-petroleum plastic sources, many works have been conducted to obtain a new generation of 3D printing materials. The use of various types of additives with increasing molecular weight and improving mechanical properties of recycled polymer has been widely studied. Research has been conducted on both additives, extending polymer chains and additives in the form of peroxides, which allow the formation of free radicals (molecular weight increase, cross-linking agent). The effect of the additive lignin on the morphology, mechanical, and thermal parameters of recycled PLA was examined. Ground PLA is mixed with lignin and extruded at 180–190 °C. The addition of biopolymer improves melting properties and decreases tensile strength (18%) and decreases Young's modulus value by about 6% in comparison with samples made of pure PLA (Gkartzou et al. 2017).[17]

Carbon fibres were also used to strengthen the material. The recycled material had 25% higher bending strength compared with the original. The material recovery rate was equal to 100% CFR (carbon fibre reinforced) and 71% PLA respectively (Tian et al. 2017).[18]

This was the first upgrade of reused polymer properties. Constant degradation of physical properties of reused polymers indicated research on new adhesive reinforcement types. On this basis, dopamine was used, which is easily adsorbed on most surfaces. This property also allows the coating of polymers. Ground PLA is placed in an aqueous solution of dopamine with stirring for 4 h. After this time, PLA is dried and extruded. It was found that the mass distribution of PLA with dopamine starts already at 200 °C, when for pure PLA this value exceeds 320 °C. The coating of the material also increased the tensile strength by about 20% (Zhao et al. 2018a). b).[19].

Oxidizing stabilizers are used to improve the properties of recycled material. Hydroquinone and troponin can play this role. Hydroquinone has been found to be a much better stabilizer, which captures free radicals and thus maintains the PLA chain length during thermal processing. Similar observations were found for the mechanical properties of the material (Pillin et al. 2008). [20].

Otherwise, polyethylene terephthalate (PET) and post pyrolysis packing waste (0.5% and 5% wt.) bio char filament was used as 3D printing material. Tensile strength increased significantly (32% and 60%, respectively) compared with the pure PET shred (Idrees et al. 2018). Likewise, the thermal and dimensional stability in the case of mixing compounds was improved. Possible application for new 3D printing of mats created on the lignocelluloses matrix (based on cellulose, hemicelluloses, and lignin) with recycled PET has been examined (Santos et al. 2018). [21].

Depending on orientation of mats (directional or oppositional) in the alignment of fibers, investigated mechanical properties had different values (for example tensile strength value for directional 15.72 MPa and for oppositional 2.5 MPa). Finally, the result disclosed potential application of mats for additive manufacturing. A significant improvement of the mechanical properties of the recycled material was noted in the presence of an additive in the form of bio carbon. Used PET bottles were mixed with bio carbon (< 100 μm) and subjected to thermal treatment. The presence of an additional component increased the tensile strength of the material by 32%. An increase in modulus of elasticity (about 60%) and higher resistance to thermal and oxidizing conditions were determined (Idrees et al. 2018). [22].

Bio carbon is also used to reinforce other materials, including the natural origin of PLA. It was found that the additives, in combination with the additives of natural origin, improve the stiffness of the samples (8%) (Notta-Cuvier et al. 2014). [23].

To increase values of recycled polypropylene (PP), filaments based on hemp or harakeke fibres or recycled gypsum (0–50 wt.) were separately added in the process of creating new types of mats. The best results were achieved for filaments made of harakeke fibbers (30 wt.; tensile strength 39 MPa, Young modulus 2.8 GPa). On the other hand, those materials have tendency to reduce their properties during printing processes (Stoof and Pickering 2018). [24].

Another attempt of enhancing quality of recycling polymers was based on the idea of incorporating nano-crystalline powders Fe, Si, Cr, and Al into PP and HDPE filament extrusion. It was found that adding 1% mix of powder (Fe-Si-Cr or Fe-Si-Al) resulted in better yield strength (37%) and Young modulus (17%) compared with the base materials values. Metals also reduces chances of crack formations (Pan et al. 2018). [25].

The most widely used 3D printing technology in today eras is fused deposition modelling. The process of creating an object without stopping till it is completed through layering is called the additive process. Whereas other similar processes to it are also used in it. In this research two different printed polyethylene terephthalate (PET) was analysed with the help of a tensile test. All 40 test pieces of PET were evaluated which were of both types. This new and old material was used in this process. Several tests were also conducted such as a comparison of values, the difference in stress incidence. (Oussai, Alaeddine 2021). [26].

In the recent times, an issue is emerging a lot and this issue is about plastic recycling, in which there is a lot of pollution due to plastic in the environment. That's why it is being told as a big issue. Plastic waste has increased a lot because nowadays it is being used everywhere from domestic tofactories. After that, when plastic was removed from use, it became an even more harmful waste. The process of reuse of plastic points towards a new direction. By recycling plastic, we can give it a new life. (Mikula, Katarzyna 2020). [27].

