Development of compostable composites reinforced with non-woven flax fibres: a study of mechanical properties and biodegradability

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Objectives:

Thanks to its specific mechanical properties, comparable to that of glass fibre, flax fibres are now used to manufacture composites in the automotive industry for interior parts (door panels/dashboard). However, polypropylene is the main thermoplastic used in these applications, which means there are recyclable materials but non-biodegradable. Because some biodegradable thermoplastics are now commercially available, making fully compostable materials using flax as a reinforcement is possible. This work is focussed on the compostability of three biocomposites using non-woven flax as reinforcement for PLA, PBS and PHA. The evolution of mass, mechanical properties and microstructure is investigated.

Materials and Methods

I) Composite manufacturing:

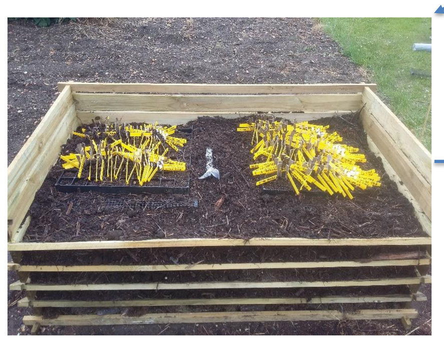
- **Three** biocomposites, made of **non-woven** flax fabrics and **biopolymer** are investigated ; polypropylene/flax is added as reference :
  - Polypropylene/flax as reference (Flax/PP)
  - Polylactic-acid/flax (Flax/PLA)
  - Polyhydroxyalkanoates/flax (Flax/PHA)
  - Polybutylene succinate/flax (Flax/PBS)
- **Virgin** polymers are investigated as reference (PP/PLA/PBS/PHA)
- **Film stacking** method at a fixed viscosity (500 Pa.s) is used, yielding a **volume fraction** of **30 ± 0.6 %** and a **porosity** of less than **2.5%.**

II) Compost set-up

- Compost is provided by the Cambridge Botanic Garden => **Garden waste compost**
- **Temperature** and **moisture** in the compost are **recorded**, as well as the outside **weather**

Garden wastes

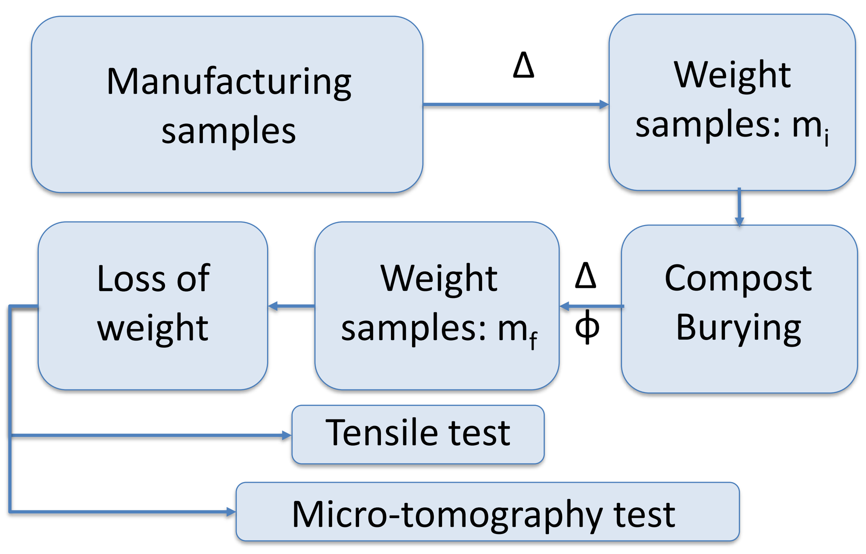
After 6 months, inoculum is ready



Bury samples and temperature recorder

Let Nature work for us

III) Investigation



Δ = dried for 24h at 40°C

Φ = cleaned by towels paper

Loss of weight:

- The loss of weight is calculated as follow : $loss\ of\ weight = \frac{m_i - m_f}{m_i}$

