An Investigation of Developing a 3D Printing Industry through the Recycling of Plastic Waste in Mauritius

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***Abstract*—Many containers used in Mauritius for storing household and industrial products are composed of fossil-derived plastic. When discarded as waste, these plastic containers pose a serious environmental and economic challenge for Mauritius. To address this issue, this research looked at the business case for, and engineering implications of, converting plastic waste into 3D printing filaments so as to reduce the amount of plastic that will end up in the landfill. Primarily, this research delved into the following critical issues: the types and volumes of plastic to recycle, the process involved the transformation of plastic waste into 3D filaments, and the commercialization of 3D printing filaments locally and regionally. For this project, we proposed to analyse the 3D printing filament chemical components and identify the most appropriate type of local plastic wastes that can be recycled. A proof of concept, with a business case on the demand projections, has been made. We also proceeded to identify and use the hardware required to build a prototype machine that can convert identified plastic wastes into 3D printing filament locally. We finally evaluated the potential of developing3D printing as a sustainable source of economy for Mauritius through the recommendations of relevant processes and policies to be put in place.**

***Keywords*—3D printing; plastic waste, recycling, filaments**

I. Introduction

The global fight to reduce plastic trash is one of the most rapidly expanding environmental concerns in history. However, it has been insufficient to make a difference in the rising volume of wasted plastic that ends up in the oceans. During the next decade, waste that enters rivers and eventually the seas will exceed 22 million tonnes and perhaps 58 million tonnes per year. That is the "good" news—because that estimate includes countless significant promises by government, industry and all stakeholders around the world to minimise plastic pollution [1]. Mauritius itself generates an average amount of 540,000 Tons of waste annually which comprises of 14% plastic wastes.

Plastic forms part of the daily routine of billions of people and is also significantly used in most industries. More than 400 million tons are produced every year. In a more specific definition, plastic is a product of polymerization of a set of synthetic materials made from hydrocarbons. Since the 1950s, plastics experienced a rapid growth to become one of the most common materials worldwide and in 2015, 407 million tonnes per annum were the numbers recorded for global plastics production [2]. Plastic is the most commonly used material worldwide due to its versatility, adaptability, and other positive features: it is lightweight, functional and durable [3]. However, the material is also extensively used in the construction, textile, transportation and electrical/electronic sectors amongst other sectors. Certain plastic polymers are predominantly utilized in a single application (for example, polyethylene for packaging purposes), whereas others are used more broadly (e.g., polypropylene) [2]. According to a 2020 Action Plan from the Ministry of Environment, Solid Waste Management and Climate Change, plastic waste represents 14% of the total wastes generated annually in the country. The 14% mentioned above represents an amount equivalent to 76,000 tons of plastic waste produced every year in Mauritius, representing the 3rd greatest type of waste generated locally, after food wastes (27%) and yard wastes (27%) and an equal amount to paper wastes (14%). It can be noted that Low Density Polyethylene (LDPE), High-Density Polyethylene (HDPE) and Polyethylene Terephthalate (PET) polymers are the most common types of plastics in domestic waste, with 29.11%, 26.78% and 16.74% share respectively.

The 3D printing industry is constantly growing. Its market size was valued at USD 13.78 billion in 2020 and is expected to grow enormously in coming years [4]. This research is being conducted to assess the feasibility of upcycling our plastic waste into 3D printing filaments. The paper emphasises on the review of available literature on using plastic waste to make new 3D filaments. Printable filaments can be produced from a wide range of thermoplastic materials, including those from waste. The types and amount of plastic waste generated in Mauritius was identified. The potential of recycling basic thermoplastic materials was established, as well as the effect of reprocessing on their mechanical properties.

The aim of this research is clearly to contribute to reduction in plastic pollution and amount of waste landfilled as the only landfill in the island is already saturated. But in parallel this research will, with all its modern attributes contribute to a new industry in the Island. With increasing concern about the Covid-19 situation which brings a lot of uncertainty concerning importation and value of our currency, this project will surely help many stakeholders. The growing demands for more filaments and greener products will help Mauritius extend its market internationally.

