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On-Campus Recycled Plastic Use in Student Projects

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ABSTRACT

CONTEXT

In university makerspaces, 3D printing and other plastics processing equipment, such as injection moulding, are used to create three-dimensional components in student fabrication projects. Such projects typically use filament or stock purchased as virgin plastic, which becomes direct-to-landfill plastic waste at the end of each term. Recycled plastic has been shown capable of recycling into 3D printing filament and pellets, albeit with possibly reduced dimensional control and material property degradation. However, since students and users have not been exposed to recycled stock, they lack awareness of recycled plastics' capability, preventing them from using recycled plastic.

GOAL

This work aims to provide students with direct experience in processing their own recycled plastic waste into engineered plastic stock, particularly filament for 3D printing and plastic pellets for injection moulding parts. The intent was to increase awareness of the reality versus preconceived perceptions of quality issues with recycled plastic stock and the means to design around them.

APPROACH

In the subject "MCEN90054 Design and Manufacturing Practice", fourth-year engineering students design parts for 3D printing, injection moulding and other processes. We introduced the students to a new recycling line enabling them to convert PLA plastic waste (previously printed and discarded parts), through shredding and extrusion, into recycled filament for use in the 3D printed parts they designed and printed for their project. We further introduced the students to several other recycled polymer stocks, including post-consumer recycled LDPE pellets for injection moulding. The students moulded a new part using recycled LDPE and used the part in the project. We conducted surveys among students before and after the project exercises to determine any change in perceptions on the suitability of using recycled plastics in engineered parts.

OUTCOMES

Before the project exercises, more than 60% of students did not think recycled LDPE could be used for such engineering parts, and they were generally unaware of the capability of recycled LDPE. After moulding and using the recycled part, the change of perception was dramatic, with roughly 90% of students agreeing that a part moulded from recycled LDPE was sufficient in performance and quality. Similarly, students were foreign to the strength limitations of recycled versus virgin PLA for 3D printing filament, where the recycled filament was sufficient for parts over 3mm thick. Again we saw students switch their perceptions to finding recycled PLA acceptable, even with the occasional difficulties due to worse filament diameter control of recycled filament versus new.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

While society needs engineers to create applications for the overabundant recycled plastic waste, engineering students are generally unaware of the capabilities and limitations of recycled plastic stocks versus new virgin plastic. Introducing students to the plastic recycling process and equipment through the hands-on experience of making their own plastic stock from waste for their own makerspace use has effectively raised awareness of the benefits of recycled plastic stock. We find widespread student enthusiasm for using recycled plastics and appreciation for learning the capabilities and limitations.

KEYWORDS

Plastic recycling, Campus sustainability, Educational institution

Introduction

Engineering education has been trending toward more practical hands-on project-based learning to provide breadth and depth (Oskam, 2009; Gupta & Bailey, 2014; Abubaker et al., 2020; Lamere et al., 2021).

This has driven the development of active learning maker spaces for students to execute design and build projects. Within university makerspaces, plastics play a central role, including 3D printers and other possible equipment, such as injection moulding or vacuum forming tools. These are used to create three-dimensional plastic parts used in student fabrication projects. Such projects typically use filament or stock purchased as commercial virgin plastic stock, which becomes direct-to-landfill plastic waste at the end of each term. Such plastic waste is now becoming significant, with 3D printer filament use growing at 25% per annum (Halaye, 2022). The trend follows the estimations made around the global plastics waste crisis, where global virgin plastics production is predicted to triple by 2050 (Geyer et al., 2017), and the annual plastics consumption in Australia is predicted to increase by over 150% from 2020 to 2050 (O'Farrell et al., 2022).