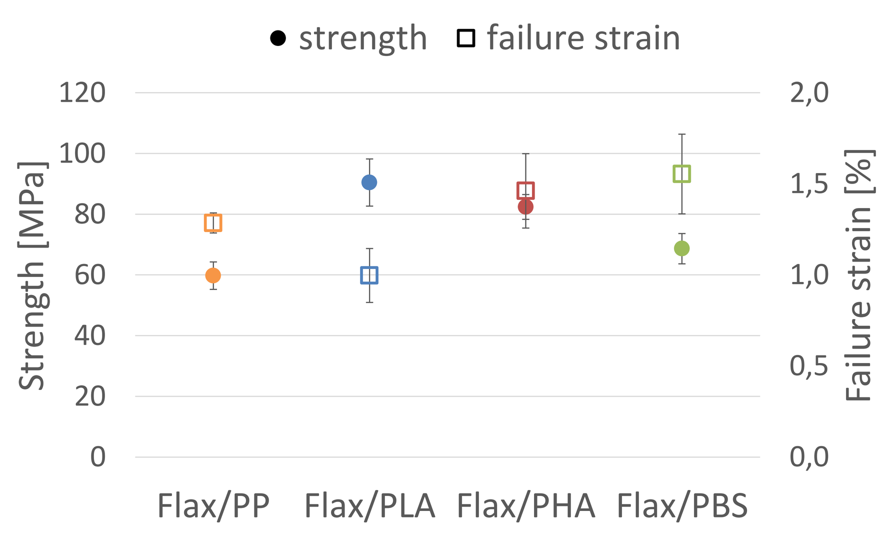
Tensile test:

- **Test based on ISO 527** : Gauge length of 25mm, displacement speed of 1mm/min, 10kN load cell

Microtomography:

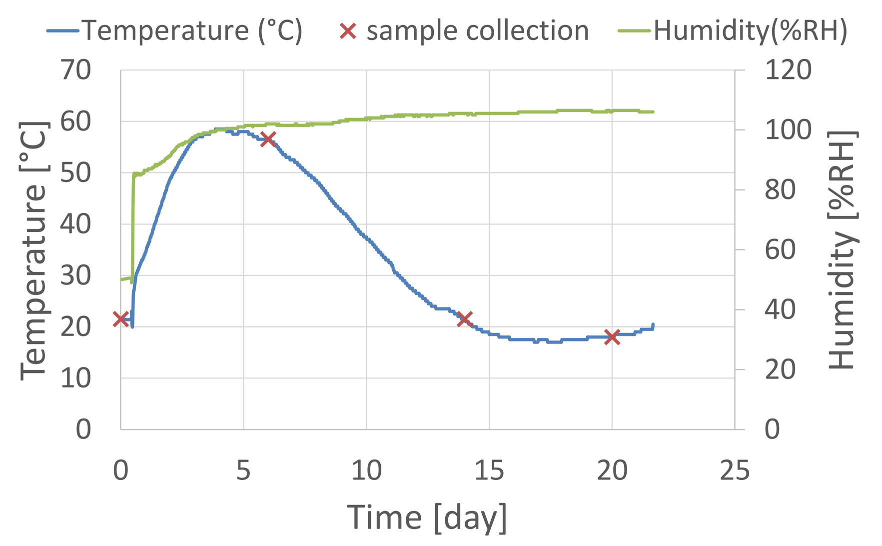
- **Porosity** is measured by contrast analysis, as well as their localisation.