A. 3D Printing in Mauritius

The 3D printing industry is slowly growing in Mauritius. The initiatives come from the government who is trying to bring in this modern concept and technology. The National

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Computer Board (NCB) has commissioned two 3D Printing centres in the country to help students, entrepreneurs, small businesses and other Around 1 Ton of 3D printing filaments are being used in Mauritius yearly and the market is expected to grow rapidly. Thermoplastic filaments are utilized in 3D printing because they are plastics (also known as polymers) that melt rather than burn when heated, may be shaped and moulded, and solidify when they're cooled. An extruder assembly in a 3D printer melts the filament by forcing it through a metal nozzle as the extruder travels along, creating the printed object layer by layer, according to the program in the 3D object file. However, even though most 3D printers only have a single extruder, there are a few models available with two extruders that can print objects in multiple colours or with different types of filaments. It is either Fused Filament Fabrication (FFF) or Fused Deposition Modelling (FDM) when plastic filaments are printed. Since 3D printing pioneer Stratasys Corp. registered the FDM acronym, other manufacturers had to come up with their own names to explain their printers' technology. Both titles are used now, with the exception of a few manufacturer's brochures.

II. Materials and Methods

A. Filament Manufacturing

Extrusion is a manufacturing process of homogenization of a raw material into a uniform shape product by squeezing it through a die. It is a continuous operation where the raw material in the form of pellets are fed through a hopper into the heated barrel of the extruder. In the barrel, the pellets are melted, blended and compressed through a die. Fig. 1 illustrates the schematics of the extrusion process, providing a visual representation of the key steps and components involved.

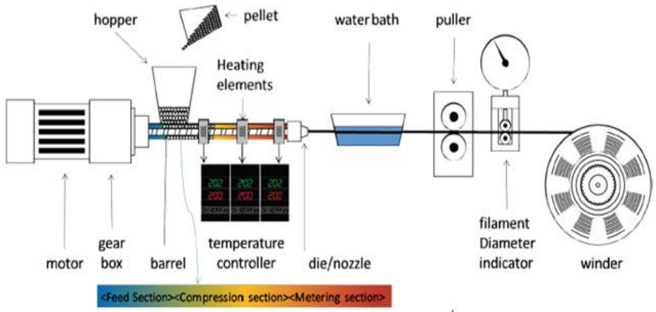

Fig. 1. Schematics of extrusion process.

B. Overall Assembly

- The extruder screw is placed inside the barrel.
- The barrel is mounted on the frame.
- The barrel is connected to the gearbox, and the gearbox is powered by an electric motor.
- The extruder die is held at the front of the barrel.
- Two heaters are placed around the barrel and one heater is placed around the die.
- Each heater is connected to a thermocouple.
- AC power is provided for the heaters and electric motor.
- The incoming recycled plastic is fed into the hopper which is attached to the barrel.
- The PID controller is set to control the temperature of the three heating elements used.

III. Analysis and Discussions

A. 3D Filaments

Thermoplastic filaments are utilized in 3D printing because they are plastics (also known as polymers) that melt rather than burn when heated, may be shaped and moulded, and solidify when they're cooled. An extruder assembly in a 3D printer melts the filament by forcing it through a metal nozzle as the extruder travels along, creating the printed object layer by layer, according to the program in the 3D object file. However, even though most 3D printers only have a single extruder, there are a few models available with two extruders that can print objects in multiple colours or with different types of filaments [5]. It's either Fused Filament Fabrication (FFF) or Fused Deposition Modelling (FDM) when plastic filaments are printed. They mean the same thing. Since 3D printing pioneer Stratasys Corp. registered the FDM acronym, other manufacturers had to come up with their own names to explain their printers' technology. Both titles are used now, with the exception of a few manufacturer's brochures.

B. Types of Common Filaments

1) Acrylonitrile-butadiene-styrene (ABS)

This material has been around for quite some time. In industrial 3D printing, this was one of the first materials to be employed. The low cost and high mechanical qualities of ABS have made it a popular material for many years. Its toughness and impact resistance make ABS a great material for 3D printing durable products that can withstand additional wear and tear. For the same reason, LEGO construction bricks are composed of this material. ABS is more resistant to heat before it begins to deform than other plastics. Thus, ABS is an excellent material for use in hot climates [6].

