Cellulose Valley

BY FONDATION GRENOBLE INP

REINVENTING PACKAGING

POSTERS POC 2025

Development of cellulose-based barrier and stretch materials to replace single-use plastics

Alanis Bré – ***ENSICAEN,***

End of study project ***FEBRUARY – JULY 2025***

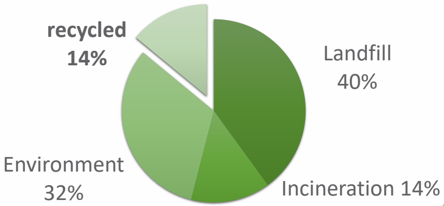
Materials Chemistry, Organic Chemistry and Macromolecules,

Cellulose Valley

BY FONDATION GRENOBLE INP

Context

End-of-life of plastic packaging

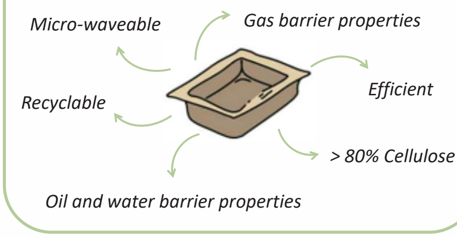


Environnemental legislations

2019	2020	2024
Single-use plastics	*Anti-Waste and Circular Economy*	*Packaging and Packaging Waste Regulation*

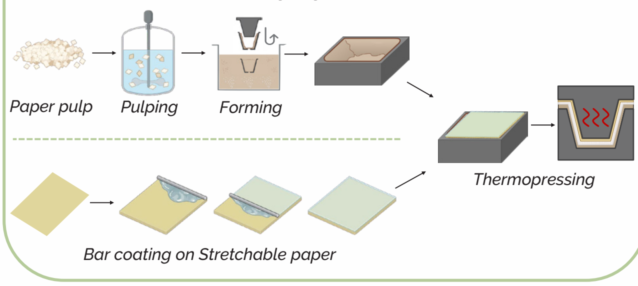
Find a cellulosic alternative to plastic film for molded cellulose tray

Food Packaging requirements

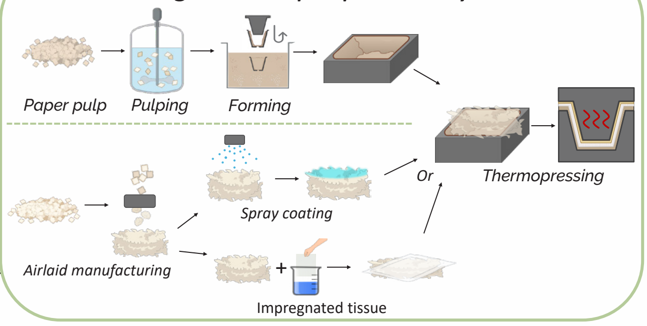


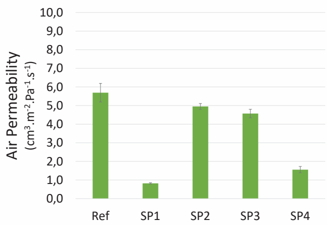
Methods - Results

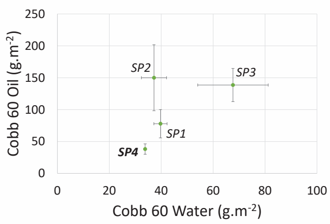
*Providing barrier properties by **stretchable papers***



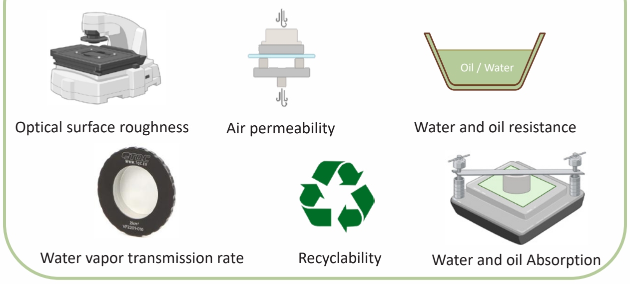
*Providing barrier properties by **Airlaid***

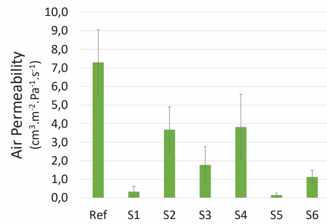


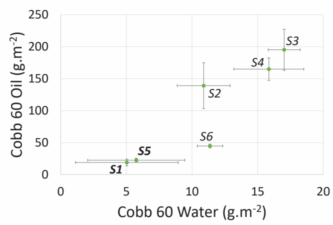




Characterization







Conclusion and perspectives

Conclusion

Stretchable paper

\+ Many folds to one fold
No tears
Good adhesion

\- One fold left
Not enough barrier properties

Airlaid

\+ No fold and tears
Good adhesion

\- water and oil barrier properties to be improved

Perspectives

- Stretchable paper by multilayer
- Determine the most suitable paper and best barrier solution
- Test with food, WVTR, Filing test with oil and water and Recyclability

How to improve recyclability of cellulosic based packaging?

Study of parameters influencing recyclability of barrier papers.