Initial samples' mechanical properties



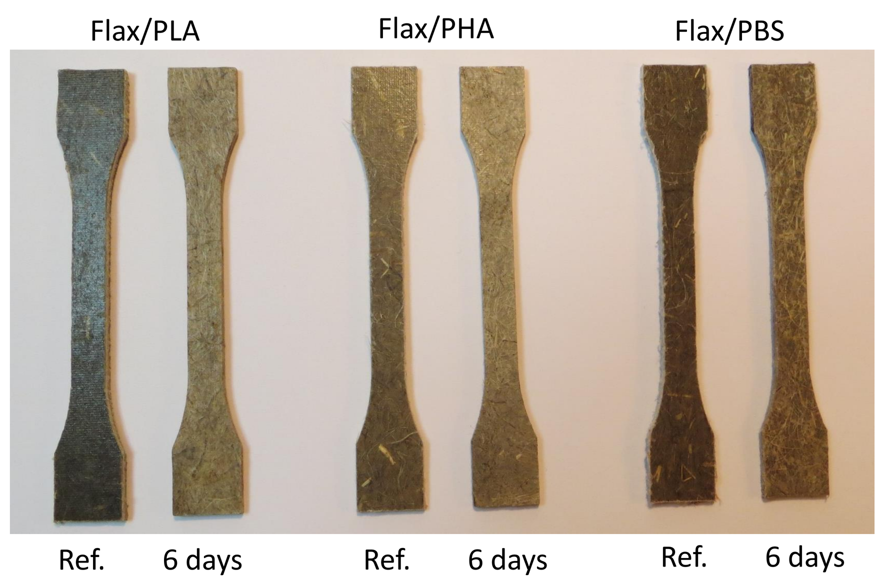
- All biopolymers have mechanical properties **similar or better** than Flax/PP.
- **Flax/PLA** shows the highest **strength** where **Flax/PBS** is relevant for higher failure **strain** application. **Flax/PHA** is a good compromise **combining both**, a good strength and a good failure strain.

Compost characteristics



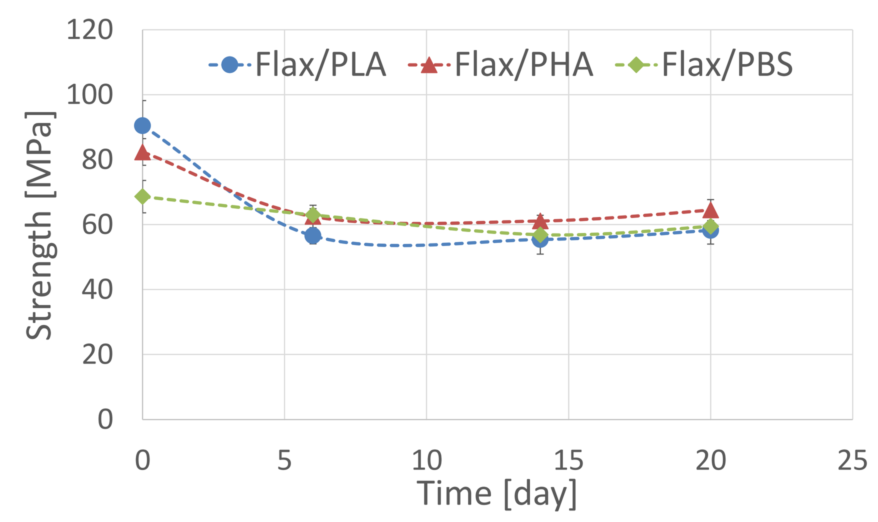
- During the first 10 days, the temperature is higher than 40°C reaching 58.5°C, which is not far from the glass temperature of the PLA (69°C)
- The drop in temperature does not seem to be due to rain or colder temperature
- **Humidity is** fairly stable, close to **100RH%**

Visual Degradation

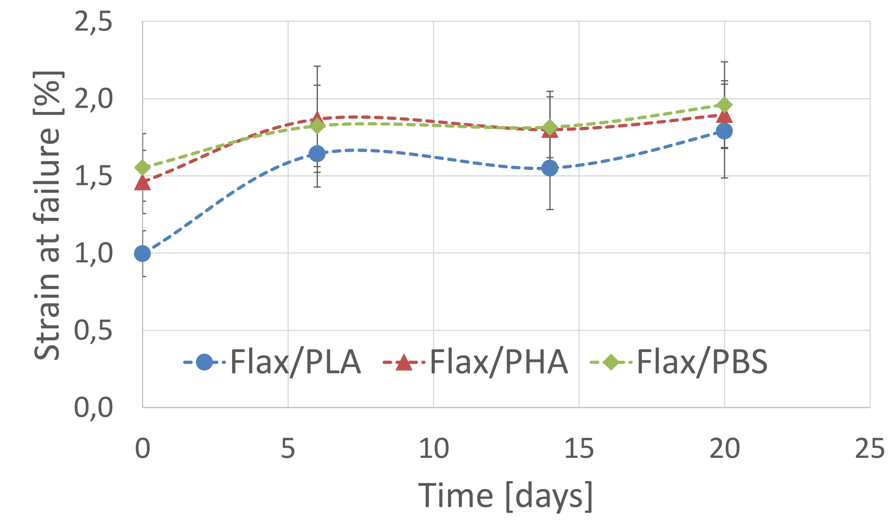


- After only **6 days**, an important **change in aspect** is observed. Fibres appear white on the surface.
- From 6 days to 20 days, **no surface change** is observed probably due to the **lower temperature of the compost**.

