The Application of 3D Printing with Recycled Plastics in the Healthcare Industry: The Ankle-Foot Orthoses Case Study

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Introduction

- Plastic waste negatively impacts the health of our planet. For example, 90% of seabirds have plastic waste in their bodies[3].
- Many healthcare devices, such as custom orthoses, are necessary for both accessibility and cosmetics reasons. However, they can cost up to six-hundred dollars[1].
- Repairs and replacements add to the base cost of the orthoses and can make living with an orthotic device very expensive.
- Three-dimensional (3D) printing[7] could be part of the solution for both environmental and orthotic issues.
- 3D printers can use recycled thermoplastics[5] as filament, which is the material 3D printers utilize to manufacture, in place of virgin plastic.
- Plastics are composed of polymers and additives. The molecular bonds that occur within a specific type of plastic determines if recycling is feasible for that material.
- Thermoplastics have weak Van der Waal forces acting between the molecules of their polymer chains, which allow for them to be melted and reformed (recycled).
- Examples of thermoplastics include high-density polyethylene (HDPE), polyethylene terephthalate (PET), and polypropylene (PP).

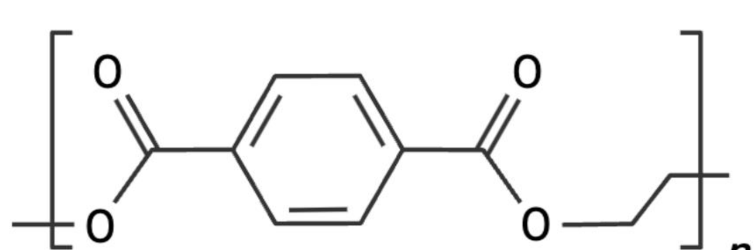

Fig. 1

PET (Fig. 1) is an example of a thermoplastic. PET is commonly used in plastic bottles. It is capable of being re-melted and re-formed into a new bottle or formed into a different plastic object. Additionally, PET is the most wasted type of plastic.

- Ankle-foot orthoses (AFOs)[2] are commonly prescribed to people after accidents, injuries, and strokes, as a rehabilitation method.
- Custom AFO's cost between 200 and 600 dollars. Additionally, each repair can cost up to 100 dollars. They also should be replaced, at least, every five years[9].

Objectives

1. Determine the feasibility of 3D printing applications involved in healthcare in order to construct custom orthoses more efficiently, by being faster and cheaper.
2. Determine the feasibility of manufacturing AFO's out of recycled plastic, by researching the mechanical properties and recycling process of plastic.
3. Determine restrictions, regulations, and limitations on utilizing recycled plastic in the healthcare industry.

Motivations

- Apply circular economy strategies to reduce and repurpose the amount of plastic waste in the environment.
- Reduce the cost and wait time for custom orthoses.
- Offer workflow guidelines for healthcare institutions in order to implement recycling strategies for plastic waste and create added-value products

Methodology

- Analyzed state-of-the-art to meet the following objectives.
  - Understanding 3D printing
  - Understanding recycled plastics
  - Understanding 3D printing and recycled plastic in the healthcare industry
- Reviewed academic articles such as, *An Overview on 3D Printing Technology: Technological, Materials, and Applications* by N. Shahrubudin, T.C. Lee, and R. Ramlan.[7]
- Summarized relevant information from the articles onto documents.
- Constructed a table comparing different forms of orthoses that could be a viable case study.
- Based on analysis table comparison, targeted the AFO as the potential product application .
- Read articles about AFO's and began analyzing the process of creating a recycled AFO beginning with plastic waste.
- Researched which type of recycled thermoplastic would be best suited towards an AFO
- Constructed a table to compare performance properties of virgin plastic versus recycled plastic, relative to what properties are vital for an AFO.
- Polyethylene Terephthalate (PET) plastic was deemed to be suitable based on the table.

