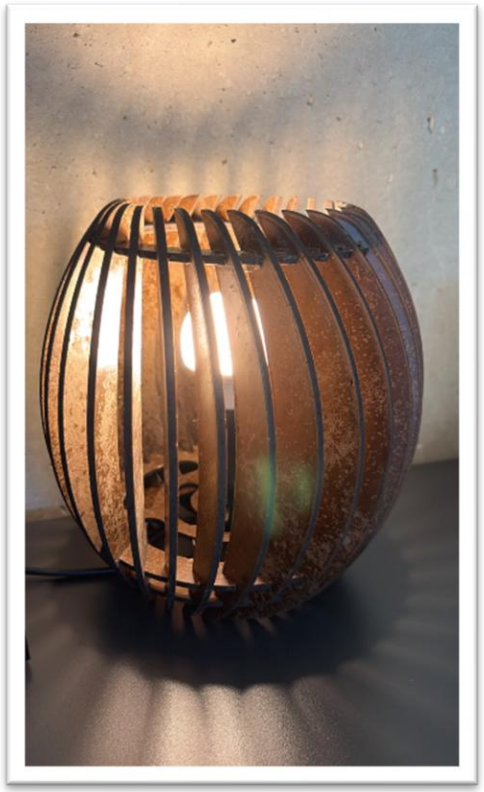
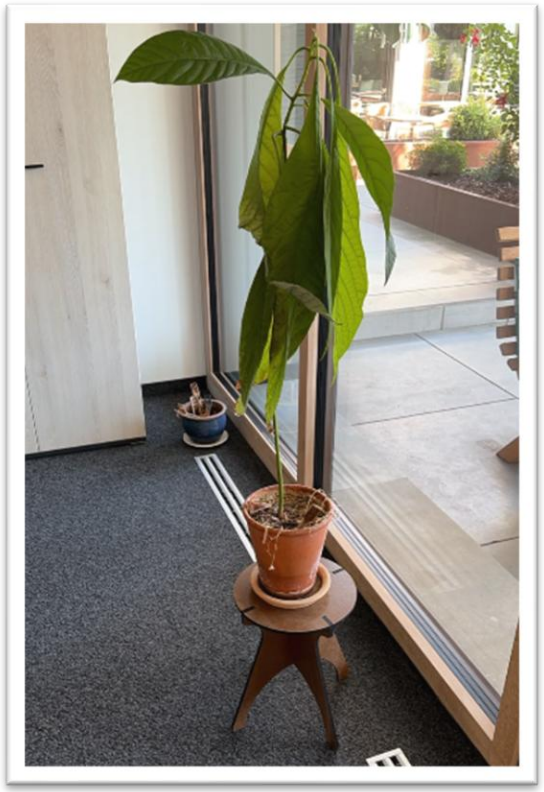


# PHA Ultimate Demontrator (PHAUD)

100% BIO







Interreg VI A-project '**EMPATHI**' – a Pilot study (TRL 3-6)

Kolja Ostendorf & Rik Voerman, September 2026
rikvoerman@triplebenefit.nl

Deutschland – Nederland

EMPHATI

**westerkamp**, our medium-sized company in Visbek, Germany, has specialized in wood grinding since 1955 and has been expanding its portfolio to include oat hulls since 2019. We produce wood flour, fibers and granulates using side streams such as sawdust, wood shavings and grain hulls. Thanks to regional raw material procurement within a 200 km radius, we keep our carbon footprint low.

westerkamp
MODERN MATERIAL MILLING

| | |
|---|---|
| **1873** | First mention of the mill |
| **1995** | Conversion to wood flour milling |
| **2003** | Start of cooperation with agromed (Austria) |
| **2005** | First certifications (DIN EN ISO 9001, QS, GMP+ & Kosher)<br>→ Quality standards established |
| **2013/14** | Construction and opening of the new Plant II |
| **2023** | Expansion of capacities & new administration building<br>→ 67 employees, 80,000 m², 45,000 tons yearly sales volume |




## Filtration

Pre-coat filtration for glucose, fructose, bio-ethanol, …

## Animals

Individual feed, mixed feed, additives, bedding, …

## Bio-based plastics

With natural fibers

## Construction

WPC, Additives for adhesives, varnishes, wood plasters, …

## Cleaning

Hand washing pastes, soaps with abrasives, …

## Paper

Paper & cardboard for stability



# Circular Plastics Lab

Circulariteit in composieten en de kunststoffen

- Projectmanagement
- Productie composieten
- Kunststofrecycling in low-income landen
  Circular River Fashion
- Recycling (thermoplastiche) composieten
- Bioplastics en biocomposieten











# Table of contents

**INTERREG Project: PHA Ultimate Demonstrator (PHAUD)**


- Introduction, objective and project approach
- WP1: Material selection and Compounding
- WP2: Biodegradation
- WP3: Injection moulding Demonstrator
- WP4: Fast sintering Demonstrator
- Conclusions & Recommendations



# Recommendations Previous work

1. Optimise sintering process (process conditions, accuracy, cycle time and define geometric freedom/limitations)
2. **Maximise wood particle content for minimum cost price**
3. **Determine biodegradation of wood filled PHA**
4. **Make demonstrator products to prove financial and technical opportunities**
5. Optimise flow moulding process

# The project

**Push the developed processes to the limit**



- compound
- fine wood particles after milling
- coarse wood particles after milling
- raw material from saw mills



# WP1: Materials - Selection & Compounding

Interreg

(Ko-/finanziert von der Europäischen Union
(Mede) gefinancierd door de Europese Unie

Deutschland – Nederland

EMPHATI

# Project PHA - Ultimate Demonstrator

**How to develop the cheapest compound with the best properties while still producible and processable?**

Systematically maximise compound properties (price vs. stiffness):

- Stiff fibres
- Highest aspect ratio
- Highest wood Vf



Interreg
(Ko-)finanziert von der Europäischen Union
(Mede) gefinancierd door de Europese Unie
Deutschland – Nederland
EMPHATI

# Material selection

Which materials for compounding?