First, we needed some data to start this research, so to collect that data we chose someplace where 3D printing was done. All the people who used to work there, we told everyone that whatever waste will come out of the 3D printer due to different reasons, it has to be put in different dustbins. After that, we collect all waste and bring it in working place. After that, we characterizing those data well, the unsuccessful printers were divided into 9 types, and research was done on them. It was discovered that in open studios about 34% of the plastic is wasted. (Ruoyu Song, Cassandra Telenko 2017). [28]

In today's era, if we do additive manufacturing, then the best and better name that comes out is that of fused deposition modelling (FDM). Additive manufacturing is a very good technology to reduce waste material. It is artisan as long as the waste released due to human error and machine error is less, but when the material waste becomes more due to human error and machine error than the total waste then this process is not an artisan. Additional failures can also be caused by improper geometry of parts, failures resulting from insufficient preheating time, user error, or printer malfunction. (Ruoyu Song, Cassandra Telenko 2016). [29]

3. METHODOLOGY

Data Collection: The first step in this project involves collecting data on various aspects such as the types and quantities of plastic waste generated, the properties of different types of plastics, and the requirements for 3D printing filaments. This data will be used to determine the feasibility of the project, identify potential challenges, and guide the design and manufacturing process.

Design: Based on the data collected, a design plan will be developed for the transformation process. This includes designing the equipment needed to convert plastic bottles into filaments, as well as the layout and workflow. The design will take into consideration factors such as efficiency, cost effectiveness, safety, and environmental impact.

3.1. Fabrication:

Fabrication is an important industry that involves cutting, manipulating and assembling materials to produce desired structures. And while different fabrication companies use different techniques, most rely on three basic processes: cutting, bending and assembling.

1) Cutting

The first process of fabrication is cutting. During this process, the metal fabrication company cuts one or more pieces of raw metal for use in the creation of a new metal structure or product. Whether it’s steel, aluminum, iron or any other common type of metal, though, cutting metal requires special tools. Some metal fabrication companies use torches to cut metal, whereas others numerical control (CNC) machines involving lasers or water jets. When finished, the company will have clean, appropriate-sized sheets or sections of metal with which to work.

2) Bending

After cutting raw metal, metal fabrication companies must bend it. Again, there are different ways to bend metal after cutting it. Some metal fabrication companies hammer the metal sheets or sections into the desired shape. Hammering can be done by hand, or it can be done using a machine (power hammering). Recently, though, many metal fabrication companies have begun using press brakes to bend their metal. This heavy industrial machine automatically presses metal sheets and sections into a specific shape when engaged. It essentially clamps the metal between a punch die, forcing the metal into the desired shape.

3) Assembling

The third and final process of metal fabrication is assembling. As the name suggests, this process involves assembling the metal sheet or sections into the desired finished product. Assembling is typically performed via welding, though other steps may be included in the process as well. In addition to welding, for example, metal fabrication companies may crimp seams, apply screws or other fasteners, and apply glue. After assembling the metal, the company will finalize the product before shipping and selling it to its customers.

Metal fabrication is a driving force behind the country's ever-growing manufacturing sector. Although there are countless machines and techniques used by metal fabrication companies, must rely on a three-step process that consists of cutting, bending and assembling. These three processes allow metal fabrication companies to transform raw metal materials into new production.

3.2. Design consideration:

Several structural design considerations should be taken into account for economical and efficient manufacturing. Many of these apply to other joining methods, and all apply to both subassemblies and the complete structure.

- The device should be suitable for local manufacturing capabilities.
- The attachment should employ low-cost materials and manufacturing methods.
- It should be accessible and affordable by low-income groups, and should fulfill their basic need for mechanical power.
- It should be simple to manufacture, operate, maintain and repair.
- It should be as multi-purpose as possible, providing power for various agricultural implements and for small machines used in rural industry.
- It should employ locally available materials and skills. Standard steel pieces such as steel
- plates, iron rods, angle iron, and flat stock that are locally available should be used.
- Standard tools used in machine shops such as hacksaw, files, punches, taps & dies; medium
- duty welder; drill press; small lathe and milling machine should be adequate to fabricate the parts needed for the dual-purpose bicycle.
- It should make use of standard parts wherever possible.
- The device should adapt easily No permanent structural modification should be made Excessive weight should be avoided, as durability is a prime consideration.

DESIGN PROCEDURE

- Definition of problem
- Synthesis
- Analysis of forces
- Selection of material
- Determination of mode of failure
- Selection of factor of safety
- Determination of dimensions
- Modification of dimensions
- Preparation of drawings
- Preparation of design report.
- DESIGN CONSIDERATIONS
- Strength
- Rigidity
- Reliability
- Safety
- Cost
- Weight
- Ergonomics
- Aesthetics
- Manufacturing considerations
- Assembly considerations

- Conformance to standards
- Friction and wear
- Life

- Vibrations
- Thermal considerations
- Lubrication
- Maintenance
- Flexibility
- Size and shape
- Stiffness
- Corrosion
- Noise
- Environmental considerations

3.2.1. AESTHETIC CONSIDERATIONS IN DESIGN

Appearance is an outward expression of the quality of the product and is the first communication of product with the user.

