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Life cycle assessment, biodegradability and sustainability of biopolymers in the textile Industry

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Abstract

The sustainability of biodegradable textiles was studied by evaluating the life cycle assessments and the biodegradation rate of various biopolymers. These two approaches allowed to determine all the aspects of the sustainability. The carbon footprint of a biodegradable garment is compared with a recycled polyethylene terephthalate (rPET), as the industry is heading towards recycling of textiles for more sustainability. The biodegradation rate of melt spun fibers is measured in a realistic environment for Switzerland weather conditions as opposed to the standards and certifications. It is investigated which measurement method is a reliable indicator of the biodegradation. The materials tested are polylactide (PLA), Poly(3-hydroxybutyrate-co-3-hydroxyhexanoate) (PHBH) and polybutylene adipate terephthalate (PBAT). Initial research showed that PLA and PBAT should not show significant biodegradation over the span of three month while PHBH is biodegradable in almost every environment.

Motivation

The textile industry is a major environmental concern. It's responsible for a lot of greenhouse gas emissions and creates a significant amount of waste. Most of the clothes we wear are thrown away after a short use, ending up in landfills. Currently, we only recycle about 1% of textiles because our recycling methods aren't advanced enough [1]. The number of synthetic fibers grows each year, 2021 around 64% of the globally produced fibers were synthetic [2]. Another problem is that when we wash clothes, they release microfibers that pollute the oceans and harm marine life. For the average consumer, the sustainability of a product is most often not intuitive. Especially, since the energy used to produce the product is not tangible. The life cycle assessment (LCA) should give insight into the sustainability of a rPET and a PLA as the base material of a T-shirt. Furthermore, the biodegradation rate of the biopolymers in fiber form is unknown.

Materials and Methods

Materials

The materials focused on in the project are all biopolymers. Biodegradation varies by environment and biopolymer type. The materials discussed are PLA, PHBH, and PBAT. PLA, from Bio Valore World SpA, is biobased and biodegradable, used in 3D printing and packaging. PHBH, supplied by Kaneka, is 100% biobased and used in various products. PBAT, from NaturePlast, is fossil-based, biodegradable, and used in packaging and agriculture (mulching films).

Melt spinning of fibers

The melt spinning plant used for creating multifilament yarn from materials like PLA, PHBH, and PBAT is manufactured by Fourné and is situated at KATZ in Aarau, Figure 2. The polymer is melted and pushed through a spinneret, which has multiple holes to shape the yarn. The multifilament yarn that was produced has 24 filaments and is not drawn or thermoset. The Figure 1 shows the yarns produced for the biodegradation experiment.

Fig. 1: The melt spun fibers wound up on bobbins.

Fig. 2: Melt spinning plant Fourné at KATZ, Aarau

Biodegradation experiment

The samples (melt spun fibers) were measured and placed in three different environments, Figure 3. The biodegradation rate was measured of samples in freshwater, in soil and on top of the soil. The timeframe of the experiment was three months, while the weight change was measured each month. The biodegradation was measured using gravimetric analysis as well as gel permeation chromatography (GPC) for the material PBAT.

Fig. 3: Biodegradation experiment, close up: in filtered freshwater from a natural pond (left), on soil from a backyard (middle) and the sample in the soil with an irrigation system (right).

References

[1] E. M. Foundation, *A new textiles economy: Redesigning fashion's future, 2017, 18-21.*
[2] T. Exchange. "Preferred fiber and materials market report." (2022), 8-12.

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Results

Life cycle assessment (LCA)

The carbon footprint of a PLA and a rPET T-shirt was compared. The T-shirt used for the calculation is a size small and has a weight of 150 g. Most T-shirts today are produced in Asia, more specifically the fiber production and processing in China and the fabric processing in India. Both countries use high carbon emitting energy sources such as coal and gas while Switzerland uses mostly hydro energy and nuclear power. Apart from the energy source the raw material influences the carbon footprint significantly. Focusing on the processes, the process of pretreatment has the biggest influence.

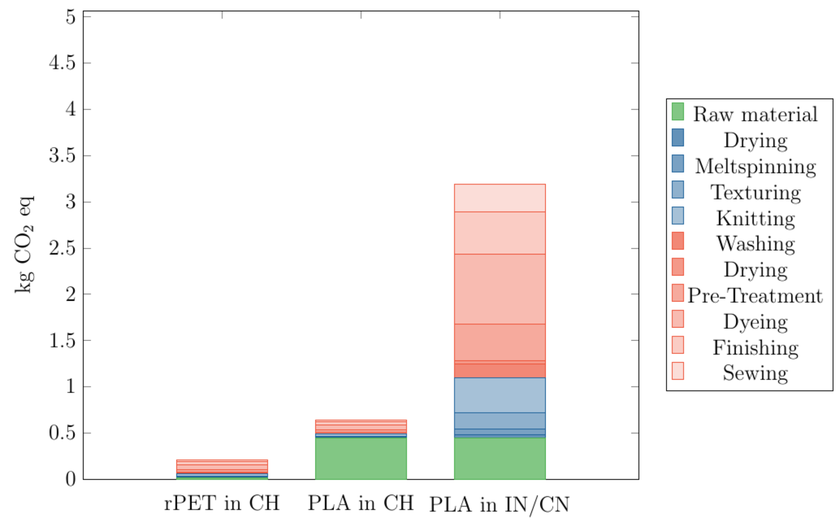

Fig. 4: Carbon footprint of one small T-shirt (150 g) made of recycled polyethylene therephthalate, polylactide fully produced in Switzerland. Additionally, the carbon footprint of a small T-shirt (150 g) in India and China.