- PHABuilder (5.850 euro/ton – nov 2024) (High MFI)
  - A = **PB3000G**: (700 kg) for highest stiffness
  - B = PB300G:**PB3430G** (70:30 and 60:40): 300 kg for reduced brittleness

    (Natureplast PHI002 or PHI011 more costly)
- Wood granule as a filler: **Lignobest C2 (was: C120);** bulk density: 320-460 g/l
- Wood as a fiber: **Lignobest GS2090 (was: GS8020);** bulk density: 135-220 g/l

PB3000G: P3HB (stiff nature)
PB3430G: P34HB (ductile nature)





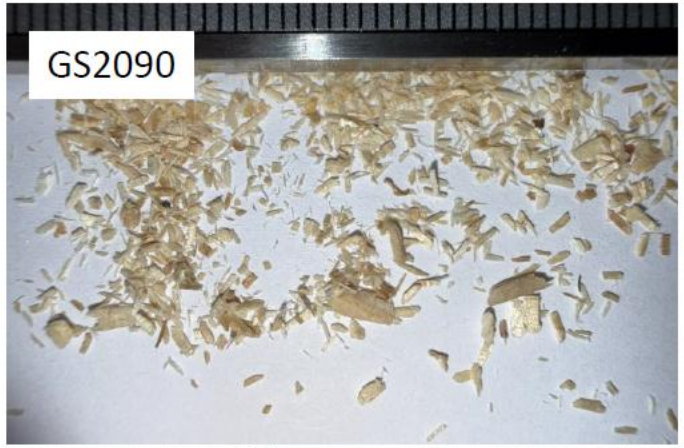

# Material selection

Wood properties before compounding

## F: GS2090 (Fibre)

- Average length 773±691 µm
- Average thickness 261±266 µm
- **Aspect ratio 3,0**
- Huge size distribution

(blue bar: 250 µm)






## M: C2 (Flour)

- Average length 1427±430 µm
- Average thickness 810±262 µm
- **Aspect ratio 1,8**

(blue bar: 250 µm)






*File: Test analysis PHAUD.pdf*

# Compounding

Compounding samples SULIS Polymers (9 January 2026)

| Variant | PHA-Blend* | | GS 2090 | C 2 | Additive | Quantity |
|---|---|---|---|---|---|---|
| A1 | 70:30 | 55% | 45% | 0% | 0% | 5 |
| A2 | 70:30 | 55% | 0% | 45% | 0% | 6 |
| B2 | 70:30 | 45% | 0% | 55% | 0% | 5 |
| C1 | 60:40 | 55% | 45% | 0% | 0% | 7 |
| C2 | 60:40 | 52% | 45% | 0% | 3% | 5 |

C1/C2: to check effect of bonding agent (BYK SCONATPPL 5112 PA)

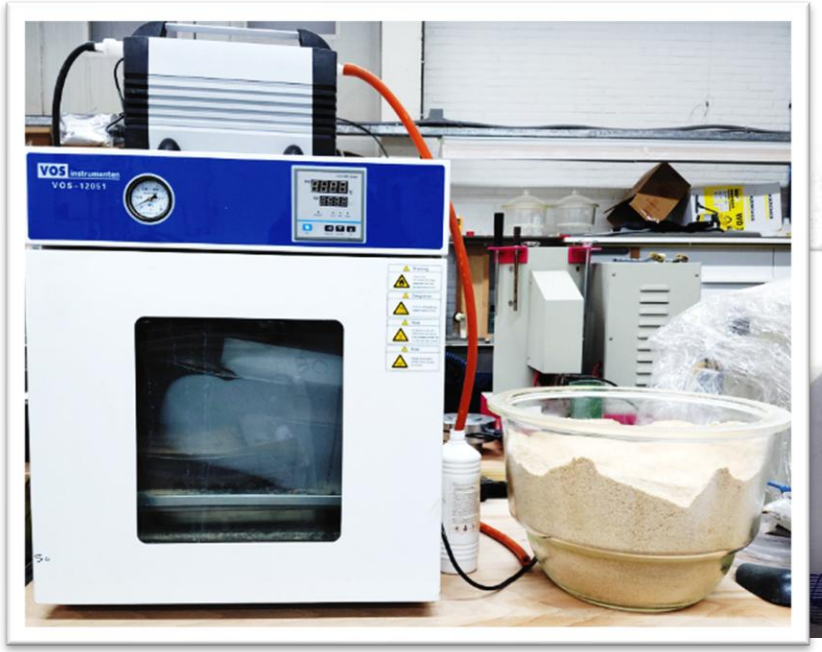
-

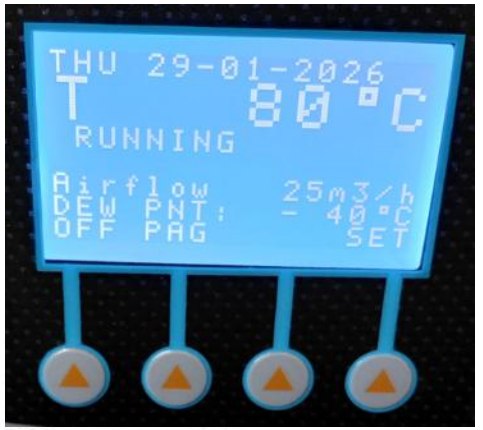


# Compounding

- Conditioning of the material
  - Storage < 50°C, dark, dry
  - No unpacking under temperature drop (avoid condensation)
  - Desiccant drying polymer 5 hours @ 80°C (dewpoint = -40°C)
  - Pre-drying wood 5 hours in vacuum oven

  Moisture content ~ 0,19%









# Compounding

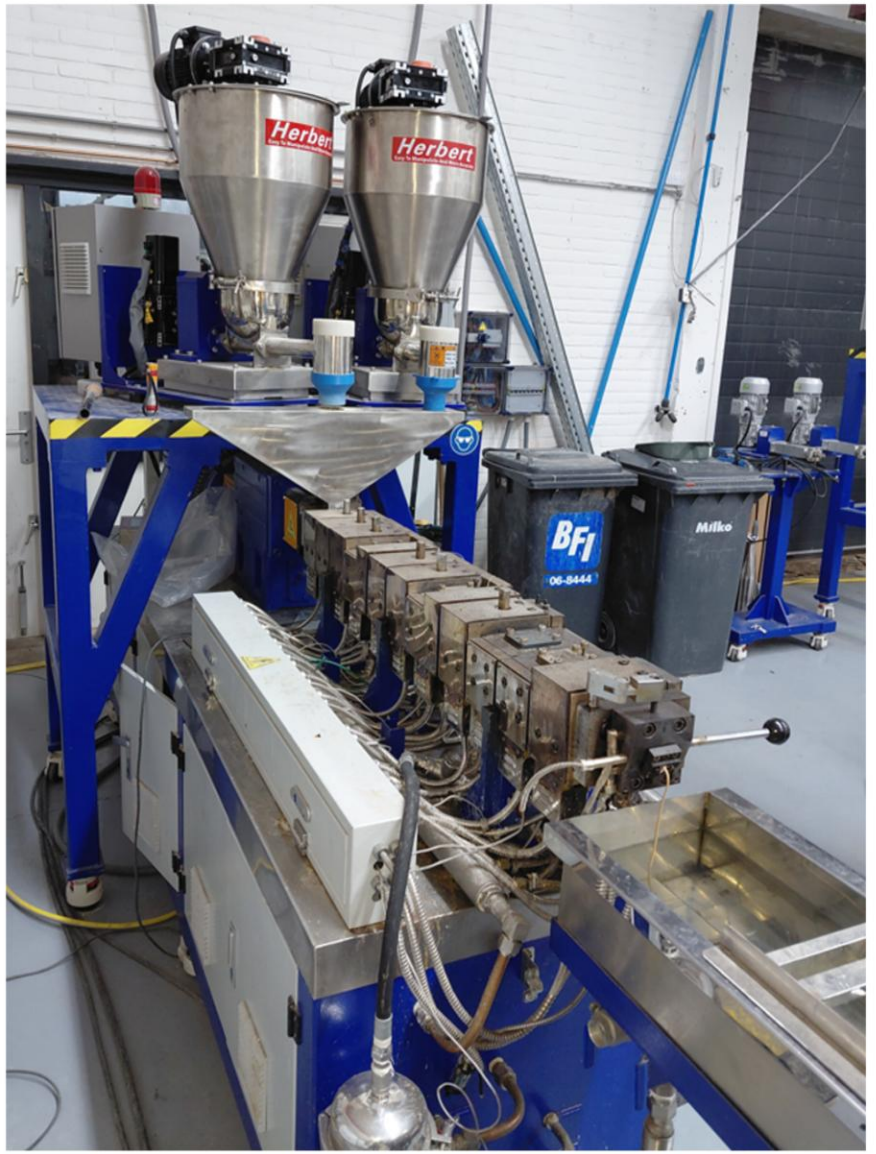
Important:

- Keep shear low
- Keep residence time low
- Melt temperature 170-175C
- Decomposition above 185°C):

Processing:

- Twin screw extruder with single die
- Feeding through the main feeding throat
- Estimated throughput: 3 kg/h
- Extruder feed zone: 85°C
- Extruder transport zones: 165°C
- End zone / die: 176°C
- Screw speed: 150 rpm
- Temperature profile: 80-120-150-160-165-170-175 °C

*File: PHAUD trials_2026.xlsx*

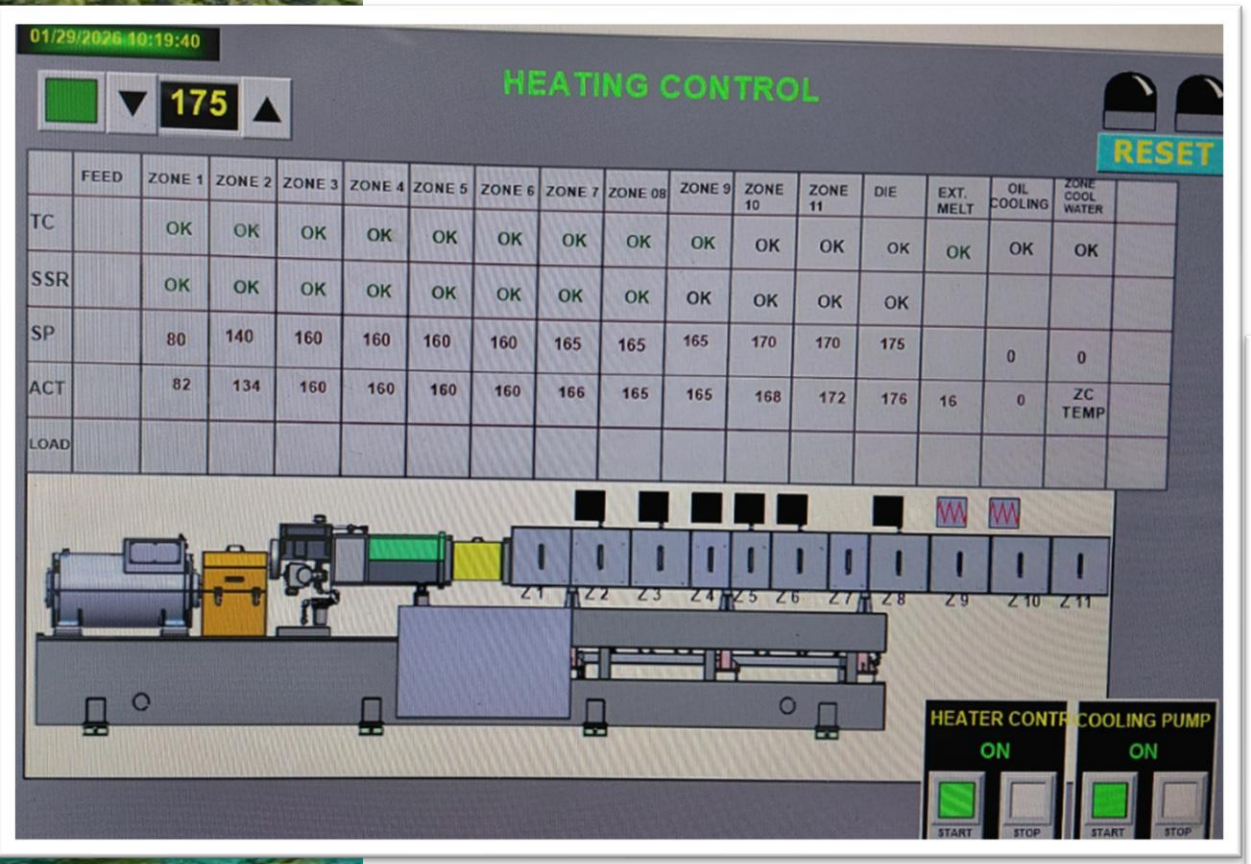


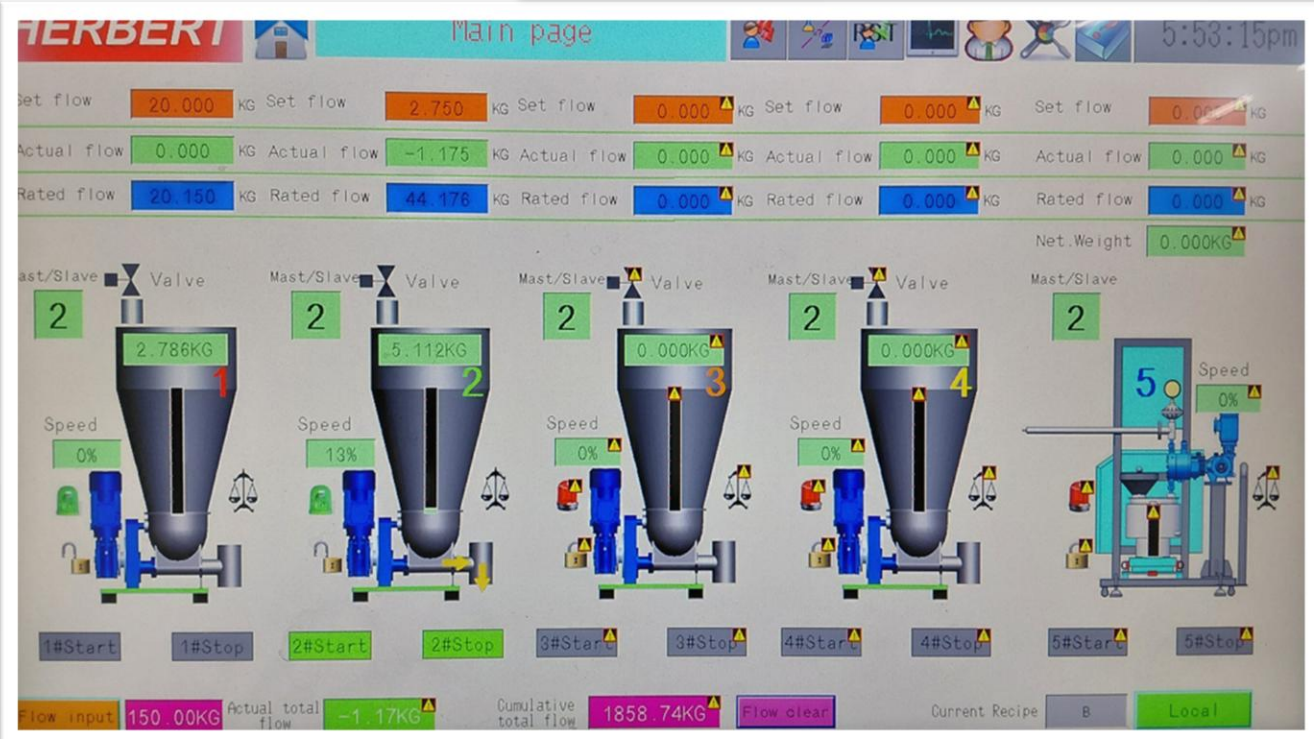
# Mixing & dosing

Gravimetric dosing at extruder (starve feeding)








# Compounding



Happy

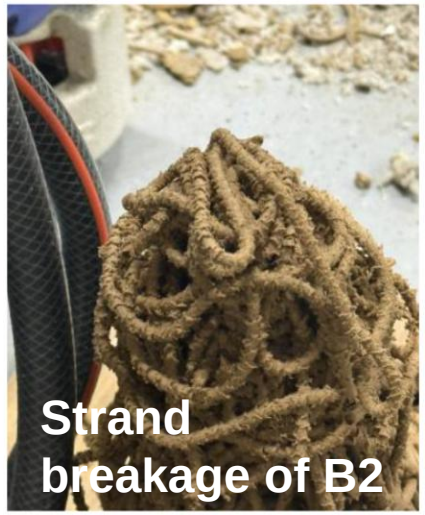


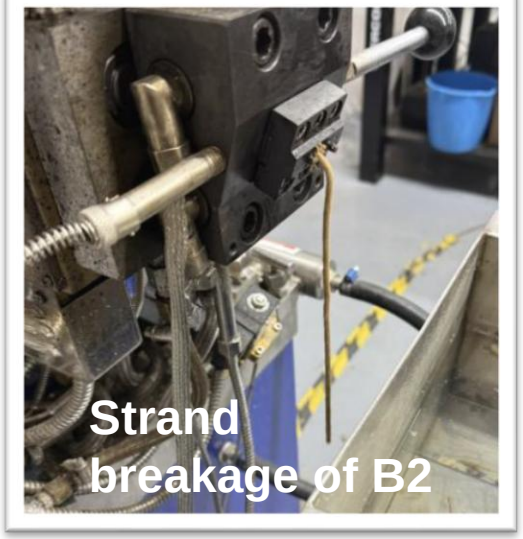
# Compounding findings

Findings during compounding

- Blend ratio of 60:40 showed better melt strength → quicker compounding
- The 45% wood content showed a stable strand
- The 55% wood had no stable strand and was hence the limit of fibre content
- C 2 better processable (continuous dosing due to higher bulk); GS2090 has a large weight distribution that causes inhomogenities and bridging issues