Aesthetics is defined as the set of principles of appreciation of beauty. It deals with the appearance of the product.

ASPECTS OF AESTHETIC DESIGN

- Form(shape)
- Symmetry and shape
- Continuity
- Variety
- Proportion
- Noise
- Contrast
- Impression and purpose
- Style
- Material and surface finish

Tolerance

3.2.2. ERGONOMICS CONSIDERATIONS IN DESIGN

- Ergonomics is defined as the study of the man - machine - working environment relationship
- It aims at decreasing the physical and mental stresses to the user
- Areas covered under ergonomics
- Communication between man (user) and machine
- Working environment
- Human anatomy and posture while using the machine
- Energy expenditure in hand and foot operations

3.2.3. MANUFACTURING CONSIDERATIONS IN DESIGN

- Minimum total number of parts in a product
- Minimum variety of parts
- Use standard parts
- Use modular design
- Design parts to be multifunctional
- Design parts for multiple use
- Select least costly material
- Design parts for ease of manufacture
- Shape the parts for minimizing the operations.

3.3. STANDARDIZATION

It is the process of establishing the set of norms to which a specified set of characteristics of a component or a product should conform

Example: Standardizing the shaft consists of specifying the set of shaft diameters and material

Objectives of standardization

- To make the interchangeability of the components possible
- To make the mass production of components easier

Objectives of the project

1. To cater to the issue of competition in the mechanical industry the need for automation is assessed by all the industry.
2. To identify the key policy avenues considered to be appropriate to meet the challenge of sustainable manufacturing and packaging industry for the future.
3. To provide alternatives for industries aiming toward reducing human effort and improvement in material handling systems by implementing automation.
4. Sustainable and practical automation solutions for the future industrial environment.

MECHANICAL PROPERTIES OF MATERIALS

- Strength
- Stiffness/Rigidity
- Elasticity
- Plasticity
- Ductility
- Brittleness
- Malleability
- Toughness
- Machinability
- Resilience
- Creep
- Fatigue
- Hardness

Objective Of Work

1. To study ergonomics and problems of project.
2. To develop some concepts based on their needs.
3. Different projects analysis and it's type and it's major uses.
4. To achieve comfort and easy response concepts that satisfying most of the needs and which gives more suitable and also economical.
5. To develop model of those concept.
6. To evaluate the CAD model in real environment.

AESTHETIC

Another important criterion in any product design is to consider the looking of the product itself, which is known as aesthetics of the product. This product's aesthetic contributes substantially to satisfy the customer needs. In the proposed chair design, several aesthetics issues such as social appeal, color, dimension, cushion material, etc., were also considered into account. Various aesthetic issues with respect to students' needs of the proposed chair are highlighted in Table X with brief explanation.

3.4. MATERIAL SELECTION

To create a sustainable fabrication of 3D printing filament from recycled PET plastic, a step- by-step methodology is followed, which is illustrated in Fig.1. This methodology is an essential step towards achieving sustainable 3D printing practices by reducing plastic waste and promoting the use of eco-friendly materials. Step by Step methodology that is followed for production of the recycled PET filament is elaborated in detail starting from material selection to extruding the filament.

As demonstrated in that the initial stage of the methodology is material selection. This includes identifying plastic waste available for 3D printing filament, which necessitates selecting certain types of plastic to serve as a source material for 3D printing. Subsequently, the properties of the plastic waste, such as melting temperature, tensile strength, and elastic limit, were observed. Plastic waste is classified into various types, such as thermoplastics and thermosetting plastics, based on their characteristics For this study, we chose waste plastic bottles made from PET plastic because most of the available waste is made up of PET plastic.

Table 1: Bottles material and Specifications.

Material	Density	Operating Temperature Range	Key Specifications
High-Density Polyethylene (HDPE)	1.04 g/cm3	220 - 260 °C2	Economical, impact resistant, good moisture barrier.
Low-Density Polyethylene (LDPE)	0.92-0.94 g/cm3	220 - 260 °C2	Squeezable and soft, particularly suited for squeeze spray or dropper applications.
Polyethylene Terephthalate (PET)	1.38 g/cm3	230 - 245 °C1	Glass-like clarity, durable.
Polyvinyl Chloride (PVC)	1.35 g/cm3	220 - 260 °C2	Transparent, rigid.
Polypropylene (PP)	0.90 g/cm3	220 - 260 °C2	Autoclavable.

3D Modelling & Drafting: Using computer-aided design (CAD) software, 3D models and drafts of the equipment will be created. These models will provide a visual representation of the design and allow for any necessary adjustments to be made before the manufacturing process begins. The 3D models will also be used to create detailed blueprints for the manufacturing and assembly process.

Manufacturing & Assembly: Once the design has been finalized and the blueprints have been created, the manufacturing process can begin. This involves fabricating and customizations the parts for the equipment, assembling them according to the blueprints, and installing them in the production facility. The manufacturing process will adhere to strict quality control standards to ensure the reliability and performance of the machinery and equipment.