Chloé Buet – End of study project

10/02/25 – 24/07/25

Grenoble INP Pagora – LGP2

Cellulose Valley BY FONDATION GRENOBLE INP

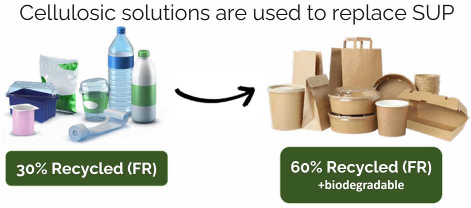
Context

SINGLE-USE PLASTICS DIRECTIVE

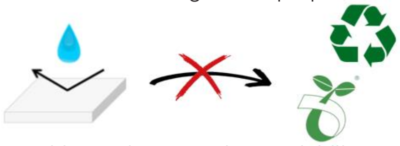
LOI ANTI-GASPILLAGE pour une économie circulaire

Approach to reduce the environmental impact of single-use packaging

Cellulosic solutions are used to replace SUP

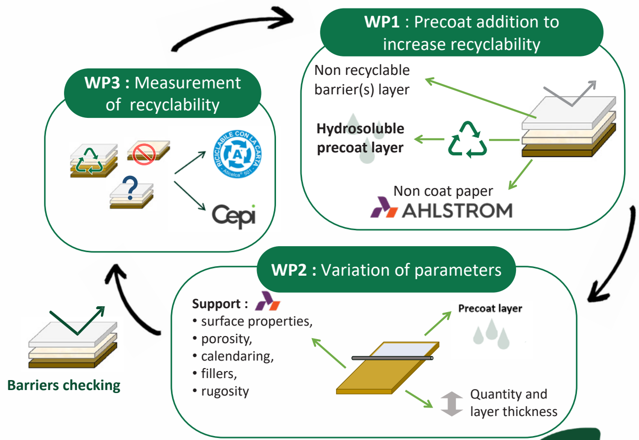


To suit food packaging requirements : papers are modified to bring barrier properties



This restricts paper's recyclability and biodegradability

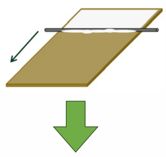
Work strategy to bring recyclability



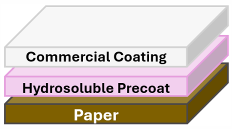
Methods - Results

Multilayer Material Elaboration

Bar Coating

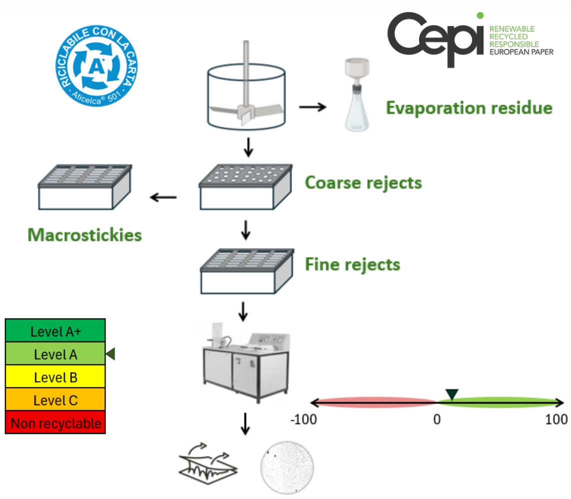


Coating Strategy

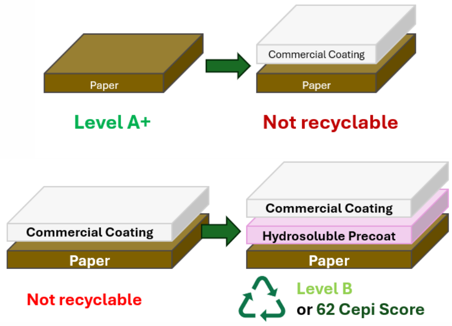


Addition of a cellulosic-based water-soluble precoat between the substrate and the barrier coating

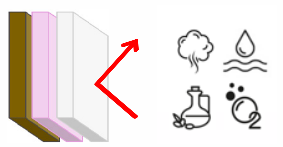
Two Recyclability Standard



Recyclability Result



Barrier Result

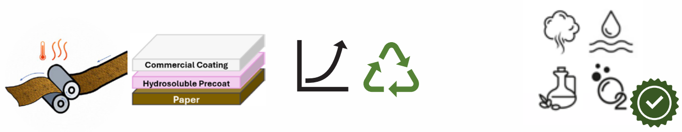


Barrier properties are ensured even with the addition of the precoat

Conclusion and perspectives

Conclusion

- Hydrosoluble precoat increase recyclability of barrier paper
- Precoat nature have an impact on recyclability
- Calendared and closed paper are more able to be recyclable
- Barrier properties are preserved with the add of a precoat



Perspectives

Deeper optimization of barrier properties and recyclability

INP Pagora UGA · lgp² · AHLSTROM · Aptar · CHANEL · CITEO · DS Smith · DECATHLON · GUILLIN we protect your food · Marie

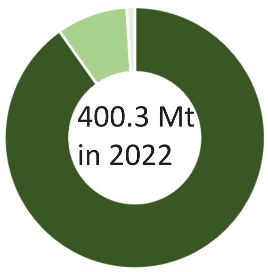
Cellulose-based formulation for injection molding with high barrier properties

CADOUX Manon Ensicaen

Grenoble INP – LGP²- Cellulose Valley (feb-jully 2025)

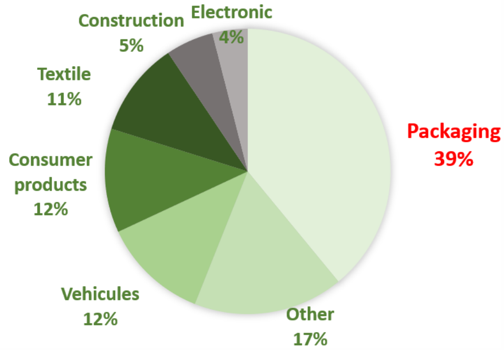
Cellulose Valley BY FONDATION GRENOBLE INP

Context



World Plastic Production in 2022

Souce: Plastics Europe



Origin of plastic waste in 2019

Souce: OECD Environment Statistics, « Global Plastic Outlook:Plastic waste in 2019 »

SUP SINGLE-USE PLASTICS DIRECTIVE — Ban certain single-use plastics: reduce marine pollution

LOI ANTI-GASPILLAGE pour une économie circulaire — Reduce waste and promote recycling

