Conference Paper

A Low Carbon Footprint Approach to the Reconstitution of Plastics into 3D-Printer Filament for Enhanced Waste Reduction

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Abstract

In this study we aim to investigate recycling of waste plastics products into filaments for use in a typical FDM 3D printing system. We investigate the parameters relating to control of the filament thickness to a variety of different plastic types, which include HDPE and ABS. Following filament generation, parameters were investigated to optimise the print parameters to produce a variety of demonstration models, which test the print resolution. Results suggest that the proposed supply chain can allow for highly repeatable ABS and HDPE filament generation with a diameter of 1.74 ± 0.1mm and 1.65 ± 0.1mm respectively. Ultimately, the production of usable filaments can provide a viable means of consuming waste plastics and reducing the burden of increased landfill.

Keywords: Recycling, plastic, filament, 3D printer, waste reduction

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1 Introduction

Plastics have become ubiquitous part of our everyday life and are found in everything from packaging, toys, micro-technology and even biomedical applications [1, 2]. The prevalence of plastics is primarily due to the wide range of advantageous material properties, such as its lightweight, durability and ability to be manufacturing using a diverse range of processes. Global plastic production is increasing rapidly and is projected to continue to increase to a level of 850 tons by the year 2050 [3]. The intensive use of plastics is now leading to several unprecedented issues relating to the disposal and recycling of this material, and is arguably now one of the biggest challenges in modern day times. As such recycling is becoming of more critical importance due to finite resources on our earth and the impact our negative actions have on the environment. Alarmingly, the Australian Bureau of Statistics has seen a growing trend in the amount of waste going to landfill, with nearly half of all waste (48%) going to landfill during 2006–2007. Australian recycling organisations highlight that plastic is the most abundant item of rubbish found during 'Clean up Australia days', representing 30% of all rubbish collected in the last 10 years [4]. This uncovers the work still required in terms of recycling education and landfill reduction to preserve the natural beauty and prosperity of the Australian and perhaps global environment for future generations.

Ideally for the lowest impact on the environment, re-use of plastics is desirable as part of the overall life cycle analysis (LCA) of a product [2]. However, this may not always be practical should a product become compromised or damaged beyond the effective usefulness, resulting in recycling as the more desirable option. Though deemed the best option for re-use of waste thermoplastics, recycling in its conventional form requires a relatively energy intensive process to form the end pelletised product for use in industrial processes, particularly the phase of plastic extrusion and granulation [2, 5]. In response to this in an effort to reduce the environmental impact research groups are embracing the concept of distributed, or localised manufacturing, enabled through the use of open-source and low-cost 3D printing technologies [6]. 3D printing is a process by which 3-dimensional objects can be fabricated in a layer by layer building process [7]. Fused Deposition Modelling (FDM) systems operate by the use of a thermo formable plastic filaments which are progressively fed into a heated nozzle and the resulting material is extruded outwards to form the respective layers of a printed object. Essentially, the filament that is used in the printers are identical to the filaments produced during the extrusion phase of the classical industrial recycling process. It is therefore believed that filament generation for FDM based 3D printing may provide a viable solution to manufacturing waste recyclable plastics from used products and packaging otherwise destined for landfill, and is an emerging area of research interest by many groups worldwide [3, 8, 9].

In this study we aim to investigate the types of plastics which a typically found in commonly found recyclable plastic waste, methodologies for their granulation before finally reconstituting this into filaments for use in a typical FDM 3D printing system. In doing so we aim to implement a philosophy of carbon footprint minimisation, such that our solutions could be implemented with minimal environmental impact. We investigate the parameters relating to control of the filament production and thickness using a variety of different plastic types, which include HDPE and composites of ABS with HDPE. Following filament generation, parameters were investigated to optimise the print parameters to produce a test demonstration model to examine print resolution. We also investigated the energy expenditure of the 3D printer during the test print and speculate over the potential for renewable technologies to operate the device during production. Results suggest that the proposed supply chain can allow for highly repeatable filament generation and that solar electrical generation could provide a viable means of low carbon emission device power. Ultimately, the production of usable filaments can provide a viable means of consuming waste plastics and reducing the burden of increased landfill, whilst potentially realising low to high value products.

2 Methodology

2.1 Plastic Granulation

Keeping with the low carbon footprint approach of this study, waste plastics were obtained from waste milk cartons (HDPE) and failed/waste 3D prints from teaching classes within the School of Engineering at Deakin University. For the purposes of testing plastic was granulated using a combination of direct cutting with scissors/wire cutters and a paper shredding machine. Pieces were then separated by size using sieves with a mesh size of approximately 5mm and 2.4mm respectively.