4. PROCESS FLOW

The each step of the process of creating filament for a 3D printer from recycled bottles:

1. Collection and Sorting:

- Plastic bottles are collected from various sources such as recycling centers, waste management facilities, or directly from consumers through recycling programs.

- Upon collection, the bottles undergo sorting based on their type of plastic (usually PET or HDPE) and color. Sorting is crucial because different types of plastic have varying properties and may require different processing techniques.

2. Cleaning and Shredding:

- Once sorted, the bottles are thoroughly cleaned to remove any contaminants like labels, adhesives, dirt, or residue. Cleaning may involve washing, rinsing, and sometimes sterilizing the bottles.

- After cleaning, the bottles are mechanically shredded into small pieces or flakes using industrial shredding equipment. These flakes provide the raw material for the filament extrusion process.

3. Extrusion:

- The shredded plastic flakes are then fed into an extrusion machine, which consists of a hopper, a screw conveyor, and a heated barrel.

- Inside the barrel, the plastic flakes are melted by heating elements and mechanical friction generated by the rotating screw. The temperature and pressure are carefully controlled to ensure proper melting and homogenization of the plastic.

- As the molten plastic moves along the barrel, it undergoes mixing and blending to achieve uniform consistency and properties.

- At the end of the barrel, the molten plastic is forced through a small opening called a die, which shapes it into a continuous strand of filament with the desired diameter (typically 1.75mm or 2.85mm).

- The extruded filament is then rapidly cooled using air or water to solidify it and maintain its shape.

4. Cooling and Sizing:

- After extrusion, the filament passes through a cooling chamber or bath to ensure proper cooling and solidification. This prevents deformation or warping of the filament.

- The cooled filament may also pass through a sizing or calibration device to control its diameter and ensure consistency. This step is crucial for achieving uniform printing quality.

5. Spooling:

- The finished filament is wound onto spools or reels for storage, packaging, and distribution. Spools come in various sizes and materials, such as plastic or cardboard.

- The spooled filament is then labeled with relevant information such as material type, diameter, color, and brand.

Overall, the process of creating filament for 3D printing from recycled bottles involves several intricate steps to transform plastic waste into a high-quality printing material. This sustainable approach not only helps reduce environmental impact but also promotes circular economy principles by giving new life to discarded plastics.

ADVANTAGES

Using filament for a 3D printer made from recycled bottles offers several advantages:

Environmental Sustainability: Recycling plastic bottles into filament helps reduce plastic waste that would otherwise end up in landfills or oceans. By repurposing waste material, it promotes environmental conservation and reduces the demand for virgin plastic production.

Resource Conservation: Recycling plastic bottles conserves natural resources by reducing the need for raw materials, such as petroleum-based plastics. It also reduces energy consumption and greenhouse gas emissions associated with the production of new plastics.

Cost-Effectiveness: Using recycled materials often costs less than sourcing virgin materials, making filament from recycled bottles a cost-effective option for 3D printing. This can be particularly advantageous for individuals, businesses, and organizations looking to reduce manufacturing costs.

Versatility: Filament made from recycled bottles can be used in a wide range of 3D printing applications, from prototyping and manufacturing to artistic projects and educational purposes. It exhibits properties similar to traditional filament, such as PLA or ABS, and can be used with various types of 3D printers.

Promotes Sustainability Awareness: Utilizing filament from recycled bottles can serve as a tangible example of sustainability in action, raising awareness about the importance of recycling and waste reduction. It encourages individuals and businesses to adopt eco-friendly practices and contribute to a more sustainable future.

Customization and Innovation: Recycling plastic bottles into filament allows for the creation of unique filament blends with specific properties, colors, and textures. This opens up opportunities for customization and innovation in 3D printing, enabling users to experiment with different materials and create innovative products.

Filament made from recycled bottles offers numerous advantages, ranging from environmental benefits and cost savings to versatility and sustainability awareness. It represents a promising approach to 3D printing that aligns with principles of circular economy and responsible resource management.

5. DESIGN ANALYSIS

Design Software Used: Solidworks

In the face of growing environmental concerns, recycling has become an essential practice in our daily lives. One such initiative is the transformation of waste plastic bottles into 3D printing filaments. This project aims to design and implement a machine that can carry out this transformation process efficiently and effectively.

A) Isometric View B) Front View

C) Top View D) Right Side View

Fig No. 3: 3D Design of Model

Materials and Components

1. Ply-wood
2. Plastic bottles
3. Bottle Strip cutter
4. Roller
5. Nozzle & heater
6. Square box Motor
7. PID Temperature controller
8. Relay
9. SMPS

The primary materials and components used in this project are:

Ply wood

Fig. No. 4. Ply wood

Plywood is a type of engineered wood panel made from thin sheets of wood veneer (called plies or layers) that are glued together. These sheets are usually arranged with the grain of each layer perpendicular to the adjacent layer, which enhances the strength and stability of the panel. This construction method, known as cross-graining, reduces the tendency of the wood to expand or shrink with changes in moisture content, making plywood less susceptible to warping and twisting compared to solid wood.