Mechanical properties needed in a AFO	Mechanical properties of virgin PET	Mechanical properties of recycled PET
Flexibility:	Flexible to semi-rigid.	Retains high to semi-rigid flexibility.
Tensile strength: Must support weight	13.77MPa[6]	21.57MPa
Durability: Long lasting is desirable. High impact resistance and high fatigue resistance contribute to the durability	PET is shatterproof making it highly durable. It has a high impact resistance and a high fatigue resistance.	It's impact resistance and fatigue resistance is are both high. PET's mean lifespan is $2.8x10^5$ recycling cycles.[4]
Water/chemical resistance: Water resistance is important for sweat resistance. Chemical resistance ensures that the AFO isn't prone to deformity from chemicals	Shows resistance to moisture, solvents, and alcohols.[8]	Retains its resistance to moisture, solvents, and alcohols.

(Table 1) Compares the mechanical properties of virgin and recycled PET relative to the properties needed in an AFO.

- Analyzed articles focused on limitations, regulations, and restrictions that exist when using recycled plastic in the healthcare industry, as shown in the following table:

Restrictions/limitations/ regulations	Reason	Possible solution
Contamination Risk	Healthcare is very particular about materials used because of the risk of infection. Especially with recycled material, due to the lack of tracking on what the material has been prior.	Focus recycled materials on medical devices that do not enter the body, such as orthoses and prothesis. Also, decontaminate the material thoroughly using techniques such as bleach, UV, and gamma radiation.
Inconsistency	Recycled material is less consistent than virgin material; the properties could change in each batch.	Thorough testing after each recycling cycle.
Hesitant to try new things	Time wasted if it doesn't work.	Preform many trial runs to prove functionality.

(Table 2) Showcases the restrictions, regulations, and limitations involved with recycled plastic in healthcare. Additionally, it demonstrates the reasons and possible solutions.

Conclusion

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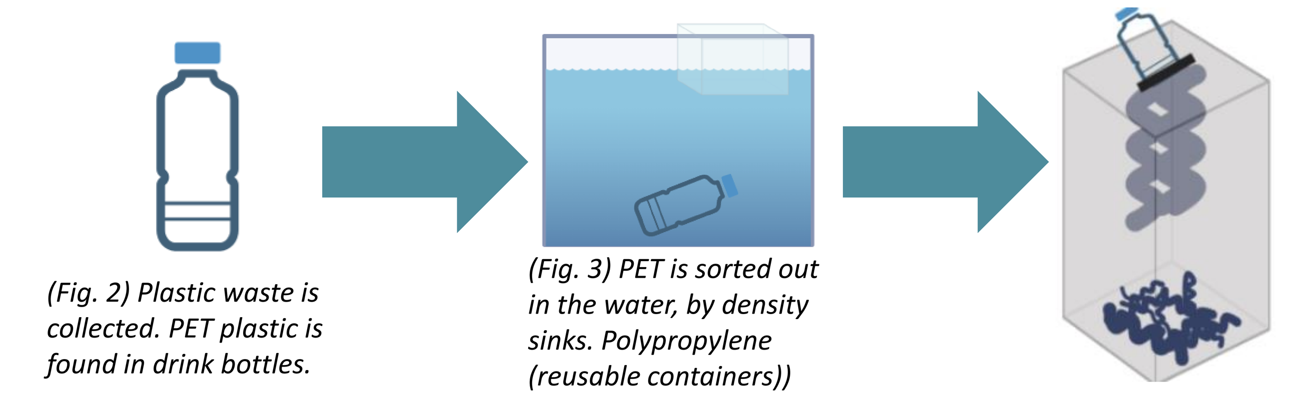
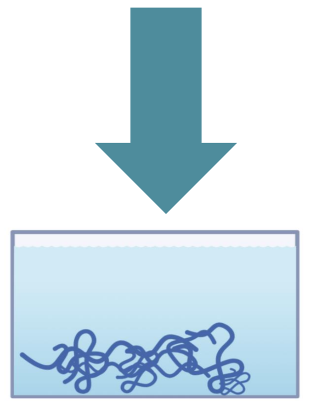