Mechanical evolution



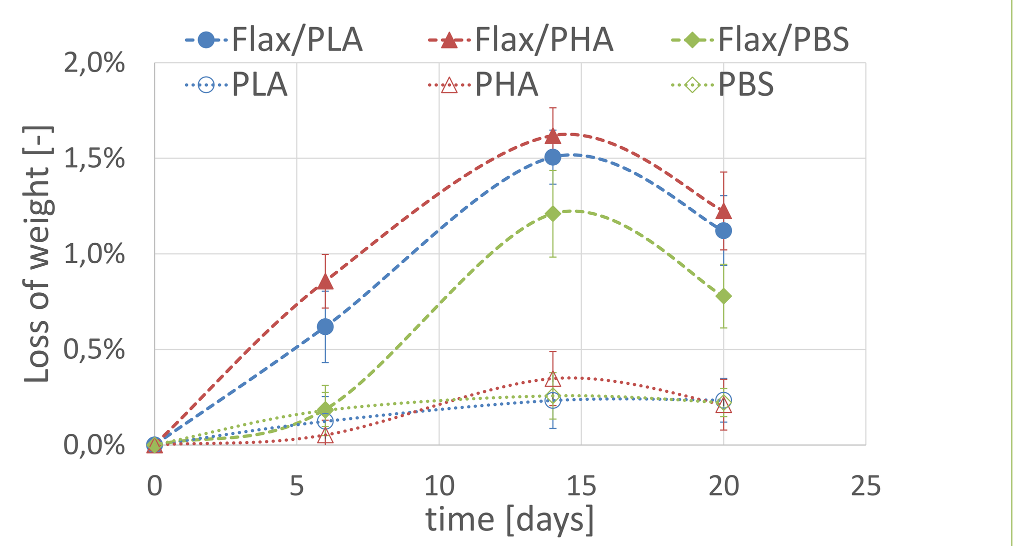
- **Strength decreases** in the first 6 days for **all composites** with a more important drop for **flax/PLA** which **lost 37.5% of strength**. **Flax/ PHA is less impacted** but it still shows an important decrease of 24.1%. On the other hand, **flax/PBS** presents a **small decrease** due to the degradation with a loss of 8.2%.
- Biocomposites show **similar strength after 6 days** in the compost and strength seems constant thereafter.



- On the opposite way, **failure strain increases** for **all composites** in the first 6 days and seems constant after.
- **Flax/PLA** is still the **most impacted** by the compost, maybe due to the temperature close to its glass temperature as well as the beginning of the PLA's hydrolyse.

=> The mechanical properties **change quickly** the **first 6 days**, probably due to the **higher temperature** in the compost. Regarding visual observation, that could also be due to **absorption of water** in the compost where the humidity is around 100 % RH.