Plywood is commonly used in construction, furniture making, cabinetry, and various other applications where strength, durability, and dimensional stability are important. It comes in various grades, thicknesses, and types of wood veneer, allowing for a wide range of applications and appearances.

Plastic Bottles:

These serve as the raw material for the filament. The bottles are collected from various sources, sorted based on their type (PET, HDPE, etc.), and cleaned thoroughly to remove any residual substances.

Fig No. 5. Plastic Bottles

Bottle Strip Cutter:

This device is used to cut the plastic bottles into thin strips. It is designed to handle bottles of various sizes and shapes. The cutter is equipped with sharp blades that can easily slice through the plastic material.

Fig. No. 6 Bottle Strip Cutter

Wire Roller Wheel

Fig. No. 7. Wire Roller Wheel

"Wire roller wheel" is a component in machinery used in wire processing. It's typically a cylindrical or disk-shaped wheel with grooves, guiding wire smoothly through machines like wire drawing or straightening equipment, ensuring controlled movement and consistent tension.

Extruder/Nozzle with Heater Arrangement:

A 3D printer nozzle is a small, typically cylindrical component that attaches to the print head of a 3D printer. It serves as the outlet through which molten filament is extruded onto the print bed or previously printed layers to create the desired object. Nozzles come in various diameters, which affect the level of detail and speed of printing

Fig. No. 8. Extruder/Nozzle with Heater

A 3D printer heater is a component that helps regulate the temperature of the nozzle and the filament during the printing process. It is typically a small heating element embedded within or attached to the nozzle assembly. The heater ensures that the filament melts consistently and flows smoothly through the nozzle, allowing for precise deposition of material during printing

Square box motor

Fig. No. 9. Square box motor

In a generic sense, "square box motor" could refer to a motor (likely an electric motor) that has a square-shaped housing or casing. Motors come in various shapes and sizes, and some may have square or rectangular housings for specific applications or design requirements.

PID Temperature controller

Fig. No. 10. PID Temperature controller

Here's what each component of PID represents:

Proportional (P): This component adjusts the output in proportion to the current error (the difference between the setpoint and the measured temperature). A higher proportional gain results in a more aggressive response to error, meaning the controller will act more strongly to reduce the difference between the setpoint and the measured temperature.

Integral (I): This component integrates the error over time, aiming to eliminate any residual steady-state error that may remain after the proportional control has acted. It continuously adjusts the output based on the accumulated error over time, effectively reducing any long-term discrepancies between the setpoint and the measured temperature.

Derivative (D): This component considers the rate of change of the error. It anticipates future error trends by dampening the controller's response if it detects rapid changes in temperature, helping to prevent overshoot or oscillations.

By combining these three components, a PID controller can effectively maintain a stable and accurate temperature control system, adjusting the output signal to the heating element (or cooling system) to achieve and maintain the desired temperature setpoint with minimal deviation.

Relay

Fig. No. 11. Relay

A relay is an electromechanical device that allows a low-power electrical signal to control a high-power electrical circuit. It consists of a coil of wire (the input or control circuit) and one or more switches (the output or load circuit). When an electrical current is applied to the coil, it creates a magnetic field that pulls a movable armature or contact to make or break connections in the load circuit.

Relays are commonly used in various applications where it's necessary to control a high-power circuit with a low-power signal. They provide isolation between the control and load circuits, protecting sensitive control electronics from high voltages or currents. Relays are used in industries ranging from automotive and industrial automation to telecommunications and household appliances. They come in various types, including electromagnetic relays, solid-state relays, and reed relays, each suitable for different applications and operating conditions.

SMPS

Fig. No. 12. SMPS

SMPS stands for Switched-Mode Power Supply. It's a type of power supply unit that converts electrical power efficiently from one form to another using switching devices such as transistors or MOSFETs.

Here's how it works:

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 04 | April - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

AC (alternating current) or DC (direct current) input power is first rectified and filtered to convert it into a higher voltage DC.

The high-voltage DC is then chopped or switched on and off at a high frequency by a semiconductor switching device.

This chopped voltage is passed through a transformer, which steps it down to the desired output voltage.

Finally, the output voltage is rectified and filtered again to provide a stable DC output.

SMPSs are widely used in electronic devices and equipment due to their efficiency, compact size, and versatility. They're found in computers, televisions, mobile phone chargers, LED lights, and many other electronic devices.

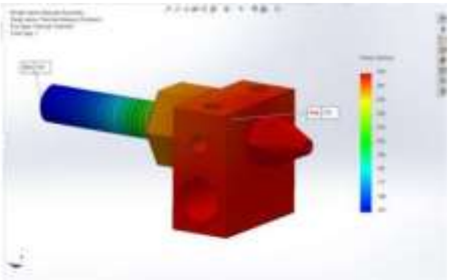


Fig No. 13: Analysis Of Heat Block

Software used: Ansys

The image represents a thermal analysis of an extruder assembly, specifically focusing on the nozzle and heat block. The colour gradient in the image represents the temperature distribution across these components, with blue indicating cooler areas and red indicating hotter areas.