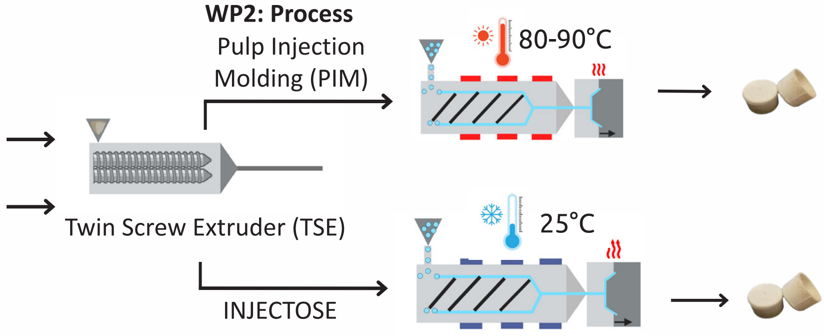
PPWR — European standards for managing packaging waste

Methods - Results

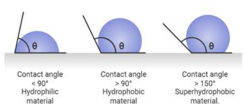
WP1: Formulation

Cellulose powder (50-60%)	Additive : AKD, ASA, Rosin	Water(40%)	Biobased polymer	PVOH
Cellulose fiber (90-95%)	Additive : AKD, ASA, Rosin	Water(60%)	functionalized cellulose	

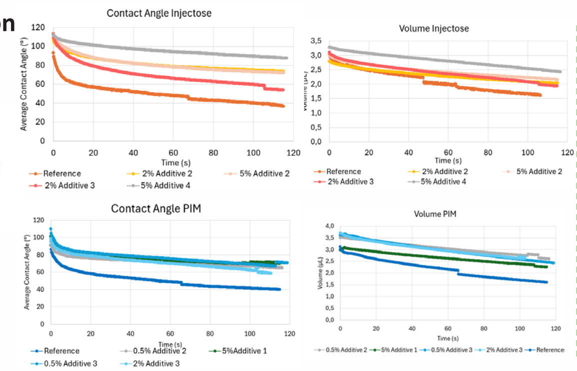
WP2: Process



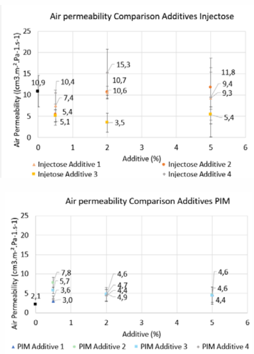
WP3: Characterization



Water Contact Angle



Air permeability



WVTR

Recycling (ATICELCA)

Conclusion and perspectives

- Adding an additive increases the hydrophobicity
- Better hydrophobicity with higher concentrations
- No impact of the additives on WVTR and air permeability

- Test other additives
- Try Recyclability test (ATICELCA)
- Analyze surface roughness using scanning electron microscopy

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Innovative lightweight and resistant corrugated cardboard

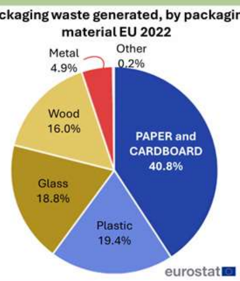
Teresa Faro

Politecnico di Torino (Italy) - MSc Material's engineering

Final project internship, February-July 2025

Context

Corrugated carton boxes are used as a secondary packaging for most of the products that we use in our daily life.
Paper and cardboard represent the highest quantity of waste that comes from packaging.

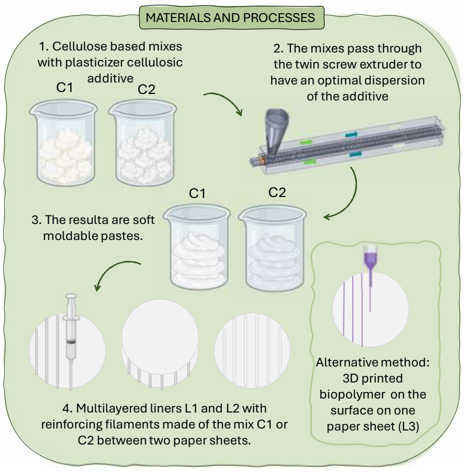


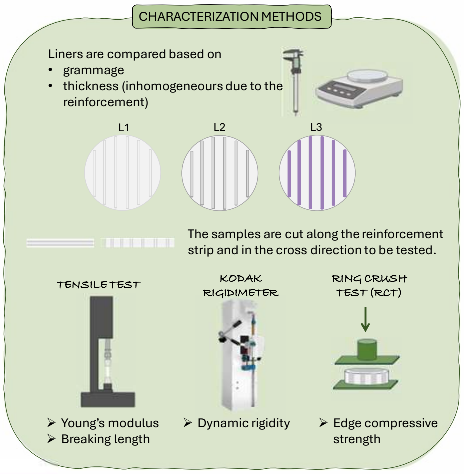
Paper bags for lighter products are reinforced with plastic grids, thus they are **non recyclable**.

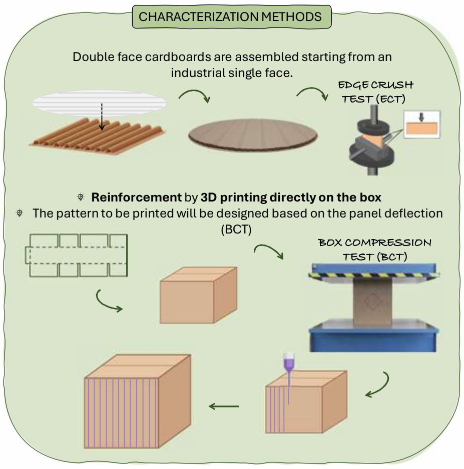
Corrugated cardboard boxes need to be reinforced in case of heavy load.
One of the current ways to do so involves the use of **plastic strips**.

Materials and methods

In this context of growth of the packaging's demand and the necessity to maintain its resistance, the objective of this study is to investigate the **reinforcement of the liners** of corrugated cardboard to make it 100% cellulose based and recyclable, with the aid of **biobased filaments**.