2.2 Filament generation

The granulated plastic products were processed through a filament production device intended for the home consumer market (Nostek Pro, Nostek, UK). The device operates using a screw-drive which feeds the granulated material into a heating zone, where the plastic liquefies and is then extruded through a brass nozzle to form the printer filament. As the speed of the drive screw is fixed on the device, the resulting filament diameter can be controlled by consideration of the granulation size, which in turn controls the plastic feed rate, and the temperature of the extruded plastic material. In this study, owing to the chaotic nature of the granulation process and the variance in the resulting granule size, only the temperature of the extruder was varied to examine to examine the influence on filament thickness. Ideally, for the FDM printer employed in this study (1.75 filament feed) a filament of approximately 1.7–1.8mm would be ideal for use in the system. Filament was generated using either pure HDPE or using a combination of 90% ABS with 10% HDPE by weight. Blends were created by forming a 100g master feedstock of each polymer combination, mixing thoroughly and then feeding the resulting feedstock into the extruder.

2.3 3D printer and power consumption measurement

In this study a FlashForge Dreamer system was used as the principal FDM printer, which operates using 1.75mm filaments, and is open source allowing for complete control of the operational parameters during printing. The printer is optimised for use with ABS and PLA plastic, commonly used commercial printing materials, and so would be amenable to examination of ABS composite filaments. To determine the power consumption during a typical printing cycle a Power Q4 Plus power meter (Metrel, Slovenia) was employed. This device could be placed to interface directly with the power lead for the 3D printer such that the absolute current and voltage measurements during actual use could be measured, and from that the real-time power consumption determined.

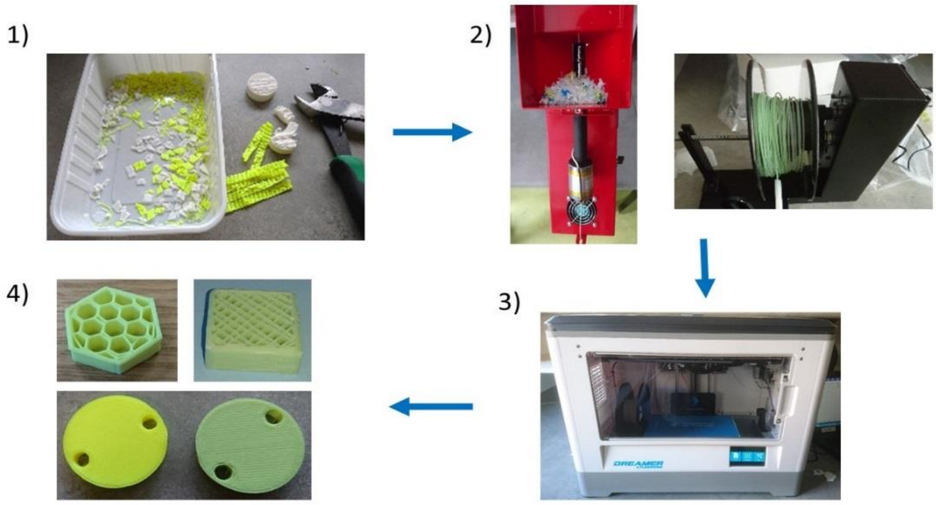

Figure 1: An overview of the proposed manufacturing process for recycled polymers, comprising 1) Granulation, 2) filament extrusion and spooling, 3) FDM 3D printing and 4) Printed final structures.

To standardise the printing process during power measurements, and also to compare the efficacy of the extruded filament against commercial filament, a generic cube design was implemented (12×12×12mm). For power measurements, three repeat runs were performed to examine the average power consumption. To compare the printability of the produced filaments, the cube model was printed in triplicate and compared against the resulting print using commercial ABS filament. Additionally, to prove the viability of the material for printing robust models, we additionally printed a simple screw and nut system. The system is designed to be dynamic, in so far as the nut will be able to travel down a screw thread on the bolt.

3 Results

3.1 Granulation

Several methods of low-cost granulation were examined, comprising from the use of scissors, hardened wire cutters and a commercial paper shredder, which was reclaimed waste in the Deakin Engineering offices. We found all such processes suitable for granulation of both waste ABS prints and the HDPE milk cartons, with each method providing advantages in a given scenario. For instance, scissors were useful in cutting down the main sides of the bottles into sheets, before feeding the resulting sheets into the paper shredder. In order to obtain granules of the HDPE, the milk cartons had to be reclaimed and processed by the shredder a minimum of five time to produce a feedstock suitable for the extruder, producing a granule size ranging from 2–5mm^3.