Nozzle: The tip of the nozzle is marked in red, indicating that it reaches the maximum temperature of 250 degrees Celsius. This is expected as the nozzle is where the plastic is heated to its melting point and extruded. The high temperature at the nozzle ensures that the plastic is sufficiently melted for extrusion.

Heat Block: The heat block appears to be uniformly heated, as shown by its consistent red colouring. This suggests that the heat block effectively maintains a high temperature, which is crucial for melting the plastic.

Temperature Gradient: The temperature gradient from the heat block to the nozzle indicates efficient heat transfer. The heat is highest at the nozzle and decreases as we move away from it, which is represented by the change in colour from red to blue.

Fig No. 14: Material Properties

This thermal analysis is crucial for understanding how heat is distributed in the extruder assembly. It helps in ensuring that the plastic is properly melted and extruded, and can also aid in identifying and resolving any potential issues related to heat distribution.

CALCULATION AND ANALYTICS

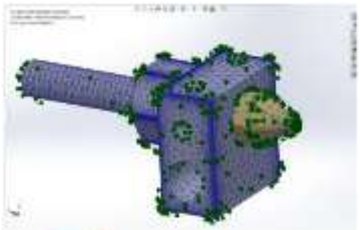


Fig No. 15: Heat Block Calculation

Three-Dimensional Stress Analysis

$$[D]=\frac{E}{(1+\nu)(1-2\nu)}\begin{bmatrix} 1-\nu & \nu & \nu & 0 & 0 & 0 \\ \nu & 1-\nu & \nu & 0 & 0 & 0 \\ \nu & \nu & 1-\nu & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1-2\nu}{2} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1-2\nu}{2} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1-2\nu}{2} \end{bmatrix}$$

Fig No. 16: 3D Stress Analysis Formula

EXPERIMENTATION RESULT

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 (Bottle PET). All print parameters of individual materials were selected to obtain the best print quality [Table 2]. 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 no.2. Material Test Table

Material	3D printer head temperature [°C]	3D printer bed temperature [°C]	Printing speed [mm/s]	Nozzle size [mm]	Infill [%]
PET-G	250	70	30	1.78	100
ABS	255	100	30	1.78	100
PLA	202	55	30	1.78	100
BPET	256	85	30	1.78	100

6.1. Microscope Examination of Filament

Samples of an ordinary PETG filament from market and BPET filament were created [Fig.17]. Transparency of both filaments was essential to make observation using an available microscope. same sample of the BPET.

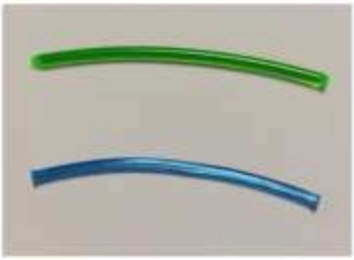


Fig. No. 17. Samples

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

Fig. No. 18. 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]. The external structure is smooth.

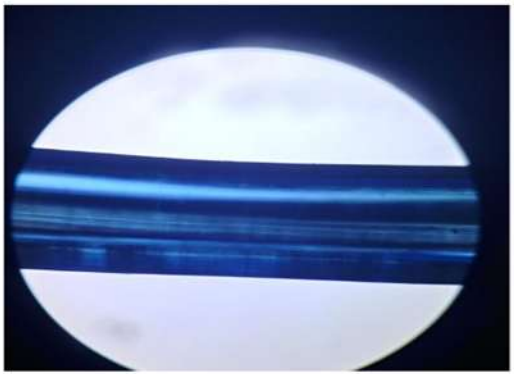


Fig. No. 19. BPET microscope examination.

6.2. 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, particular materials and temperatures at which the sample began to change its shape are shown.

Fig. No. 20. Samples at the initial stage of melting.

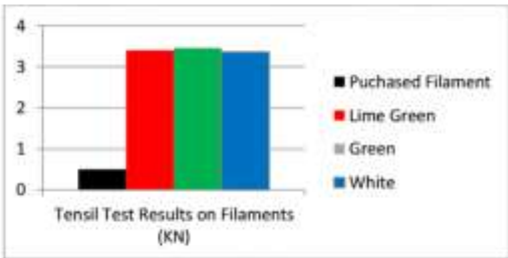
The temperature was consistently raised until the sample is completely melted. The temperatures and shape of the sample are shown in the picture below fig.

Fig. No. 21. 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.