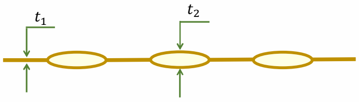




Results and perspectives

	Grammage $\overline{W}_i$ [g.m^{-2}]	$\overline{W}_i$ St. Dev. [g.m^{-2}]	Thickess T_i [µm]	T_i St. Dev. [µm]
Ref1	79	2	109	3,50
Ref2	126	2	170	2,08
L1	125	4	185	8,42
L2	125	3	183	8,26

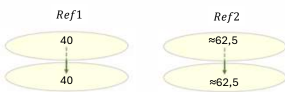
$$T_{L1}, T_{L2} = \frac{t_1 + t_2}{2}$$

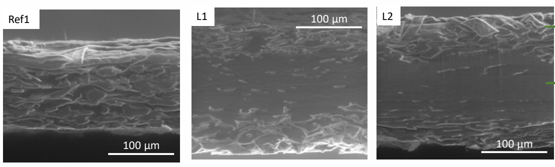


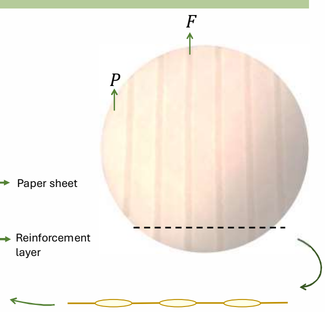
References are made by drying two paper sheets together, without adding the reinforcement:

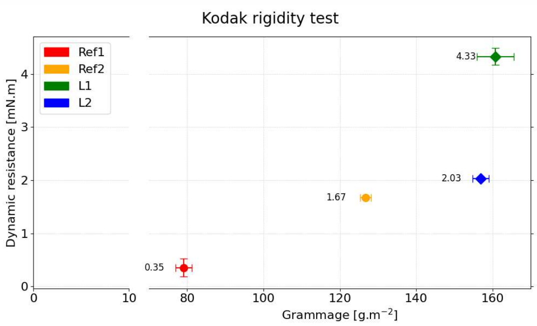
$$\overline{W}_{Ref1} = \overline{W}_P + \overline{W}_F$$

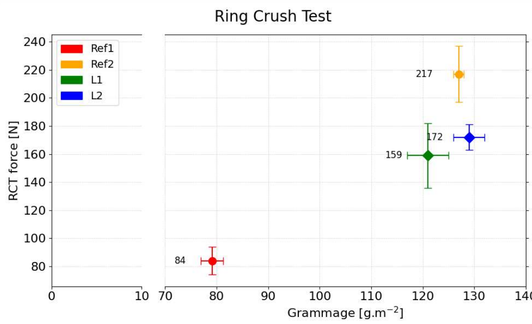
$$\overline{W}_{Ref2} = \overline{W}_P$$











CONCLUSIONS

- **Good adhesion** between all layers, some detachement appears in L2;
- **Increased rigidity** in L1 thanks to C1;
- **Increased RCT** force thanks to stiffeners.

Development of sealable bio-based packaging with barrier performance

Authors: *Houssou Michel*

Institutions: *Grenoble INP PAGORA / UGA*

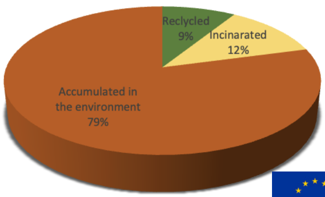
Duration: February – July 2025

Cellulose Valley BY FONDATION GRENOBLE INP

Context

Millions of tons of plastic debris enter the oceans each year, breaking down into microplastics ingested by flora and fauna eventually reaching humans through the food chain.

Accumulation of plastic waste

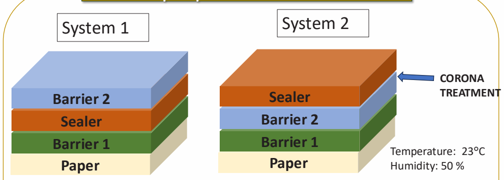


Governments and international institutes are taking action. The European Union, for example, has banned certain single-use plastics and aims to make all packaging recyclable or reusable by 2030.

Paper-based packaging As a viable alternative to plastic, paper offers:
- Renewability and biodegradability
- High recycling rates
- Widespread use and infrastructure

Materials and methods

Barrier properties measurement



- Three type of paper tested.
- Two type of barrier solutitions tested.
- Three type of sealer tested

Characterization
- ✓ Grammage
- ✓ WVTR, OTR
- ✓ Cobb oil/ water

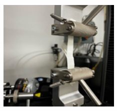
Sealing process optimization

✓ **Sealing method**

Ultrasonic Sealing
- Welding Force (daN)
- Energy (J)
- Amplitude (%)

Heat Sealing
- Temperature (°C)
- Pressure (kPa)
- Time (s)