As such, the approaching 2030 Sustainable Development Goals (SDGs) require radical increases in circular and sustainable alternatives. However, utilisation of recycled stock for plastics is often deemed unrealistic, despite the local demand, due to the low price of virgin stock. This suggests the need of economic viability for recycling processes via implementing a closed-loop approach within the local infrastructure. At the University of Melbourne, the On-Campus Recycling Laboratory has been established in line with the Mechanical Engineering faculty's goal to reach a *zero-to-landfill fully circular makerspace*, where students are inherently provided recycled material stocks for projects. Engineers must have skills in specifying and using recycled materials, particularly plastics (Beagon et al., 2023). Many school curricula, however, currently lack training in sustainable development (Tabas et al., 2019). Since students and users have not been exposed to recycled plastic stock, they lack the awareness of recycled plastics' capability, preventing them from understanding how to use recycled plastic in future engineering work. Many questions arise, including:

- How well does recycled plastic perform compared to commercial grade?
- How many times can plastic be recycled before performance degrades?
- What material properties degrade with each recycling iteration? How?
- Are adjustments required for the printer or moulding machine settings when using recycled plastic?

In this paper, we show here our experiences in fourth-year mechanical engineering subjects when providing students with recycled poly lactic acid (PLA) plastic filament for their use in 3D printing parts for their projects, and their experience with using post-consumer soft plastic low density polyethylene (LPDE) in an injection moulded part project. The intent was to increase awareness of the reality versus preconceived perceptions of quality issues with recycled plastic stock and the means to design around them.

Related Works

An obvious opportunity is for student makerspaces to use recycled plastic stocks, such as recycled filament. Peeters et al. (2019) interviewed makerspace managers and found wide interest in using recycled filament if it was readily accessible and equal in formability (e.g. doesn't jam the printer or produce low quality prints). Recent works have shown streamlines of conventional plastic wastes capable of being recycled and utilised for 3D printing filament and pellets, albeit with possibly reduced dimensional control and material property degradation. Sanchez et al. (2017) found that the mechanical properties of PLA significantly deteriorate after 5 iterations of mechanical recycling. Devra et al. (2022) successfully converted the post-consumer waste polyethylene into print filament but found dimensional control difficult. Other papers also report on superior filament production from additives and composites (Gomes et al., 2022).

Background

The Engineering Subjects

A typical engineering design and manufacturing subject is the “Design and Manufacturing Practice” for Mechanical Engineering students at the University of Melbourne. The project-based subject aims to equip students with both a systematic approach to undertake abstract and concrete design tasks, and also to consider the broader manufacturing and supply chain and select suitable manufacturing processes to realise their designs.

The project involves the assembly of a Prusa 3D printer kit (Prusa 2019). However, the students must also redesign parts for fabrication by alternative processes and improve the ease of assembly. They then fabricate their part designs, assemble the printer kit with their own revised and improved part designs, and observe the efficacy of their new printer redesign.

Students are tasked with assessing the original design for parts and assemblies that are most difficult to fabricate and assemble, and then to simplify the manufacturability using pre-defined processes. Further, students are tasked with improving the design on disassembly and recyclability. Students fabricate and install their designed parts and evaluate the outcomes. The approach offers students an in-depth exploration of three distinct manufacturing processes: CNC machining, injection moulding, and sheet metal forming. Each possesses distinctive attributes that make them well-suited for specific applications. By the end of the subject, students will have an enhanced understanding of the nuances and capabilities associated with each.

In addition to improving fabrication and assembly procedures, the project presents an opportunity to address sustainability. The Prusa comes with 3D printed parts made with PLA filament, a material that is not widely used or recycled. By incorporating materials such as soft plastics that are more widely recycled, the components can become more sustainable. However, students and engineers are not widely familiar with using LDPE or recycled plastics for such parts.

Further, to recycle parts upon end-of-life, the students must also consider improvements in the disassembly process. Many parts are not easily removed without damage or require tedious processes. Students are encouraged to employ principles that facilitate non-destructive and simplified disassembly. By incorporating features such as modularity, tabs with fewer fasteners, and clear top-down separation points, components can be disassembled efficiently, enabling easier maintenance, repair, and replacement.