Biodegradation

One approach to measure the biodegradation was the measurement of the weight. The material PHBH biodegrades in 2 months fully in the soil and approximately 4 months on the soil. The PLA fibers show biodegradation in the soil over the span of the experiment. Best case the PLA fibers will biodegrade within 1 year or worst case within 27 months. PBAT shows no biodegradation over the span of the project (3 months). The Figure 5 displays the measured change in weight over three months.

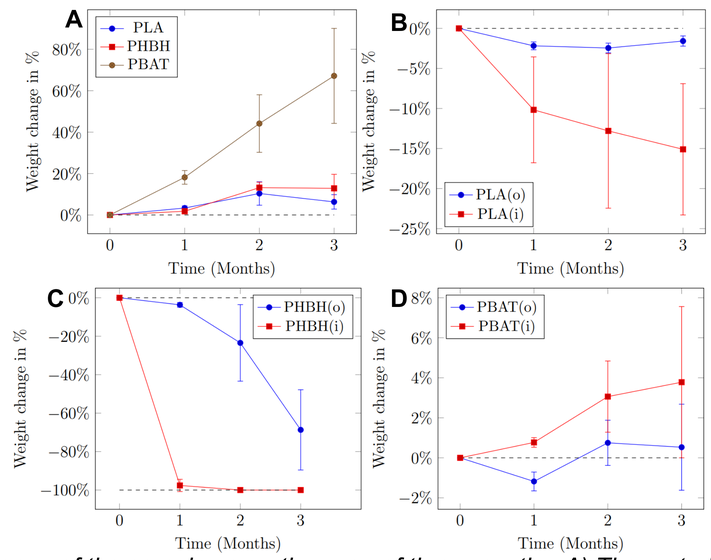

Fig. 5: Weight change of the samples over the span of three months. A) The material in the freshwater environment B) PHBH in (i) and on (o) soil, C) PLA in (i) and on (o) soil and D) PBAT in (i) and on (o) soil.

The GPC measurement of the molecular weights proved to be more precise than the gravimetric analysis. However, the fibers didn't fully dissolve. PBAT showed biodegradation over the span of the project in all environments. The most promising environment seems to be the freshwater environment which is displayed in Figure 6.

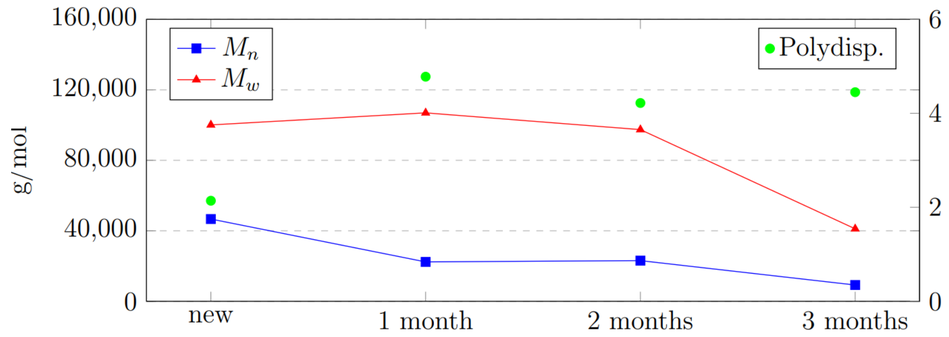

Fig. 6 Gel permeation chromatograph measurements of the PBAT fiber in a freshwater environment over the span of three months. With the sample new as the reference, it is the virgin material pre melt spun. The decrease in Mn and Mw shows a shortening of the molecular chains.

Conclusions and Outlook

The measurement of the weight to determine biodegradation is not reliable, especially not for short term experiments and not for all environments. The better indicator might be the gel permeation chromatography (GPC). The key factor for GPC is that the material needs to be fully dissolvable. However, no conversion factor from GPC to biodegradation rate was researched. PHBH showed good biodegradation. Although not suitable for clothing PHBH could be suitable to agriculture applications. The life cycle assessment (LCA) showed that a rPET T-shirt has a lower carbon footprint than a PLA one. However, the advantage of PLA lies within the biodegradability. A biodegradable polymer could bridge the gap until we have an efficient microfiber filtration and closed loop recycling.

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