✓ **T-Peel Test ASTM F88**



Sealing performance evaluation

✓ **Sealing integrity verification**

Measurement of the WVTR of the Coated paper sealed with Cacl2 inside

LOW WVTR Confirms effective seal and barrier agent

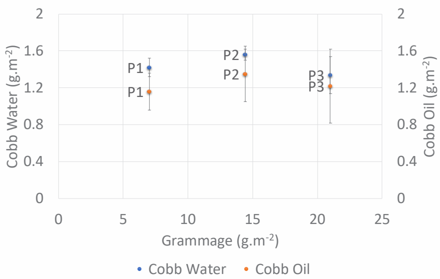
HIGH WVTR Seal agent ineffective

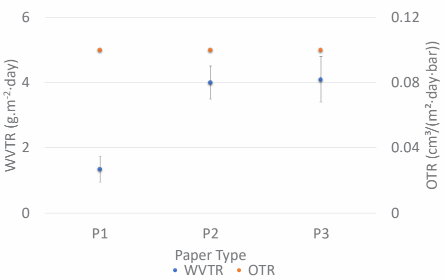
Recyclabity test ATICELCA

Results

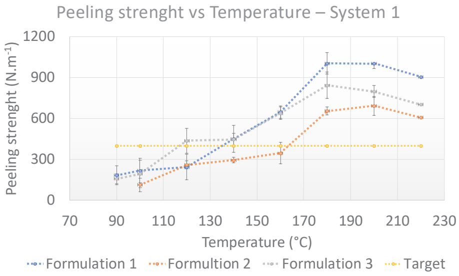
Temperature: 23°C
Humidity: 50 %

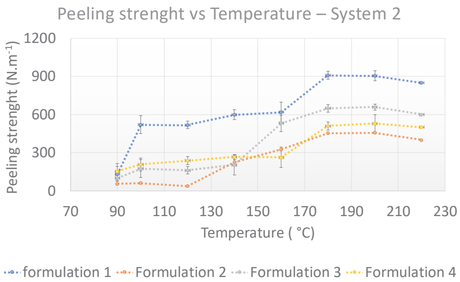
Samples characterization



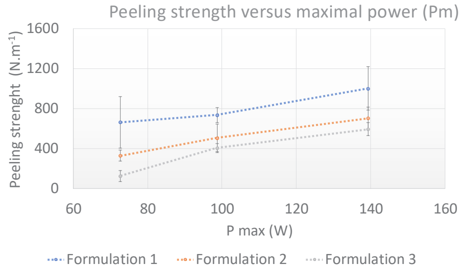


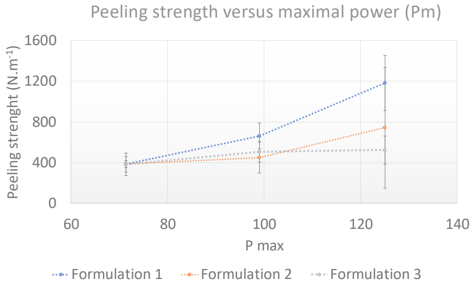
Heat sealing optimization





Ultrasonic Sealing optimization





Conclusions and persectives

Conclusions

- ✓ Paper based packaging developed demonstrate a good barrier properties and sealing performances.
- ✓ Recyclable with global level B

Perspectives

Futher research will focus on:
- ✓ Global Migration test.
- ✓ Evaluate industrial scalability and performance on commercial sealing and filling lines.
- ✓ Environmental Impact Assessment

GRENOBLE INP Pagora UGA · lgp2 · AHLSTROM · Aptar · CHANEL · CITEO · DS Smith · DECATHLON · GUILLIN we protect your food · Marie

Active cellulose foam packaging for moisture protection.

Authors: Kitso Charmaine MACUCWA

Institutions: Toulouse INP-ENSIACET, France.

Duration: March – August 2025

Cellulose Valley BY FONDATION GRENOBLE INP

Context

Project context

Products' shelf-life issues

Cargo transportation of textiles and electronics

During the Cargo transportation there are changes of relative humidity.

Resulting in damage of electronics and textiles

Corrosion — Mold growth

Traditional way of how these products are packaged they utilise a plastic bag.

Drawbacks of plastics:

- Non-biodegradable
- Pollution
- Hard to recycle

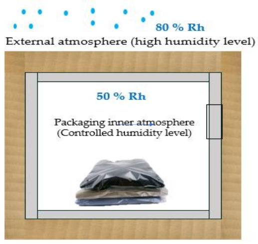
Solution:

To replace plastic bag with a bio-based material like cellulose foam because it is:

- **BIODEGRADABLE** — Breaks down naturally without polluting the environment
- **PLANT-BASED** — Made from renewable resources like wood pulp
- **RECYCLABLE** — Can be reused in new products
- **POROUS & LIGHTWEIGHT** — Provides cushioning and Insulation while reducing material weight

Plastic bag

Corrugated board box



Multiple Layers of active cellulose foam using an active agent (desiccant).

Yildirim et al (2018). Active Packaging Applications

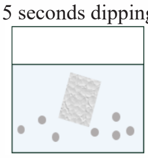
Wyser et al (2020) Barrier shift strategy.

Methods

Active cellulose foam layer preparation

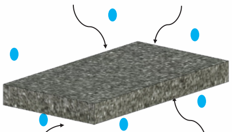
Impregnation of the cellulose foam

5 seconds dipping



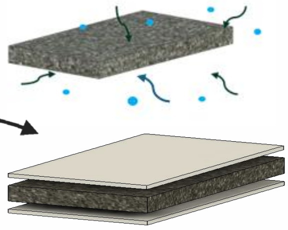
Dry at 105 °C for 1 hour

Solution (alcohol + desiccant)



Active cellulose foam

Multilayer material approach

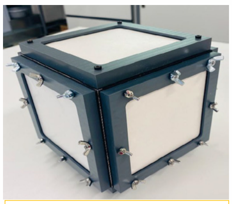


Addition of Non-barrier or Barrier paper

Application

Moisture buffer capacity tests using different boxes.