While these efforts were enlightening, the subject did not utilise any recycled plastic stocks in the new part fabrication efforts. Thus, commencing in 2023, the teaching team incorporated two significant changes. First, the injection moulded parts were designed to be made from soft recycled LDPE plastic. Secondly, students were provided with recycled PLA filament to be used with their completed redesigned printers. These modifications are intended to equip students with practical knowledge and hands-on experience in utilising recycled materials in newly engineered devices and provide skills for accomplishing the broader objectives of sustainable manufacturing practices and environmental consciousness.

The Makerspace

The Telstra Creator Space (TCS) is the makerspace for engineering students on the University of Melbourne campus. TCS has a 3D printer farm with multiple printers operating 24-7 to support student projects with their design concepts and 3D printing experiments.

When printing a part, along with the successfully printed piece is often waste plastic from the fabrication process, including supports, brims and skirts. Further, often students will not print a successfully functioning part the first time, and they will print multiple iterations. This generates PLA plastic waste in the makerspace. Additionally, once all projects are completed and demonstrated at the end of the term, all 3D printed parts become waste and previously ended up in the landfill.

The Plastics Recycling Laboratory

To give the waste plastic another life, the authors instantiated a new facility on campus to take plastic waste and process it into recycled plastics stocks. Collection bins were placed to collect PLA waste parts for the new on-campus recycling facility. Across the university, waste bins are piloted for collecting Polylactic Acid (PLA) from 3D printing activities and Polyethylene (PE) from food packages and chemical laboratories.

The recycling laboratory facility consists of a set of Filabot plastics recycling equipment. This includes a set of two-stage shredding and granulating machines, an EX6 extruder, as well as cooling and spooling equipment. The entire line is shown in Figure 1. The equipment is capable of recycling PLA or other polymers, including soft plastic LDPE.

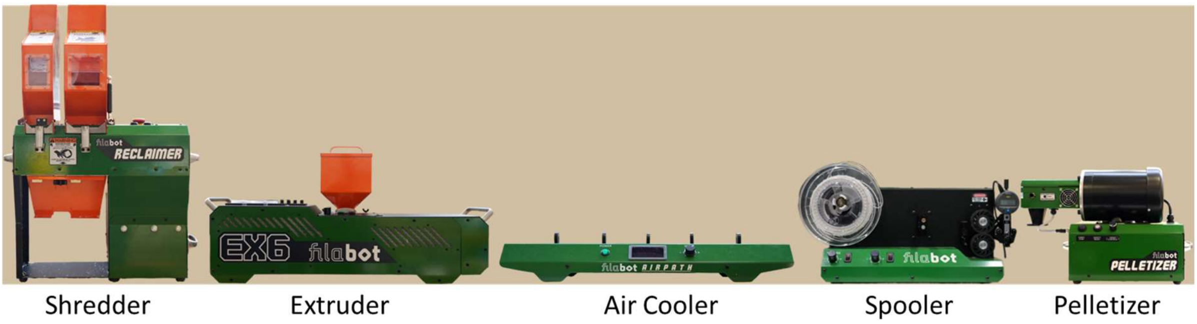

Figure 1: Plastics Recycling Equipment

From the makerspace waste collection bins, the parts are sorted by colour and size. Large parts are sawcut to roughly 3cm chunks. These are then fed into the shredder machine (Figure 1) that takes small plastic parts and shreds them to roughly 5mm sized shreds. The granulator machine then takes these shreds and reduces them to roughly 1mm sized shredded granules. The shredded granules can then be fed into the extruder machine, which melts the shredded granules and extrudes into, for example, a 1.7mm diameter filament which is cooled and spooled, ready for use in 3D printing. The extruded filament could also be cut into pellets using the pelletizer machine to create pellets for injection moulding and other processes.

The recycling laboratory facility has been used to successfully create recycled PLA filament over multiple iterations of recycling. Beyond PLA, post-consumer food packaging sourced soft plastic LDPE has also been recycled into LDPE filament for use in 3D printing with LDPE. Also, LDPE shreds and pellets have been used in injection moulding and novel pellet printing (Extrudinaire, 2023).