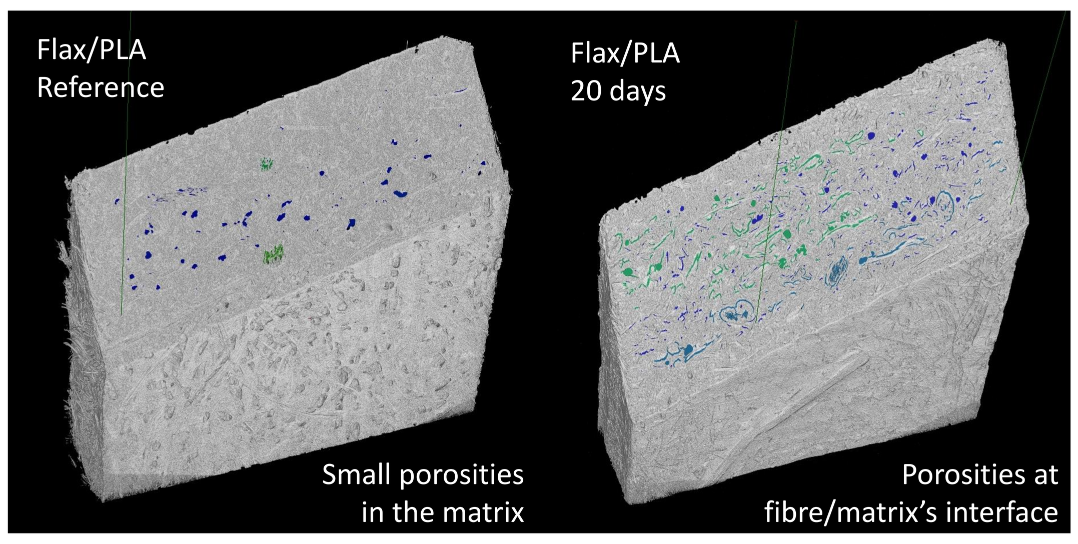
Weight evolution



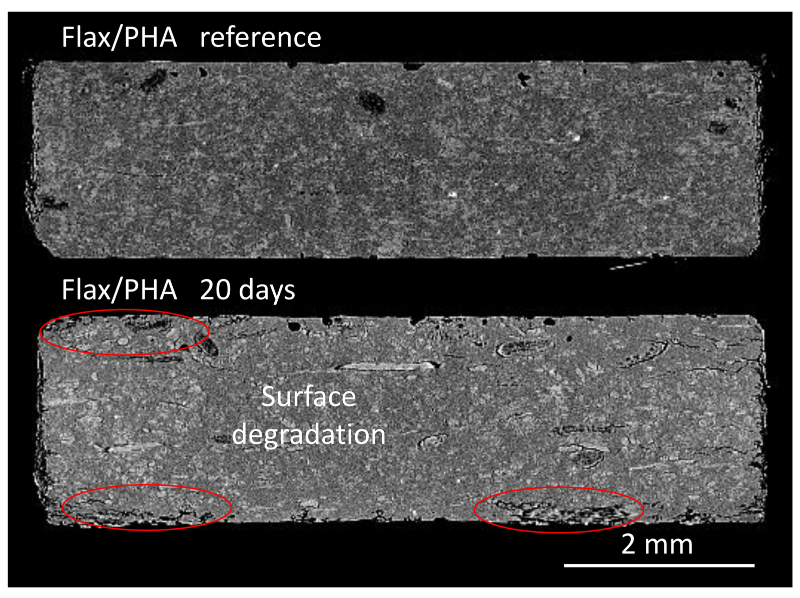
- **The flax** non-woven **speed up** the **degradation**, however, after 20 days, the loss of weight is still small.
- There is **no clear relation** between **strength** and **weight** evolution, after 14 days, the weight still evolves while the strength becomes stable.

Microtomography analyses:

- **Porosity** mainly appears at the **interface** between matrix and flax fibres. This is clearly observed in the case of Flax/PLA.
- After 20 days in the compost, the porosity volume fraction reaches 5.84% for the **Flax/PLA** versus 2.22% before any degradation => **Bulk degradation** occurred for this composite.



- **Flax/PHA** doesn't show a significant increase of porosity in its volume, but some cracks appear all around edges meaning that the **biodegradation** mostly takes place **in the surface**.



- **Flax/PBS** presents **no important change** in its micro-structure which is consistent with the small evolution of its mechanical properties.
- The **microstructure evolutions** are in **good agreement** with the evolution of **mechanical properties**, Flax/PLA is the most affected, then flax/PHA and finally flax/PBS which seems to not be affected yet.

Conclusion

- Regarding mechanical properties, using PLA, PBS or PHA for making **flax biocomposite** is a **good alternative** to replace flax/PP used in the industry.
- As expected, **biocomposites degrade faster than virgin polymer** due to the presence of flax fibres.
- As the evolution appears in first 6 days, the biodegradation looks to be really **temperature dependent**.
- The **biodegradation affects** mainly the **interface** between matrix and fibres, however, **flax/PHA** is more **surface sensitive** where **flax/PLA** is degraded in **its volume**.

- The investigation will continue taking care of the temperature evolution and its influence on biodegradation.
- Biodegradation of Flax/PP will be recorded and will bring more knowledge about the loss of weight contribution from the non-woven flax fabric.

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