It was found that due to the irregular shape and hardness of the ABS miss-prints that the paper shredder was less suitable for granulation of these products and a manual

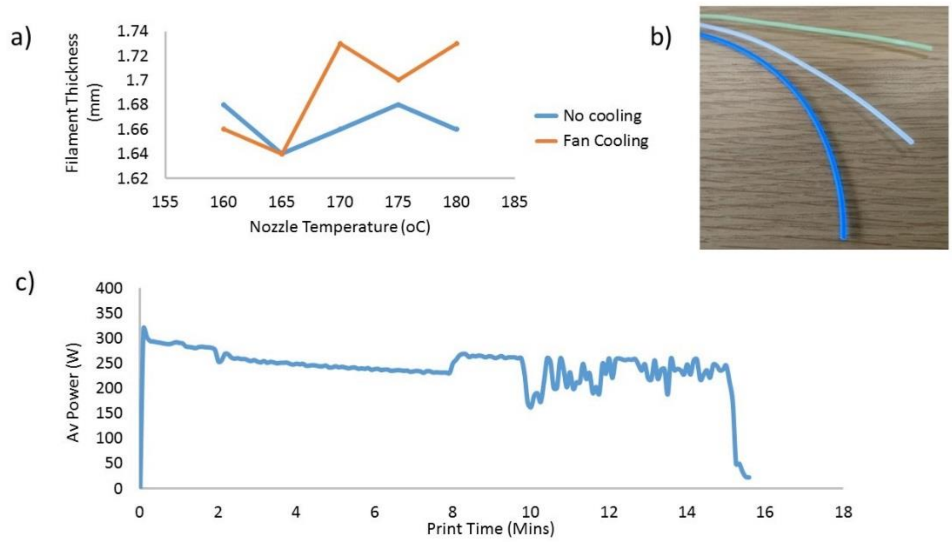

Figure 2: a) A graph illustrating the change in extruded filament thickness of 90% ABS and 10% HDPE, for varying extrusion temperature and the use of fan cooling. b) Filament comparisons comprising ABS/HDPE composite filament (green), HDPE filament (translucent) and commercial ABS (blue). C) A graph of the real-time average power usage of the Flashforge printer during a typical printing cycle.

approach with wire cutters was appropriate. Using this approach granule sizes of between 3-7mm in diameter and 2-3mm in thickness could be repeatable produced. Figure 1 shows a picture of the resulting polymer granulated products used in this study. Typically in a commercial filament generation system, pelletised product would be used. We measured 20 commercially available pellets of ABS and assuming a uniform spherical shape, was found to have an average diameter of 4.23mm, across a range between 3-6mm. This compared favourably to the granule size obtained in this study, implying we should be able to process the material with minimal issues relating to the size of the feedstock.

3.2 Filaments

Once the Feedstock had been produced the granulated products were fed into the extruder for processing. As a guide an initial temperature of 30°C above the melting temperature of the material was used to establish a baseline parameter. Based on the flow properties of the polymer out of the extruder head the temperature was either raised should flow be minimal, or decreased, should the materials exhibit signs of degradation (burning). The temperature was adjusted in 10°C increments until a temperature produced filament within or close to the desired 1.7–1.8mm diameter range. At this point the temperature was adjusted in 5°C increments until a desired optimal temperature parameter was established (Figure 2a).

The Nostek system employed in this study is designed with a fixed rotational speed of the feedstock drive screw that was estimated to be approximately 1–2 rotations