Implementation

Three separate assignments in recycling were assigned to the student.

1. Make recycled PLA filament from recycled waste PLA parts
2. Use recycled LDPE to injection mould a part
3. Use their self-made recycled PLA filament in printing PLA parts

Making PLA Filament from Recycled PLA Waste

In this exercise, students ran the recycling extruder machine to create their own spool of recycled PLA filament for their own use. The waste plastics were collected from the bins at the makerspace. Before processing, the waste plastics were sorted manually by materials (PLA and PE) and colours. The sorted plastics were then fed into the first stage shredder, breaking down large the plastics into smaller pieces and from there, the shreds are fed into the Granulator that breaks the pieces down to the final extrudable size.

The students fed the granules into the extruder machine to make a melted plastic filament extrusion. The extruder has a rotary screw speed control and four temperature control zones. This allows for a polymer-specific speed and temperature zone profile control which the students were provided for PLA. The students fed the extruder and melted and extruded a 1.7mm filament. They also set the forced air convection machine for proper freezing and set the spooler's adjustable wheel speeds for properly tensioning the filament as it was cooled and wound.

Injection Moulding New Parts with Recycled LDPE Shreds

Figure 2 shows the injection moulder that students used in their injection moulded part exercise, where the parts were made from recycled LDPE plastic. This machine is intentionally highly simplified for student learning, with a single zone temperature controller and manual pressure control. The machine is a small desktop moulder capable of up to 16cc volume of molten plastic.

Any different part moulded requires a different mould. Here, the student project was the Prusa 3D Printer kit, and a particular part was chosen for fabrication by moulding. The moulded part chosen was the filament sensor cover, as it was a simple shape and required a simple 2-part mould.

The students set up the moulding machine including mould preparation and temperature settings, and then poured in recycled LDPE shredded granules. When ready, the injection process is a manual operation of the students pulling the handle down and holding it for a few seconds to maintain packing pressure. Students then removed the parts from the mould and carried out the manual post-processing including gate and flash removal.

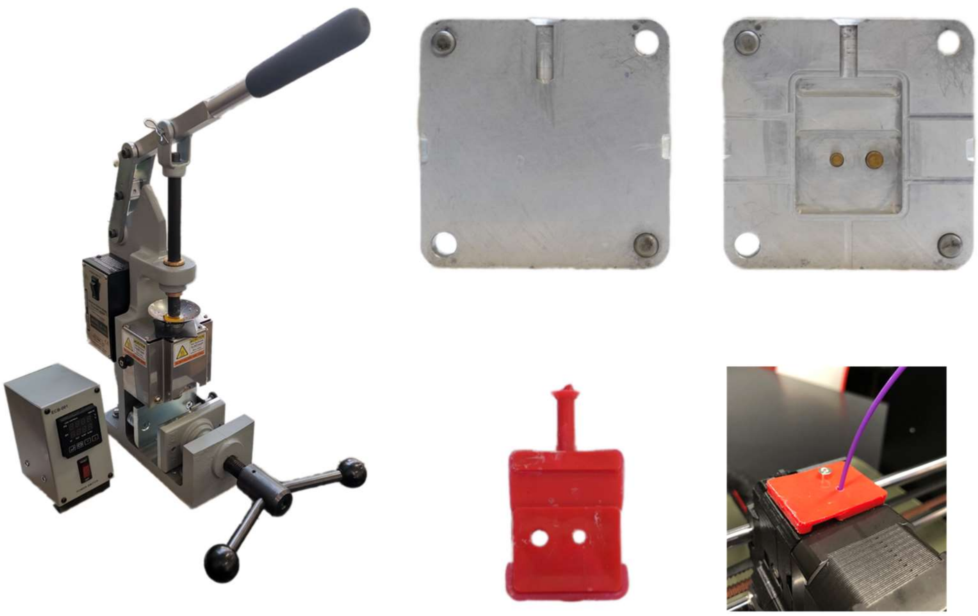

Figure 2: Injection moulder, mould, and LDPE moulded parts

3D Printing Objects Using Recycled PLA Filament

Near the end of the term, the student teams have successfully constructed their Prusa printer, assembled with student-redesigned moulded, cast, sheet metal and CNC parts. These student-designed and fabricated parts replaced several of the original Prusa 3D-printed parts in the original printer kit. Therefore, the student printers are almost the same as the original Prusa printer, but with student designed parts redesigned to be easily made with non-3D-printing processes.