| Variant | PHA-Blend* | | GS 2090 | C 2 | Additive | Quantity (kg) |
|---|---|---|---|---|---|---|
| A1 | 70:30 | 55% | 45% | 0% | 0% | **5** |
| A2 | 70:30 | 55% | 0% | 45% | 0% | **6** |
| B2 | 70:30 | 45% | 0% | 55% | 0% | **5** |
| C1 | 60:40 | 55% | 45% | 0% | 0% | **7** |
| C2 | 60:40 | 52% | 45% | 0% | 3% | **5** |
| C3 | 60:40 | 55% | 0% | 45% | 0% | **16** |


Strand breakage of B2


Strand breakage of B2



# Compounding findings

The MFR shows a wide range:

**MFR (190 °C/2.16 kg)**

- PB3000G (supplier): 3 – 15 g/10 min
- C3 sample: 6,1 - 18,7 g/10 min
  (60%PB3000G:40PB3430G with 45% C2)

**MFR (175℃, 2.16kg)**

- PB3430G (supplier): < 10 g/10 min

*Files: PHA_Wood_Composites_ FinalReport.pdf*
*TDS-PB3000G.pdf, TDS_PB3430G.PDF*

# Aspect ratio

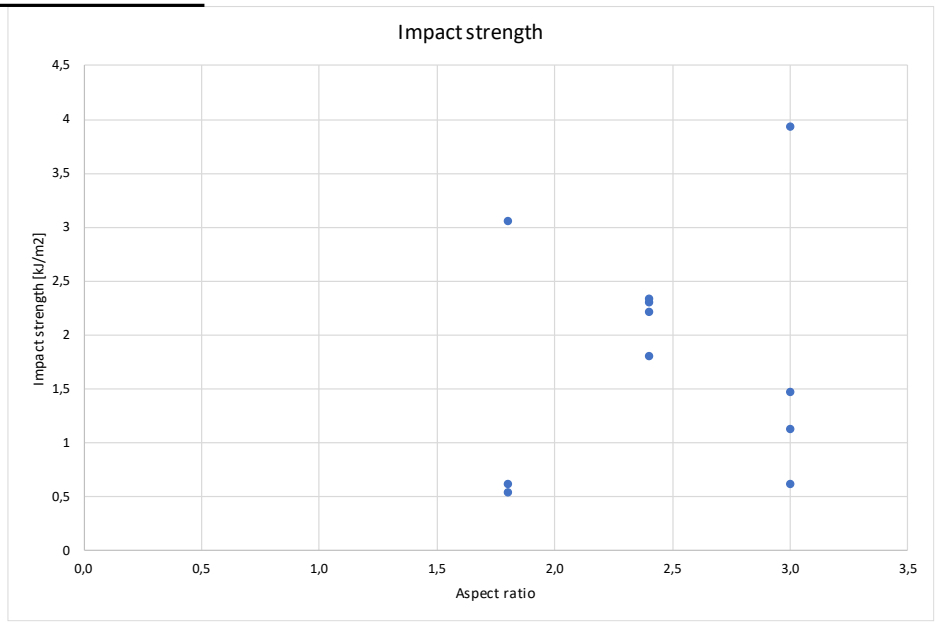
Impact strength related to fibre properties, including PWP project results:

| | Aspect ratio | out of | Average length *[µm]* | Average thickness *[µm]* |
|---|---|---|---|---|
| **GS8020** | 2,4 | 200 | 2230 | 1030 |
| **C120** | 3,0 | 250 | 46 | 17 |
| **GS2090** | 3,0 | | 773±691 | 261±266 |
| **C2** | 1,8 | | 1427±430 | 810±262 |