2) Polylactic Acid (PLA)

PLA, or Polylactic Acid, is a typical 3D printing material made from a polymer called polylactic acid. Because it prints at a low temperature and doesn't require a heated bed, it is the default filament for most extrusion-based 3D printers. PLA is economical, easy to print, and produces pieces that can be utilized in many different ways. Additionally, it is environmentally sustainable, making it a desirable filament to use in 3D printing. PLA is renewable and, most importantly, biodegradable because it is made from crops like corn and sugarcane. This has the added benefit of allowing the plastic to emit a pleasant odour while being printed [6].

C. Extrusion to Obtain Recycled 3D Filament

Plastic filament for 3D printers is manufactured by a process called extrusion. Plastic waste is collected, cleaned if necessary and sorted. This process begins with the feeding of plastic material (pellets, granules, flakes, or powders) into the barrel of the extruder through a hopper. Mechanical energy created by rotating screws and heaters positioned along the barrel gradually melts the material. The molten polymer is then pushed into a die, which moulds it into filaments of around 1.75 mm or 2.85 mm in diameter. It is a good practice to check all feedstock streams meticulously to ensure homogeneity; which can be achieved by shredding properly all materials. During the extrusion phase, it is important to continuously measure the filaments' diameters to achieve high standards. There are laser measuring systems with alarms that can be used to constantly measure diameter. Filament is then spooled in bulk and then into small individual rolls. Quality verification is the most important step after producing the filaments. Each batch produce must be tested rigorously to ensure mechanical and other properties (Diameter and roundness). Filaments not meeting with desired properties can always be re-melted and extruded.

1) High density polyethylene

This material is used to make plastic bottles, food containers, and corrosion-resistant pipes. Filament can be recycled to obtain new filament, though it is recommended that you have a cooling system in place to facilitate the process. A study on recycled HDPE filament was carried out and comparison was made with common commercial filaments ABS and PLA. It was noted that recycled HDPE filaments had more or less the same characteristics as PLA. More specifically melt flow, yield strain melt temperature and extruding temperature were nearly same as PLA. It was also observed that lowering the melt flow rate gave a higher mechanical strength to HDPE filaments. Similar characteristics to PLA make waste HDPE a very interesting source for 3D filaments as it will easily fit into available extrusion machines and printers [7].

2) Polypropylene

Polypropylene (PP) is a widely utilised plastic in a broad variety of industrial and consumer uses. Additionally, it is one of the most difficult materials to 3D print with. However, once learned, it has several advantages: Chemical resistance and relative flexibility are two of PP's benefits over conventional filaments such as PLA. This makes this filament advantageous for 3D printing. Because polypropylene has a potential to warp, it requires a constant printing chamber temperature (it is strongly suggested to use an enclosed chamber), a heated bed, and a high extrusion temperature. For the majority of plastics, the hot ends can reach 220 °C and the bed can reach 85 °C [8].

3) Polystyrene

Polystyrene (PS) foam is one of the few thermoplastics that is entirely recyclable; nevertheless, it is not widely recycled due to the high cost of transportation to recycling facilities. A study shows that recycled PS (rPS) filament of roughly 1.75 mm had about 45% higher tensile strength than commercial filaments made of High-Impact Polystyrene (HIPS). Recycled polystyrene filament had also an enhanced stiffness of 52% compared to virgin ones. The only issues observed was the increase in brittleness in models made with rPS and irregularity in tensile properties due to different amount of air bubbles and impurities. It was concluded that on an overall basis, some mechanical properties of rPS are comparable to commercial HIPS, which makes it a reliable feedstock for 3D printing [9].

4) Polyethylene terephthalate

This is arguably the most popular material, often used in bottles, flacons, and a variety of other applications. PET can be converted into new filament, but it is quite difficult. Occasionally, it absorbs the odour of the food and liquids for which it is used as a container, and it is especially well-suited for blow moulding. As a result, extruding it is complicated [10]. A recent study showed that the recycled filament's hardness decreased to 6%, while its tensile and shear strengths improved to 14.7% and 2.8%, respectively. Comparing the mechanical characteristics of virgin and 3D printed recycled PET found no discernible difference. Problems were encountered while producing the recycled filaments. Impurities tends to clog the extrusion nozzle but this can be tackled by filtering out maximum impurities before extrusion.