6.3. Tensile Strength test

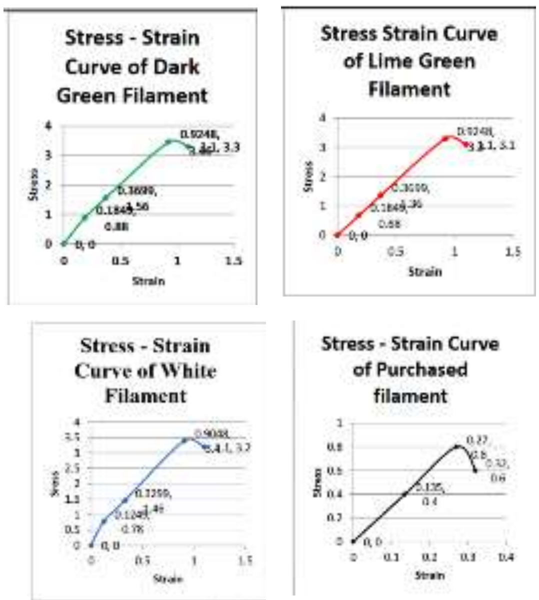
First of all, we collected plastic waste from many resources. After that our main aim is to convert plastic waste into a useful product. So, to make plastic waste useful we made a filament extruder. A filament extruder is a machine that converts plastic waste into 3D printer filament with the extrusion process. After successfully making a filament extruder we produced three types of filaments. These three types of filaments are divided by their different colours Lime Green, Dark Green, and White. After that, we do some tests like the tensile test and Ductility test on filaments to know if they are better than available filaments in the market. When we compare the data of our Dark green filaments with purchased filament it is unbelievable because our filament is 5 times more tensile and ductile than the purchased filament. The maximum Stress-Strain value of purchased filament is (0.8-0.27) and our filament Stress-Strain value is (3.46-1.1) which is 76% more than purchased filament. After that, we also compare our other two limes green and white filaments with purchased filament they also give very high stress-strain value as compared to the purchased filament. And the ductility of our filament is also more reliable than purchased filament. This all tests are done in our college labs.



Graph. No. 1. Tensile Test Result

This Figure shows our new filaments tensile strength is much more than purchased filament. It is about 78.87% more than purchased filament

This Stress-Strain Diagrams shows comparison between purchased filament and our three types of filaments (Dark Green, Lime Green, White)



Graph .No.2. Stress & Strain Graph

6. CONCLUSION

The project "Transformation of Waste Plastic Bottles into 3D Printing Filament" has successfully demonstrated a practical and effective solution to two pressing issues in today's world - the environmental impact of plastic waste and the growing demand for affordable 3D printing materials.

Throughout the project, we have seen how waste plastic bottles can be transformed into a valuable resource. The process involves several stages, including the collection of waste plastic bottles, cutting the bottles into thin strips, melting and extruding the plastic into a thin filament, and winding the filament onto a spool. Each stage has been carefully designed and implemented to ensure the efficiency and effectiveness of the process.

One of the key achievements of this project is the significant reduction in plastic waste. By recycling waste plastic bottles, we are not only reducing the volume of plastic that ends up in landfills and oceans but also decreasing the demand for new plastic production. This contributes to environmental sustainability and aligns with global sustainability goals.

Another major achievement is the production of affordable 3D printing filament. The filament produced from this project is significantly cheaper than commercial 3D printing filaments, making 3D printing more accessible and affordable. This has the potential to stimulate growth and innovation in the 3D printing industry.

Furthermore, the project has provided valuable educational opportunities. It serves as a practical demonstration of recycling processes, material science, and 3D printing technology, making it an excellent educational tool for students and educators.

Looking forward, there is significant potential for further development and expansion of this project. The process could be scaled up to recycle larger quantities of plastic waste, or adapted to recycle other types of plastic. There are also opportunities for further research into improving the efficiency of the process, developing new applications for the recycled filament, and exploring the properties and performance of the filament in various 3D printing applications.

The "Transformation of Waste Plastic Bottles into 3D Printing Filament" project has been a resounding success. It has demonstrated a practical and effective solution to a global issue, contributed to environmental sustainability, stimulated growth in the 3D printing industry.

Plastics are not susceptible to biodegradation and their decomposition causes additional contamination of the environment. Recycling was found to be the most advantageous method to valorize post-consumer plastics that stays in line with a concept of circular economy. Degradation of plastics lasts from 10 to 450 years. From the historical point of view, recycling has been undertaken by the means of large centralized plants that produce commodities of low value. This is related with high costs of transportation. 3D printing enables different approaches. Desktop 3D printing makes it possible to produce complicated plastic products at home instead of in factory. It is estimated that the value of this sector will increase intensively the next years. The idea is that consumer can produce goods directly from his own used materials. This provides several savings: environmental and buying commercial plastic goods and enables to close the loop of circular economy. recently, during coronavirus crisis, we observe individual applications that are possible for given needs. There are examples of 3D printing of, e.g., visors as a medical cover that protects eyes from coronavirus infection. By popularization of 3D printing, it is possible to adjust production to temporary needs.

REFERENCES

1. Muyiwa Oyinlola et al. (2023) Electronic waste (e-waste) plastics from end-of-life printers, predominantly polycarbonate, were up cycled and transformed into sustainable 3D printing filaments.

2. Manoj Nikam et al. (2023) The findings from this research will offer valuable insights into the potential of recycled PET bottles as an environmentally friendly alternative for 3D printing filaments.

3. Katarzyna Mikula et al. (2021) In recent times, the issue of plastic recycling has become one of the leading issues of environmental protection and waste management. Polymer materials have been found and applied in many areas of daily life and industry.

4. Aubrey L. Woern et al. (2018) To assist researchers explore the full potential of distributed recycling of postconsumer polymer waste, this article describes a recyclebot, which is a waste plastic extruder capable of making commercial-quality 3-D printing filament.