Impact values at lower limit of impact tester: Is redone with other tester

*File: Test analysis PHAUD.pdf*

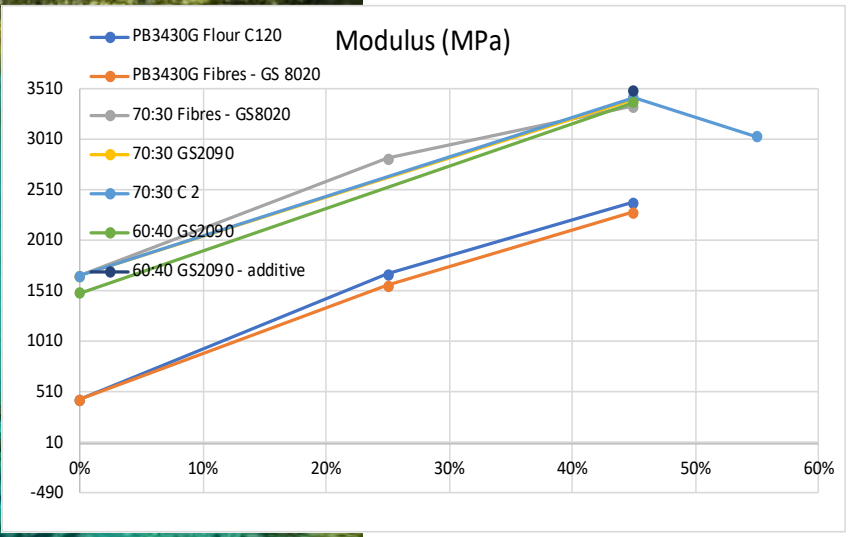


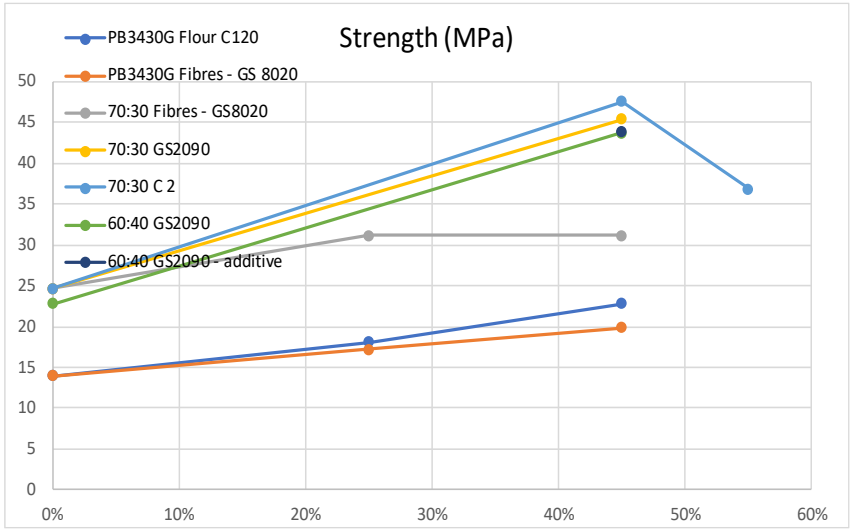


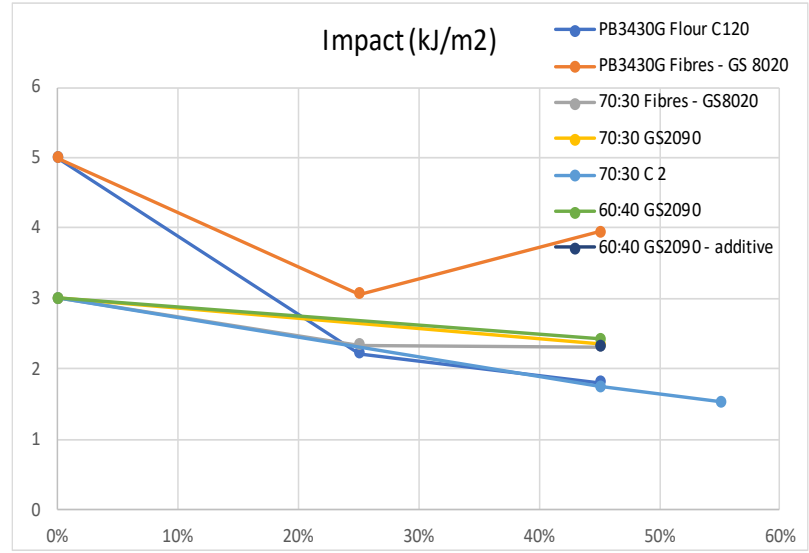
# Compounding findings

## Material testing

- Modulus increases with higher wood content
- At 55% wood content the properties decrease
- The used fibers and flour have comparable effect on mechanical properties; a higher aspect ratio (GS2090 and C120) did not show significant better impact or strength
- Impact resistance decreases at higher fiber content
- Adhesion between matrix and fibers seems to be good; the additive did not show significant change
- Unblended PB3430 shows lower modulus and strength (lower modulus of the matrix)




*File: Test analysis PHAUD.xlsx*



# WP2: Biodegradation

Interreg

[Ko-/finanziert von der Europäischen Union / (Mede) gefinancierd door de Europese Unie]

Deutschland – Nederland

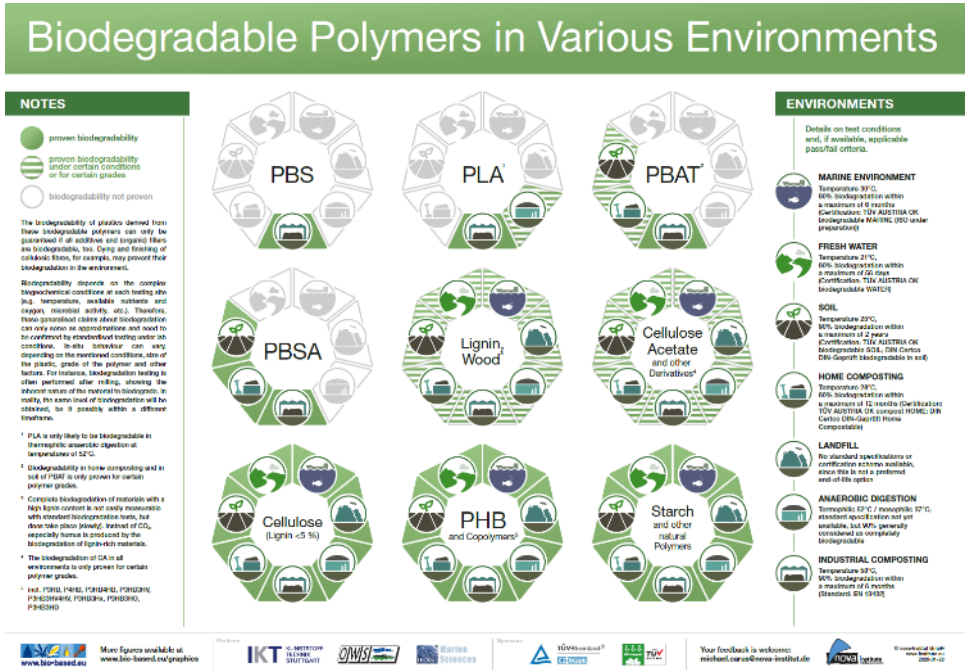
EMPHATI

# Biodegradation

**What are the consequences of biodegradation when adding wood to PHA?**

Analyse biodegradation: what is influence of wood fibres?