D. Plastic Materials for Making 3D Filaments

When it comes to 3D printing, a high-quality finish must be obtained as a product outcome. It must be strong and long-lasting; as a result, it is preferable if the filament that is created produces good results that are also hard and resistant. Some common type of plastic used currently for the making of 3D filaments are as follows:

1) Polylactic Acid (PLA)

PLA, or Polylactic Acid, is a typical 3D printing material made from a polymer called polylactic acid. Because it prints at a low temperature and doesn't require a heated bed, it is the default filament for most extrusion-based 3D printers. PLA is economical, easy to print, and produces pieces that can be utilized in many ways like cups, vase, toy pieces etc. Additionally, it is environmentally sustainable, making it a desirable filament to use in 3D printing. PLA is renewable and, most importantly, biodegradable because it is made from crops like corn and sugarcane. This has the added benefit of allowing the plastic to emit a pleasant odor while being printed. PLA has high strength, low flexibility and medium durability. With a printing temperature of 180-230 ˚C, it is very easy to use. Required print bed temperature is 20-60 ˚C but practically not necessary. It has minimal shrinkage factor and is not soluble which means prints can be used under wet conditions as well [11].

2) Acrylonitrile-butadiene-styrene (ABS)

The second most used filament is ABS. ABS, despite being more difficult to print, has material qualities that make it slightly better than PLA. Having high strength and durability, ABS has medium flexibility and is slightly difficult to use. This material has been around for quite some time. In industrial 3D printing, this was one of the first materials to be employed. The low cost and high mechanical qualities of ABS have made it a popular material for many years. Its toughness and impact resistance make ABS a great material for 3D printing durable products that can withstand additional wear and tear. For the same reason, LEGO construction bricks, car parts and computer casings are composed of this material. ABS is more resistant to heat before it begins to deform than other plastics. Thus, ABS is an excellent material for use in hot climates [6]. It also requires a printing temperature of 210–250 °C and printing bed temperature of 80–110 °C.

However, ABS is soluble in esters, acetone and ketones and warp considerably after printing. Moreover, ABS, is more prone to warping without a hot print bed and bed adhesive.

3) Polyethylene terephthalate (PET)

PET is one of the most widely used plastics in the world. Although it is most usually associated with water bottles, it is also used in garment fibers and food containers. While "raw" PET is rarely used in 3D printing, its derivative PETG (Polyethylene terephthalate glycol) is becoming more popular. It is naturally more transparent, less brittle, and, most importantly, easier to print (220–250 °C) with, than its base form. As a result, PETG is frequently regarded as a good compromise between ABS and PLA, as it is more flexible and durable than PLA, while being easier to print than ABS. PETG is normally used to make transparent and translucent films, covers and plastic bags [12].

4) Thermoplastic elastomers (TPE)

Thermoplastic elastomers, are polymers with rubber-like properties, which make them very flexible and durable. As a result, TPE is often utilized in the manufacturing of automobile components, domestic appliances, and medical supplies. While TPE is actually a vast group of copolymers (and polymer mixes), it is used to identify a large number of commercially accessible varieties of 3D printer filament. These filaments are soft and stretchy, allowing them to resist physical abuse that neither ABS nor PLA can. On the other side, printing is not always straightforward due to the difficulty associated in extruding TPE.

5) Thermoplastic polyurethane (TPU)

Thermoplastic polyurethane is usually used as 3D printer filament. TPU is somewhat more stiff than common TPE, which makes it simpler to print. Additionally, it is slightly more durable and has a better ability to retain its elasticity in low temperature regions. TPU is often used in caster wheels, instrument panels for automobiles, sports goods, power tools, medical equipment, footwear, drive belts, inflatable rafts, and a variety of other extruded film and sheet applications.

TPU is also an excellent material for the outside shells of mobile devices such as tablets and smartphones.

6) TPC (thermoplastic co-polyester)

TPC is another kind of thermoplastic co-polyester, however it is not as widely used as TPU. While TPC is similar to TPE in most ways, its primary benefit is its increased resistance to chemical and ultraviolet radiation, as well as heat since it can withstand temperatures of up to 150 °C. TPC is used to manufacture products where a soft touch finish is required, covers for moving parts, bumpers and other energy absorbing parts.