Simulation box



Box + cellulose foams + papers

Corrugated boxes

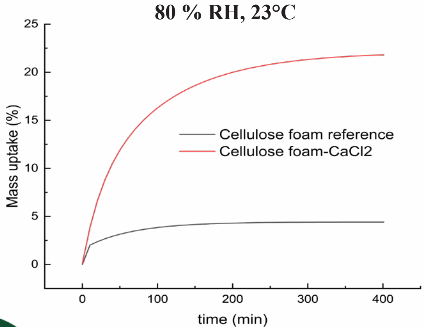
Box + cellulose foams

RESULTS

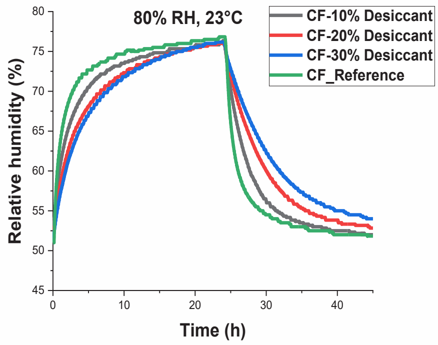
Moisture adsorption capacity

Addition of $CaCl_2$

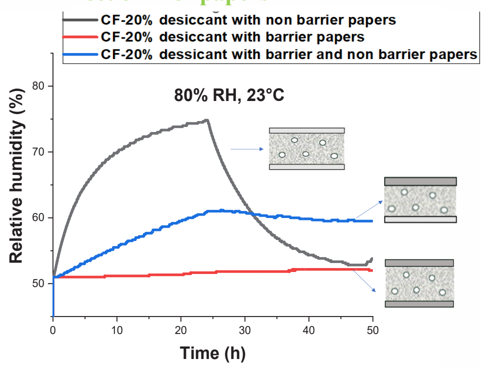
80 % RH, 23°C



Moisture Buffer Capacity



Effect of liner papers



Conclusion

- Addition of a desiccant increase moisture adsorption of cellulose foams, being potential for use as moisture buffer layer.
- Addition of barrier paper to activated cellulose foam modifies the adsorption of the foam, exhibiting a linear behaviour.

Perspectives

- Combinations of barrier materials and desiccants enable smart control of moisture behaviour in cellulose foams.
- These materials show strong potential for use in packaging, insulation, and moisture buffering applications.

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Developing self-folded architectured paper to replace regular flute of corrugated board

Paul Morbin – End of study project

Grenoble-INP Pagora – LGP2 – Tuesday 6th July

International School of Paper, Printed Communication and Biomaterial

Cellulose Valley BY FONDATION GRENOBLE INP

Context

In a context of reduced environmental impact and resource management, lightweight materials are becoming a priority. The idea is to reduce the amount of material used while maintaining equivalent mechanical performance. The aim of this project is to design a self-folding, 3D-architected paper capable of replacing the conventional fluting of corrugated board with a more optimized, lightweight and durable structure.

ECO design

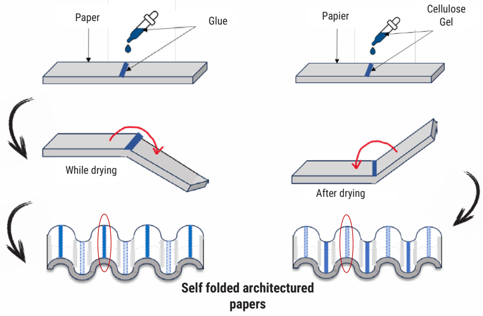
Packaging and Packaging Waste Regulation

DS Smith

*This **Chair Cellulose Valley** project is in collaboration with **DS Smith***

Two theoretical approaches

To autofold paper :



By **hydroexpansion** By **drying shrinkage**

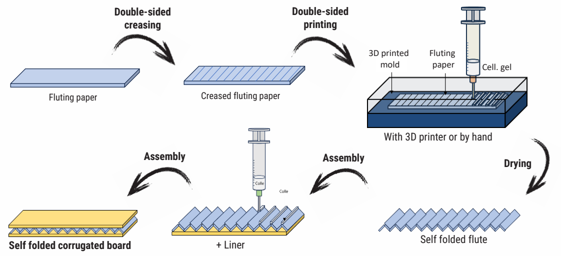
Methods

Raw materials:

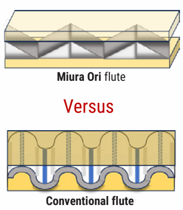
- **Fluting paper:** 90 g.m^{-2}, 130 µm.
- **Liner (KraftLiner):** 140 g/m^{-2}, 19 µm.

Cellulosic gel (12% mass concentrated).

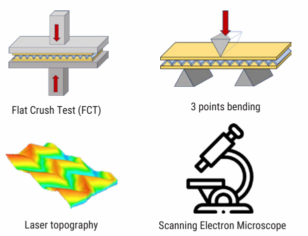
A drying shrinkage protocol:



An optimized design:
Miura Ori

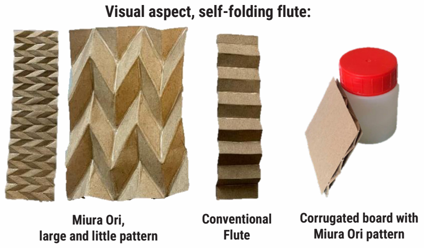


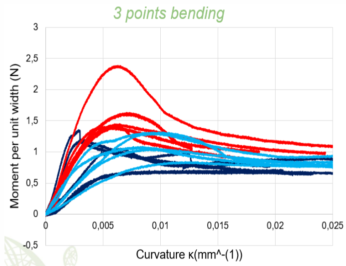
Characterization:

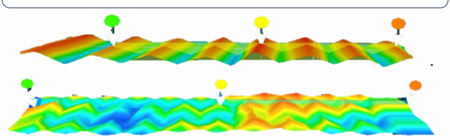


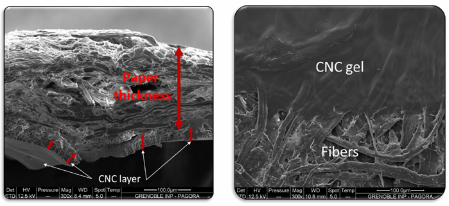
Results

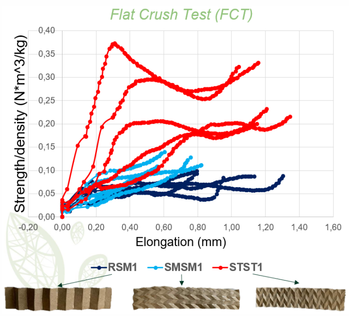
Visual aspect, self-folding flute:







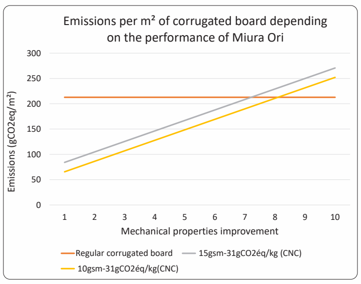


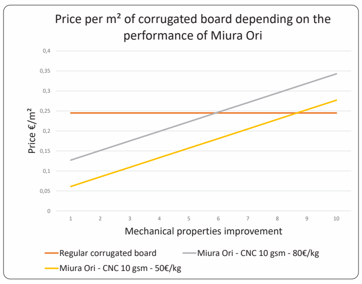


Conclusion

Conclusion

- Protocol for self-folding paper according to the chosen motif
- Positive economic balance if 13% mechanical performance obtained
- Positive environmental balance if material lightened by 15%.