- Related to wood content
- Aquatic / soil / UV?
- Desk research
- Empiric research

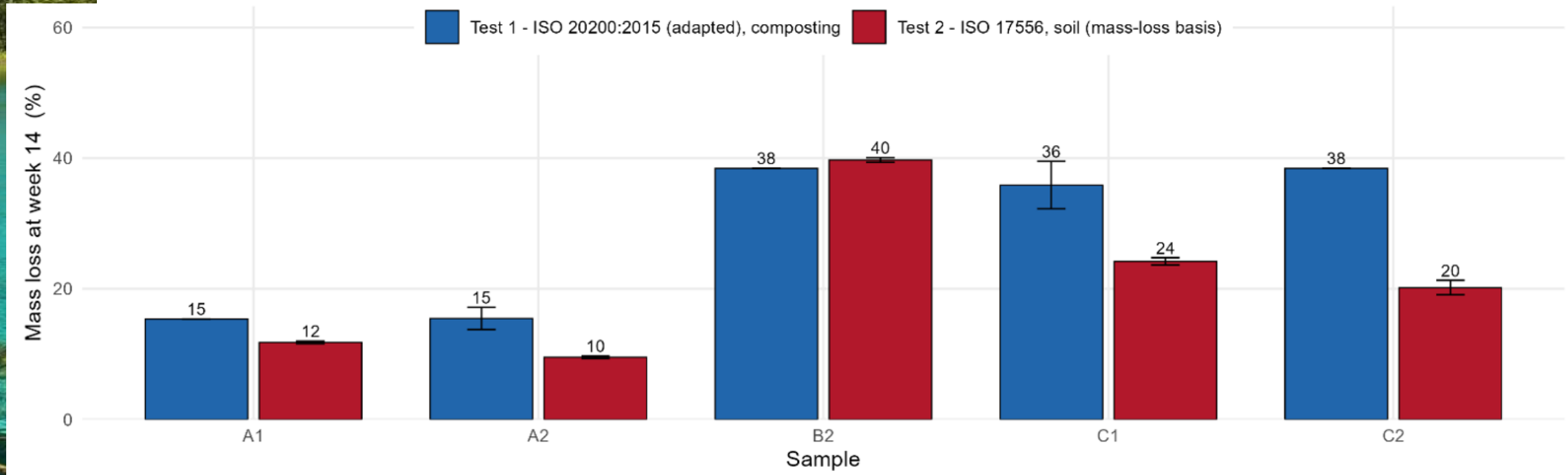



Interreg
(Ko-)finanziert von der Europäischen Union
(Mede) gefinancierd door de Europese Unie
Deutschland – Nederland
EMPHATI

# Biodegradation

Disintegration under two standards: Composting and Soil:

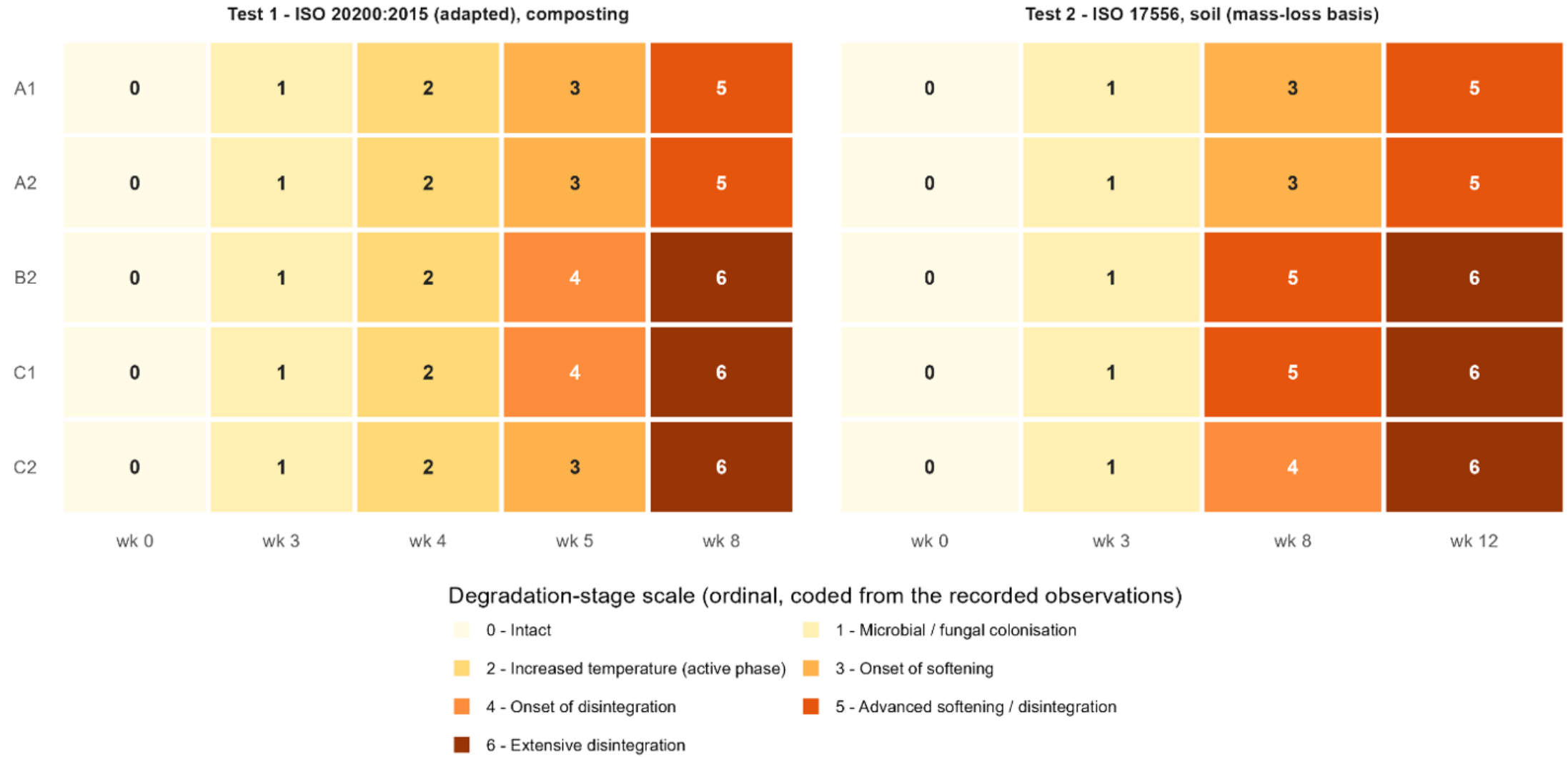
- Mass loss after 14 weeks exposure



# Biodegradation

Disintegration under two standards: Composting and Soil:

- Qualitative degradation over time





# Biodegradation

## Key findings after 14 weeks:

- Formulation A (A1, A2) is the most resistant to disintegration in both environments [70:30 polymer blend]
- Formulation B2 disintegrates the most: Highest wood content: 55 %; according to Chan et al. (2019) biodegradation in PHA-wood composites increases with higher wood content (0, 20, 50 %)
- Formulations C1 and C21 using 60:40-blend shows accelerated biodegradation in comparison to 70:30-blend; according to Weng *et al*. (2011): P34HB disintegrates faster than PHB (lower crystallinity)
- The ranking A < C < B2 is consistent across both standards.
- No proof was found for difference in coarse or fine particles (GS2090 and C 2)
- Qualitative staging aligns with the mass-loss data:
  B2 and C1 reached onset of disintegration earliest and extensive disintegration (stage 6) by the end, whereas the A formulations progressed only to advanced softening (stage 5).


Chan, C. M., Vandi, L. J., Pratt, S., Halley, P., Richardson, D., Werker, A. & Laycock, B. (2019): Insights into the biodegradation of PHA/wood composites: Micro-and macroscopic changes. *Sustainable Materials and Technologies* 21, e00099.

Weng, Y. X., Wang, X. L. & Wang, Y. Z. (2011): Biodegradation behavior of PHAs with different chemical structures under controlled composting conditions. *Polymer Testing* 30 (4), pp. 372-380.



# WP3: Injection moulding Demonstrator

Interreg

(Ko-)finanziert von der Europäischen Union
(Mede) gefinancierd door de Europese Unie

Deutschland – Nederland

EMPHATI

# Injection moulding

**Can the application of these compounds be proven in IM processes at industrial scale?**

Demonstrator product: Scoop, grade C3

- Minimise cycle time while mould temperature not too low
- Minimise dwell time in extruder









# Injection moulding parameters

Injection moulded scoop

*Source: Process conditions.xlsx*

| | | |
|---|---|---|
| Cycle time | 55 | s |
| Product weight | 261,5 | g |
| | | |
| Die-heating | 180 | C |
| Extruder zone1 | 180 | C |
| Extruder zone2 | 175 | C |
| Extruder zone3 | 170 | C |
| Extruder zone4 | 160 | C |
| | | |
| Tool temperature | 40 | C |
| | | |
| Injection pressure | 120 | bar |
| Injection speed | 43 | |
| Holding pressure | 600 | bar |
| Holding time | 6,6 | s |
| Holding pressure | 50 | bar |
| Holding time | 7 | s |
| Cooling time | 36 | s |

Interreg
(Ko-)finanziert von der Europäischen Union
(Mede) gefinancierd door de Europese Unie
Deutschland – Nederland
EMPHATI



# WP4: Fast sintering Demonstrator

Interreg

(Ko-)finanziert von der Europäischen Union
(Mede) gefinancierd door de Europese Unie

Deutschland – Nederland

EMPHATI



# Circular Plastics Lab

Circulariteit in composieten en de kunststoffen

- Projectmanagement
- Productie composieten
- Kunststofrecycling in low-income landen
  Circular River Fashion
- Recycling (thermoplastiche) composieten
- Bioplastics en biocomposieten









# Fast sintering

**Can the application of these compounds be proven in Fast sintering processes at industrial scale?**

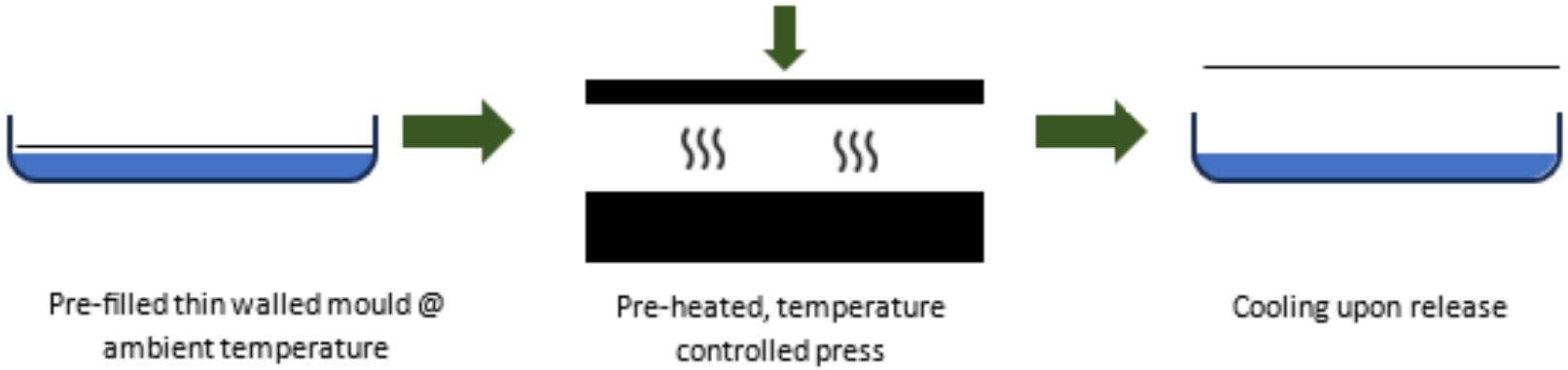
Demonstrator product: lamp



Interreg
(Ko-)finanziert von der Europäischen Union
(Mede) gefinancierd door de Europese Unie
Deutschland – Nederland
EMPHATI

# Fast sintering

## Panel sintering process



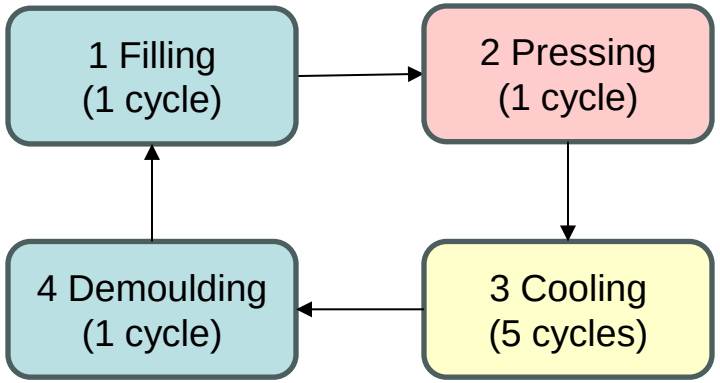

**PHA processing using a panel sintering method:**

- Extremely thin walled panel moulds → minimum heating time
- Reusable moulds bended from metal plates → extremely cheap
- Press platen remain hot → minimum heat losses
- Controlled cooling outside press possible
- Laser cutting of panels → small series possible at low costs