E. Desired Characteristics of Market Filaments

When it comes to 3D printing, a high-quality finish must be provided as a product outcome. It must be strong and long-lasting; as a result, it is preferable if the filament that is created produces good final results that are also hard and resistant [5]. In comparison to PLA, ABS is a less popular 3D printing material. ABS, despite being more difficult to print, has material qualities that make it slightly better than PLA. ABS, on the other hand, is more prone to warping without a hot print bed and bed adhesive. The most commonly used filament PLA has high strength, low flexibility and medium durability. With a printing temperature of 180–230 °C, it is very easy to use. Required print bed temperature is 20–60 °C but practically not necessary. It has the minimal shrinkage factor and is not soluble which means prints can be used under wet conditions [6]. The second most commonly used filament is ABS. Having high strength and durability, ABS has medium flexibility and is slightly difficult to use. It also requires a printing temperature of 210–250 °C and printing bed temperature of 80–110 °C. ABS is soluble in esters, acetone and ketones and warp considerably after printing. PET is one of the most widely used plastics in the world. Although it is most usually associated with water bottles, it is also used in garment fibers and food containers. While "raw" PET is rarely used in 3D printing, its derivative PETG is becoming more popular. PETG's 'G' stands for "glycol." It is naturally more transparent, less brittle, and, most importantly, easier to print (220–250 °C) with than its base form. As a result, PETG is frequently regarded as a good compromise between ABS and PLA, two other commonly used types of 3D printer filament—it is more flexible and durable than PLA, while being easier to print than ABS.

F. Recommendations for the Segregation, Collection, Cleaning and Preparation of Plastic Waste for 3D Filament Making

The most appropriate way for collecting and separating plastic waste is through source segregation. However, this requires a huge logistic to be put in place with respect to the separation, collection, and transportation. The existing waste management system in Mauritius does not include waste segregation at source. Hence, from the current system, the most suitable method of collecting plastic waste form the waste stream is by processing the collected Municipal Solid Waste through an Material Recovery Facility (MRF). The processes for an MRF are shown in Fig. 2. The sorted plastic bottles can be collected and then separated into HDPE, PE, PS, LDPE, PP, PET for further upcycling into 3D printing filaments.

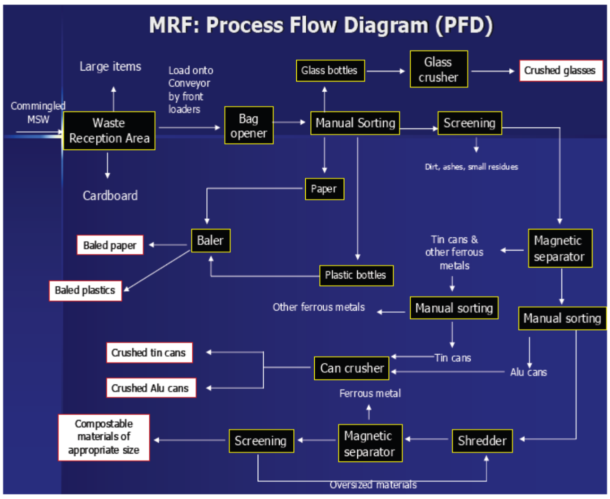

Fig. 2. Process flow diagram for MRF.

IV. Conclusion

Plastic waste in Mauritius is a serious environmental problem. Measures taken by the local Government has drastically reduced the number of plastic wastes that reach our landfills or fragile eco-system. In this report, we have been able to identify specific plastic materials that are commonly used in local households and industries.

Following identification of those plastic materials and their chemical nature, we have investigated the process required to convert those plastic waste into 3D filaments. To do so, we have analyzed the chemical component of 3D printer filament and we shall now move to the next step, which is the design and implementation of our prototype for converting locally produced plastic waste into 3D printer filament.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

D. Seebun conducted the lab work, while P.Jeetah provide her contribution with respect to the types of plastics that can be used for the project. P. Jeetah, Y. Chuttur, K. Tahalooa provided their expert supervision and guidance throughout the research process. All authors have approved the final version.

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