Perspectives

Perspectives

- Detailed study of drying mode/temperature
- Creation of a duplex printing driver (flexography)
- Improved repeatability for more accurate results

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3D & 4D Printing of Cellulosic Materials for Luxury Packaging

Feb, 2025 - July, 2025

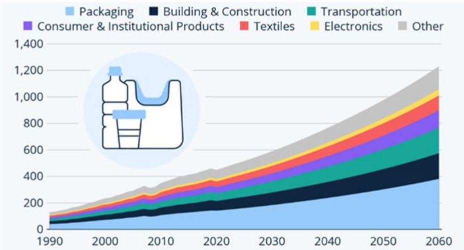
Bilal TAHIR

Masters in Materials Science and Engineering (Biorefinery and Bio-based Materials) - Grenoble INP, France

Institution: Laboratory of process engineering for biorefinery, bio-based materials and functional printing

Cellulose Valley BY FONDATION GRENOBLE INP

Context



Between 2000 and 2019, global plastic waste reaches 353 million tonnes. Projections from 1990 to 2060 highlight a significant rise in total plastic use—more than sixfold—raising concerns about sustainability, waste management, and environmental impact if current consumption patterns persist.

The luxury industry faces growing scrutiny over its packaging practices. While rising demand for premium products, personalization, sustainability, and e-commerce drive market growth, high costs of eco-friendly materials and packaging waste pose major challenges for the sector's future.

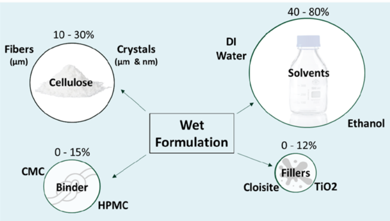
The stringent EU policies push the industry, including the luxury sector, toward achieving 100% recyclable, reusable, and biodegradable packaging by 2025–2030, driving innovation and sustainability in packaging development.

Methods - Results

3D Printing of Cellulosic Materials

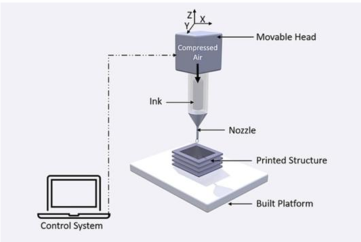
Formulation Development

A series of cellulose-based hydrogels were formulated by varying solid content and component ratios to optimize printability and reduce drying shrinkage. The goal was to achieve an optimal balance of viscosity, flow behavior, and structural integrity for luxury packaging applications.



Direct Ink Writing (DIW)

Cellulose based hydrogels were printed using a modified commercial printer via DIW, a room-temperature extrusion method. Print quality dependence on ink rheology, nozzle size, and print speed was observed. Solidification occurred through evaporation.



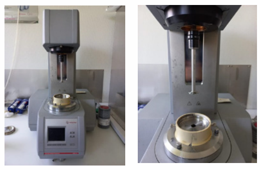
Rheological Analysis

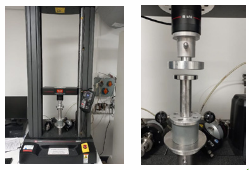
Rheological Evaluation

Flow curve, thixotropy, and oscillatory tests were conducted to assess the rheological behavior of the cellulose hydrogels. These confirmed shear-thinning for smooth extrusion, fast viscosity recovery for shape retention, and sufficient viscoelasticity for self-supporting structures after printing.

Injection Flowability Test

A custom piston-cylinder setup developed at LGP2, combined with an Instron machine, was used to extrude pastes through a capillary. Force profiles measured extrudability and flow resistance, simulating 3D printing conditions.

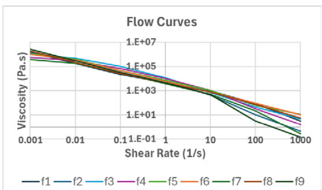




3D Printing Results

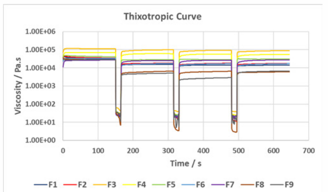
Using 0.96 mm and 1.5 mm nozzles, good printability was generally achieved at ~300 N extrusion load. Most formulations exhibit good printability; however, post-drying shrinkage varies significantly between samples. Agglomeration can also cause variability, particularly hindering extrusion through the smaller diameter tip.

Rheology Results



Most formulations exhibit consistent shear-thinning behavior, with minor deviations at higher shear rates.

Thixotropy tests confirm good structural recovery post-shear, indicating robust rebuildability of the paste networks.



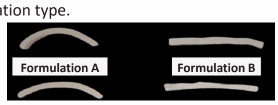
Shape Monitoring for 4D Printing

Method

Cellulose based hydrogel was loaded into a custom 3D-printed mold to ensure consistent shape and volume. The mold was weighed before and after drying to quantify moisture loss. Post-drying, curling or bending was assessed using image analysis tool.

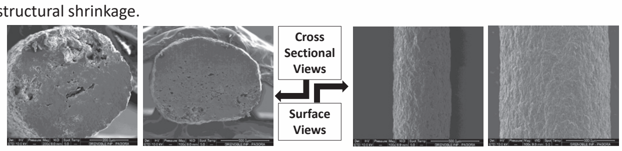
Results

Formulations showed ~10% weight loss, while dimensional shrinkage ranged from 10–30%. Increasing solid content helped reduce shrinkage, but noticeable curling still occurred, depending on the formulation type.