An assignment is to prove their printer works by making arbitrary 3D printed items. Here, the students are given both commercial PLA filament, as well as the recycled PLA they made earlier in the term. This allows them to observe and understand any differences.

Student Experiences

The result of the filament making exercise was the students were given experience in making recycled plastic filament from waste plastic. The experience showed that engineering plastic stocks could be made from recycled waste, whether filament, pellets, extrusions or even sheets, given the right equipment. A typical resulting filament spool is shown in Figure 3.

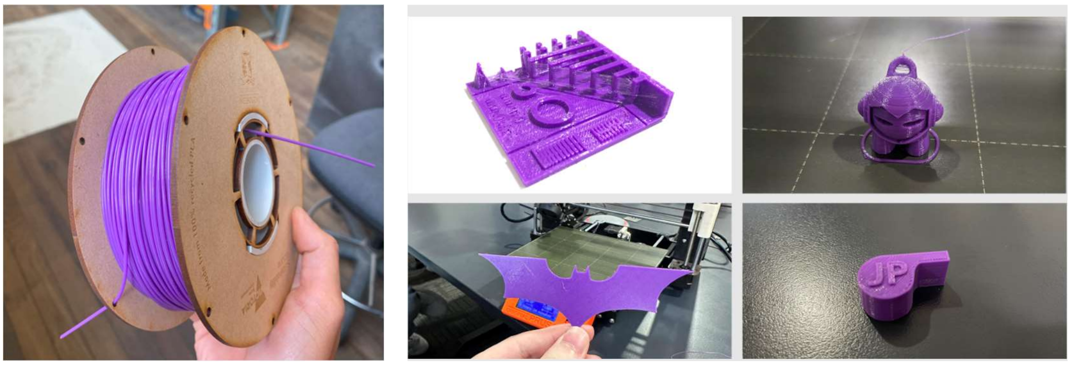

Figure 3: Filament and example printed parts made from recycled plastic

Making recycled filament can lead to filament defects, primarily on foreign particle matter and filament diameter control. Foreign debris was not an issue with makerspace recycled PLA, and there are usually few surface contaminants on the waste parts. Rather, the difficulty was in the process control of the melt extrusion to ensure low variability diameter. Here, the exiting temperature, cooling rate and tension of the filament are all critical to ensure a uniform filament diameter. Using the rapid classroom exercise process, the students made filament with ten times larger diameter variability than commercial grade, which can lead to issues when printing (discussed below).

The second assignment was on using post-consumer waste plastic in engineered functional parts made through injection moulding. The result here was that students were given experience in using recycled post-consumer soft plastics for an engineered part, as shown in Figure 2. Again, the exercise showed parts can be readily moulded from recycled plastic granule shreds, and the major difficulty is in ensuring the part is properly moulded – no underfills or voids in the part. These are again managed by the process controls, to ensure proper temperature and pressure profiles during the pack and fill phases of the moulding process. The students directly learned these aspects of moulding.

Lastly, the students also printed objects with both commercial and recycled PLA for their printer project final demonstrations, as shown in Figure 3. The main difference with the recycled PLA made by the student was the filament quality and diameter control. The extrusion process controls require adjustment into a steady state to extrude a proper consistent filament diameter. The exiting molten filament is under adjustable molten plastic temperature, air cooling rate and filament tension, which leads to diameter variability. If the diameter becomes too large at positions down the filament, the filament can jam during printing. Students experienced this directly. The more rapid setup and adjustment applied on the filament fabrication assignment led to recycled filament with more diameter variability than found in commercial PLA filament stocks. If the filament diameter remained within the upper limit of the printer, however, there was little / no difference in using the recycled PLA filament. The students directly learned these aspects of filament extrusion processing.