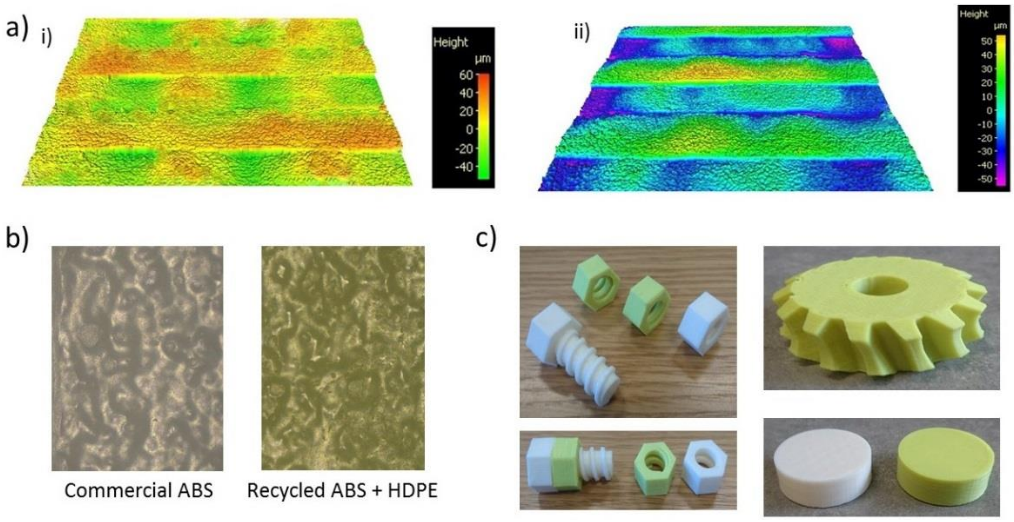

Figure 3: a) Surface topography results for a printed flat region containing several polymer tracks using i) recycled ABS/HDPE composite and ii) commercial ABS, b) Microscope image (20x zoom) of a printed track using commercial ABS and recycled ABS/HDPE, and c) various examples of 3D printed models using commercial ABS (white) and recycled ABS/HDPE (green) comprising nuts, a bolt, a cog and cylinders.

of the screw per second. As the speed is fixed, the rate of material delivery is entirely controlled by the granule size of the processed material. Given the relatively wide range to the size of the granulated material, and the enclosure nature of the extruder, the average feed volume was not determined.

It was found for the ABS/HDPE blend, the ideal extrusion temperature was 170°C to produce a filament with an average thickness of 1.74 ± 0.1mm. The HDPE filament proved problematic to obtain the desired thickness and we were able to produce a filament of 1.68 ± 0.15mm for an extrusion temperature of 205°C.

3.3 3D printing

Once the desired filament had been created, it was loaded into the 3D printer using the standard loading procedure. The systems employed are optimised for use of 1.75mm filament, both with respect to the loading guide hole and the mechanism for feeding the filament, therefore thicknesses of the filament was required to be ideally within the 1.7–1.8mm threshold to ensure a continuous feed, and consistent print. Attempts were made to load filaments of a thickness <1.65mm but it was found the gears of the filament feed mechanism would slip over the filament not allowing to be fed into the print head. The consequence of this was that the tolerances for filament generation must be strictly adhered to such that a produced filament does not fail to be loaded during a typical print, leading to part fabrication failure.

The loaded recycled polymer filaments were then used to print the cube design to assess the printability of the material relative to commercial grade ABS. While printing was occurring, we set up the power meter to record the live voltage and current consumption by the printer during a print cycle. A live graph of the power usage can be seen in figure 2c), where it can be seen that the peak power usage is approximately 320W and integrating over the complete print cycle, the average consumption was determined to be 63W/hrs. Speculating, the majority of the power consumption was during the initial and maintained heating of the printer bed (230×150mm), and should a printer with a smaller print bed, or if printing was performed with lower or no bed heating, further reductions in power could be realised. Based on our findings, we believe that our system could easily be powered using a solar panel and battery system, where typically powers of 90W can be easily realised from single system photovoltaics (Boulder 90, Goal Zero, Australia) and power storage capacity of >300W at 33Ah, can be realised from battery packs (Yeti 400, Goal Zero, Australia).

With respect to printing, we found that the filaments, despite comprising 90% ABS, required slight adjustment of the printing parameters relative to commercial ABS parameters, to produce repeatable prints. It was found that increasing the extrusion temperature from 230°C to 235–240°C produced much more consistent prints. This change in the printing temperature may imply some form of degradation of the ABS following a complete print, re-extrusion into filament and re-print cycle. Typically when a material is recycled commercially, some degree of virgin material will be used prior to processing. In this instance we have exclusively used recycled materials, which would have implications upon the ability to continuously form quality filament from the recycled ABS. We hope in future work to investigate these elements of material fatigue from using only recycled and combination of virgin and recycled material. Figure 3a and 3b show various microscope images of the printed ABS/HDPE composite and commercial grade ABS filament, where it can be seen there is minimal difference in the surface roughness and print track resolution. Figure 3c) shows a comparison of parts printed using commercial ABS filament against the recycled filament, where it can be seen that there is some drop in print layer consistency, but overall reasonably well defined prints were achievable in both instances.

4 Conclusions

In this study we have demonstrated a low-cost and efficient system with the ability to take waste plastics, granulate these down into a feedstock with which to form into 3D printer filament, and then to use this filament to print parts of a similar quality to commercial polymer filaments. We believe such a system to be an efficient means of converting waste polymers into usable using FDM based manufacturing processes and could be instrumental in reducing waste output from the use of this popular form of 3D printing technology. Additionally, such a manufacturing process presents several interesting commercial opportunities in the conversion of waste into low to high value products, in addition to reducing out ecological footprint. The power output from the 3D printer examined demonstrated that such technology could feasibly be operated using renewable/sustainable, off-grid sources of power generation. This opens several interesting possibilities in the use of this technology in low resource environments and remote communities.

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