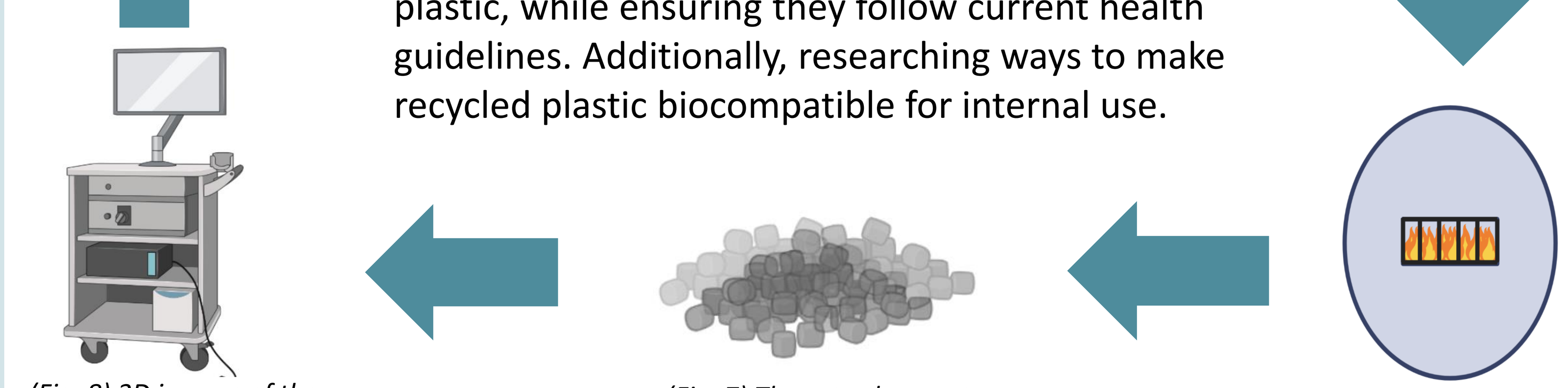
(Fig. 2) Plastic waste is collected. PET plastic is found in drink bottles.

(Fig. 3) PET is sorted out in the water, by density sinks. Polypropylene (reusable containers)) don't.

(Fig. 4) PET plastic is shredded.



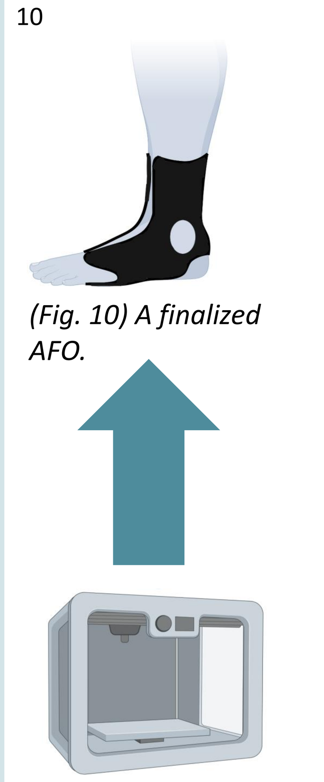
(Fig. 5) The PET is washed in cold water.



(Fig. 6) The shreds are melted and put through an extruder.

(Fig. 7) The extruder creates pellets, which can later be melted into filaments.

(Fig. 8) 3D images of the foot and ankle are taken via an imaging machine.



(Fig. 9) The recycled filament is used in fused filament fabrication.

(Fig. 10) A finalized AFO.

- Based on the mechanical properties of virgin PET versus recycled PET, an AFO is feasible.
- An AFO must be flexible but have a high enough tensile strength to support weight.
- An AFO should be water resistant, so that it is sweat resistant
- Recycled PET sufficiently meets these standards and with proper testing, would follow regulations.
- The next step would be using a modelling software and 3D printer to create the AFO.
- Further studies could include studying the viability of other 3D printed medical devices with recycled plastic, while ensuring they follow current health guidelines. Additionally, researching ways to make recycled plastic biocompatible for internal use.

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