5. S. Kim, M.A. Rahman, M. Arifuzzaman, D.B. Gilmer, B. Li, J.K. Wilt, E. Lara- Curzio, T. Saito, Closed loop additive manufacturing of upcycled commodity plastic through dynamic cross-linking, Sci. Adv. 8 (22) (2022) 1–10.

6. M. Cristea, D. Ionita, M.M. Iftime, Dynamic mechanical analysis investigations of PLA-based renewable materials: how are they useful? Materials (Basel) 13 (22) (2020) 1–24.

7. M. Attaran, The rise of 3-D printing: the advantages of additive manufacturing over traditional manufacturing, Bus. Horiz. 60 (5) (2017) 677–688.

8. A Charles, E. Harper, Handbook of Plastics, Elastomers, and Composites, 2014.

9. N. Turner, R. Strong, and S. A. Gold, “A review of melt extrusion additive manufacturing processes: I. Process design and modeling,” Rapid Prototyping Journal, vol. 20, no. 3, pp. 192–204, Apr. 2014.

10. K. Dzierzeket al., “Design and static tests of an all-terrain suspension system for electric wheelchair,” in Proc. 2018 International Conference BIOMDLORE, Bialystok, 2018, pp. 1–5.

11. M. Rećko, J. Tołstoj-Sienkiewicz, and P. Turycz, “Versatile soil sampling system capable

12. of collecting, transporting, storing and preliminary onboard analysis for mars rover analogue,” Solid State Phenomena, vol. 260, pp. 59–65, July 2017.

13. P. Tomaszuk, A. Lukowska, M. Recko, K. Dzierzek, and P. Straszynski, “Active wheel speed control to avoid lifting the swingarms in rocker-bogie suspension,” in Proc. 2019 International Young Engineers Forum (YEF-ECE), Costa da Caparica, Portugal, 2019, pp. 36–39.

14. P. Tomaszuk, A. Lukowska, M. Rećko, and K. Dzierzek, “Integrated drive system of robotic arm joint used in a mobile robot,” in Proc. 2018 23rd International Conference on Methods & Models in Automation & Robotics (MMAR), Miedzyzdroje, 2018, pp. 509–514.

15. Lukowska, P. Tomaszuk, K. Dzierzek, and L. Magnuszewski, “Soil sampling mobile platform for Agriculture 4.0,” in Proc. 2019 20th International Carpathian Control Conference (ICCC), Krakow-Wieliczka, Poland, 2019, pp. 1–4.

16. Prusinowski and R. Kaczyński, “Simulation of processes occurring in the extrusion head used in additive manufacturing technology,” Acta Mechanica et Automatica, vol. 11, no. 4, pp. 317–321, Dec. 2017.

17. Mosaddek, H. K. R. Kommula, and F. Gonzalez, “Design and testing of a recycled 3D printed and foldable unmanned aerial vehicle for remote sensing,” in Proc. 2018 International Conference on Unmanned Aircraft Systems (ICUAS), Dallas, TX, 2018, pp. 1207–1216.

18. Woern, D. Byard, R. Oakley, M. Fiedler, S. Snabes, and J. Pearce, “Fused particle fabrication 3-D printing: Recycled 1392 materials’ optimization and mechanical properties,” Materials, vol. 11, no. 8, p. 1413, Aug. 2018.

19. N. E. Zander, M. Gillan, Z. Burckhard, and F. Gardea, “Recycled polypropylene blends as novel 3D printing materials,” Additive Manufacturing, vol. 25, pp. 122–130, Jan. 2019.

20. N. Aliheidari, C. Hohimer, A. Ameli, A. R. Kakroodi, Y. Kazemi, and C. B. Park, “Mechanical properties of 3D printed polylactide/microfibrillated polyamide composites,” in Proc. Annual Technical Conference - ANTEC, Conference Proceedings, 2018, vol. 2018-May.

21. F. Decuir, K. Phelan, and B. C. Hollins, “Mechanical strength of 3-D printed filaments,” in Proc. 2016 32nd Southern Biomedical Engineering Conference (SBEC), Shreveport, LA,

22. USA, 2016, pp. 47–48, doi: 10.1109/SBEC.2016.101.

23. Mikula, Katarzyna, et al. Environmental Science and Pollution Research 28.10 (2021): 12321-12333.

24. Song, Ruoyu, and Cassandra Telenko. "Material and energy loss due to human and machine error in commercial FDM printers." Journal of cleaner production 148 (2017): 895-904.

25. Dubashi, Jay, Brian Grau, and Alex McKernan. "AkaBot 2.0: pet 3D printing filament from waste plastic." (2015).

26. Singh, N., Hui, D., Singh, R., Ahuja, I. P. S., Feo, L., & Fraternali, F. (2017). Recycling of plastic solid waste: A state of art review and future applications. Composites Part B: Engineering, 115, 409-422. 7. Gu, Lei, and Togay Ozbakkaloglu. "Use of recycled plastics in concrete: A critical review." Waste Management 51 (2016): 19 42.