Student Survey

Within this context, we studied the students' perceptions of sustainability and circularity, specifically about the engineering issues with using waste plastic and what students can do to mitigate it in their engineering future. To examine university students' perceptions, we conducted surveys along with the exercises, as shown in Table 1. The subject had 20 project teams, and the voluntary response rate for the moulding question was 37 students, and for the printing questions was 16 teams.

As shown in Table 1, prior to the exercise and activity with recycled stocks, approximately 65% of students hadn't considered recycled LDPE suitable for such an engineering plastic part. Their perspective significantly shifted after the activity, with 86.5% of students thinking that LDPE was sufficient in performance for the injection moulded part ($p<0.0001$ difference, sample size of 37).

Table 1: Student Responses

	Yes (%)	No (%)
Moulding with Recycled LDPE		
Before this exercise, would you have considered recycled LDPE for such an engineered plastic part?	35.1	64.9
Do you think LDPE is sufficient in performance for this part?	86.5	13.5
Printing with Recycled PLA		
Was the recycled filament feasible for printing with your printer?	81.3	18.7
Was the resulting printed part using recycled filament suitable?	93.8	6.2
Was the recycled filament equivalent to new filament?	37.5	62.5

With respect to making and using recycled PLA filament, 81.3% found the recycled filament feasible for printing engineered parts. This was lower than expected and was due to the laboratory filament making equipment having insufficient diameter control and generating filament with occasional thick filament sections, which would jam during printing and require attention. Yet 93.8% found their parts, when successfully printed, were sufficient for their needs using recycled PLA. This is despite the recognition that makerspace recycled PLA was not equivalent to commercial grade PLA, primarily due to differences in diameter control. The combination of these two questions showed the students recognised the quality control limitations of the makerspace filament making equipment but could nonetheless get the filament to work for their needs, and that recycled PLA was equivalent to commercial.

Discussion

In comparison to the previous literature results, our work confirms and highlights many of the earlier studies. Beagon et al. (2023), in their study of engineering student competencies of Sustain Development Goals, showed a lack of sustainable development awareness. Lamerea et al. (2021) built on this by suggesting a possible integration of education for sustainable development (ESD) into the Undergraduate Engineering Curriculum. Abubaker et al. (2020) also found in their student surveys of engineering student team projects that over 50% felt there would be drawbacks to implementing sustainability concerns into their designs. All of these studies are similar to our pre-study result of 64% of students would not have considered using recycled plastic for their parts before this exercise.

Gupta and Bailey (2015), Lamerea et al. (2021), Beagon et al. (2023) all made recommendations for the curricula to impact this lack of awareness problem on competencies to enhance in general, generally through project based learning. We here executed this for work with recycled plastic and offer evidence to support these previous claims on project based learning efficacy. We see this shift after their experience with recycled plastic, where it significantly reduced to under 20%. This gives hope that providing students with recycled materials for use in design can be successful at alleviating concerns of incorporating sustainability concerns into their design work.

Conclusion

We find introducing practical exercises of sustainable engineering relevant and actionable in the curriculum. We find it helpful to not only offer subjects dedicated to sustainability, but rather also to make sustainability intrinsic to current subjects. Learning offers are required on the differences between raw and recycled materials and any changes needed to make recycled materials function well. This includes characterisation of the engineering properties of recycled stocks, as well as assessment and improvement of designs on disassembly down to unique materials.

We found students to be highly engaged, appreciative and accepting of using recycled materials, even when their properties were less than raw stocks. Low quality recycled filament was often preferred by students for their typical printing use cases, for students to promote their own sustainability. The engineering challenge of making their designs and fabrication processes work with recycled materials provided an engaging experience.

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