SEM Imagery Results

SEM images of 3D printed layers from different formulations reveal generally continuous, yet rough-textured surfaces due to the presence of fibers—unlike the smooth finish typical of conventional PLA prints. Visible defects arise from water removal and the associated structural shrinkage.



Conclusion and Perspectives

Blends with MCC, CMC, and CNC showed the best performance among tested formulations. Visual analysis revealed nozzle size sensitivity. While wet printability was good, drying caused shrinkage, curling, and dimensional changes—indicating wet-state results don't always reflect final quality. Good shear-thinning and thixotropic recovery were observed, highlighting the need for printer and formulation optimization for luxury packaging.

Future work will explore advanced characterization, humidity response, and tailored applications for luxury packaging. It will also investigate why extrusion is more successful with larger nozzles and use various techniques to better understand the underlying chemical and physical factors.

References

Thibaut, C. (n.d.). Development of fibrous cellulosic materials for the production of bio-based 3D printed objects by extrusion. https://theses.hal.science/tel-02570560v1

"Eco-Packaging Trends to Watch in 2025: A Comprehensive Guide," Imperial Paper Co.

Baniasadi, H, Et al (2024). Innovations in hydrogel-based manufacturing..... Advances in Colloid and Interface Science, 324,103095. https://doi.org/https://doi.org/10.1016/j.cis.2024.103095

New recyclable paper-based packaging with high stretchability

Yuliya Zhukava

Master 2 Internship: February-July 2025

BIOREF, Erasmus Mundus

Cellulose Valley
BY FONDATION GRENOBLE INP

Context

Background

- ✘ ***Environmental issues*** *related to plastic waste pollution (360Mt/year)*
- ✘ *Recent regulations to* ***reduce single-use plastic*** *materials in packaging*
- ✘ *Current research and development of* ***innovative cellulose-based materials*** *to replace plastic film for stretchable* ***recyclable packaging*** *without using petroleum-based additives (plasticizers) or waxes*
- ✘ *Now paper-based packaging contains* ***petro-based compounds and waxes → not recyclable***

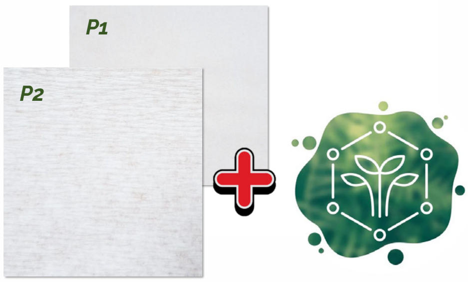
Industrial project

- ✓ *Create a* ***novel packaging*** *for confectionary (candy wraps)*
- ✓ *Packaging specifications:* ***paper based*** *(>80% is paper)*
- ✓ *Use commercial paper –* ***scale-up perspectives***
- ✓ *Bring* ***specific properties*** *to the final packaging (****twistability, stretchability, recyclability, barrier, safe for food contact****)*
- ✓ *Use* ***recyclable*** *and possibly* ***fully-biobased materials***
- ✓ ***Development and optimisation*** *of the production*

Materials & Methods

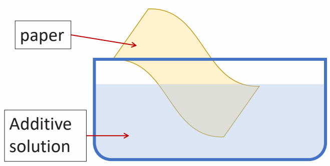
Raw materials

Commercial ***paper*** *(P1, P2) +* ***additives*** *(biobased polymers and molecules)*



Method

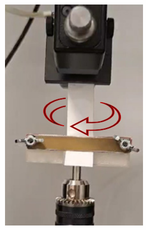
Impregnation *in bath (bulk) → at 60°C, 30s*



- ✓ ***Allows penetration*** *of long chains into paper fiber matrix*
- ✓ ***Industrially developed*** *method for paper coating*

Characterisation methods:

- ❖ ***Tensile strength*** *test → elongation and Young's Modulus*
- ❖ ***Twistability*** *test*
- ❖ ***Resistance to tearing*** *test*
- ❖ ***Barrier properties*** *(WVTR)*
- ❖ ***Recyclability*** *test*

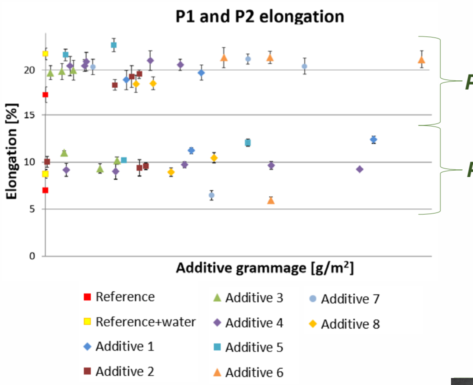


Characterisation of additives solutions:

- ❖ ***Stability*** *(homogeneity preservation)*
- ❖ ***Viscosity***

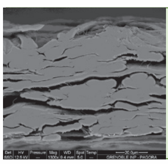
Results, Conclusions & Perpectives

Results: improvement in elongation



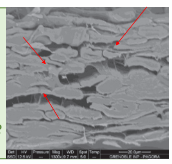
Factors influencing the elongation:

- ❖ *Drying mode (shrinkage is desired)*
- ❖ *Fibers direction (CD and MD)*
- ❖ *Additive amount*



SEM images *of P1 reference*

and P1+additive



Conclusions

- ➢ *Impregnation in bath is simple, fast and scalable method for additives incorporation into paper*
- ➢ *For low additive deposits (<10g/m2) we can obtain lightweight material gaining up to 23% elongation*

Perspectives

- ➢ *Create prototypes of the final packaging*

Candy wrap ***prototypes*** *made from P1 and P2 references*

- ➢ *Investigate barrier properties and recyclability of the prototypes*

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