# Fast Sintering

**Sequence**:

1. A thin walled mould is filled with raw material (weighed)
2. The mould is pressed and heated
3. The mould cools down during 5 cycles (ambient)
4. The panel is demoulded

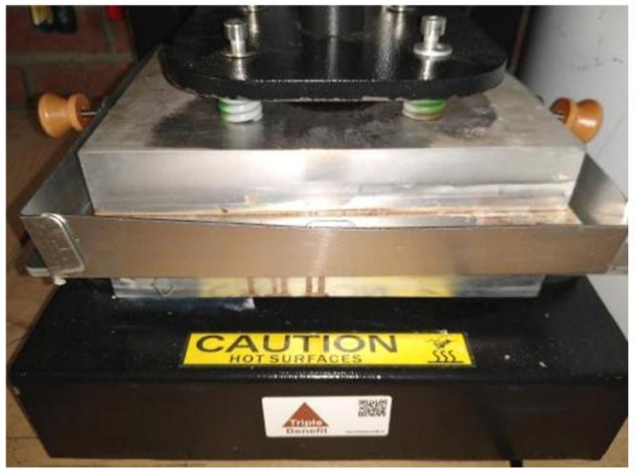


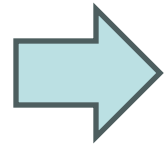

Cycle time: ~ 6 minutes

Semi-continuous production possible with 8 moulds

# Processing by sintering

Force controlled press: Desktop → Industrial







# Processability by sintering

**Quick sintering with mould exchange:**

- No change-over losses
- No (pre-) heated mould
- No cycle time loss during mould cooling
- Minimal energy loss due to small mass
- Extremely cheap, also with small series
- Combined with laser cutting, extremely flexible

**Injection moulding**:

- Change-over losses / purging
- Heated mould → tiny process window
- Heating and cooling of mould difficult
- Mould exchange per cycle not feasible
- Moulds are costly
- Only cost effective with large series

**Cut-offs can be recycled**

# Project PHA - Ultimate Demonstrator

## Panels with increasing PB3000G (21x21 cm):

**0% PB3000 : 100% PB3430**
(45% GS8020) - #4



**60% PB3000 : 40% PB3430**
(45% GS2090) – C1



**70% PB3000 : 30% PB3430**
(45% GS2090) – A1



***PB3430 improves processability / matrix flow → max. 60% PB3000G***

# Project PHA - Ultimate Demonstrator

**Panels with increasing flour content (21x21 cm):**

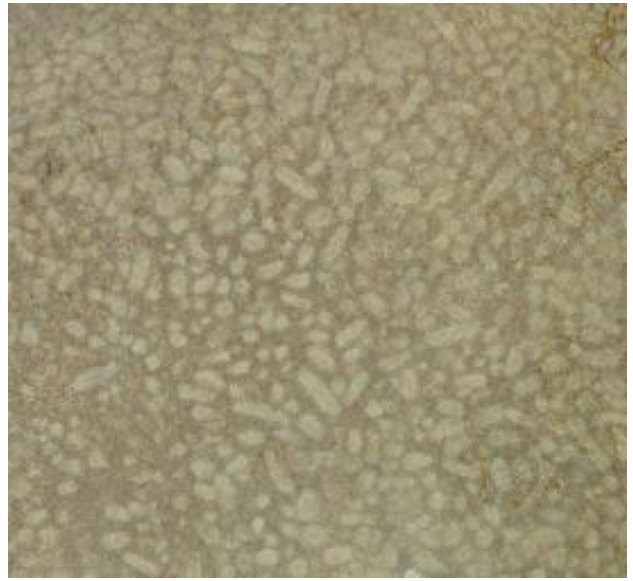
**25%** (C120, **PB3430**)
#1



**45%** (C2, 70:30)
A2



**55%** (C2, 70:30)
B2



***55% flour makes material inhomogenous → max. 45% flour***

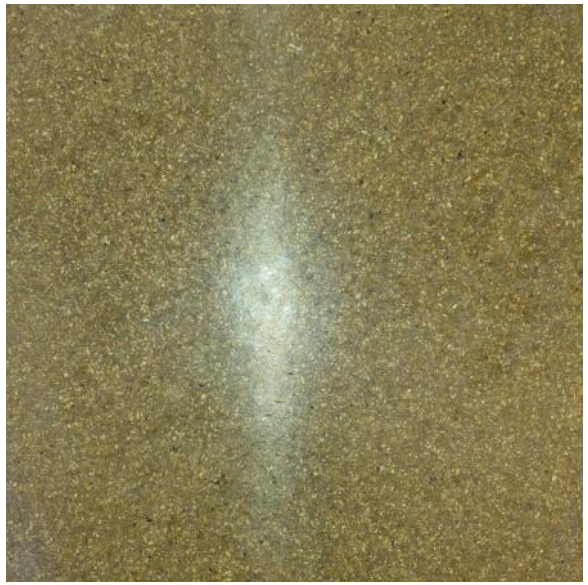
# Project PHA - Ultimate Demonstrator

**Panels with increasing fibre content (21x21 cm):**

70% PB3000 : 30% PB3430:

**25%** (GS8020)

#5



**45%** (GS8020)

#6



**45%** (GS2090)

A1



***45% fibre content is feasible***

# Project PHA - Ultimate Demonstrator

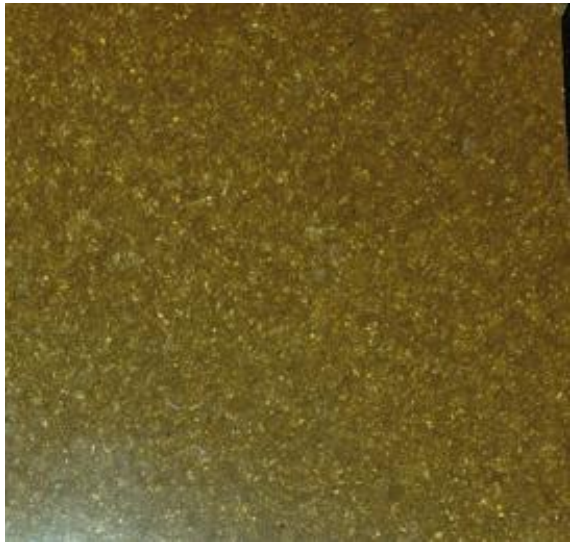
**Panels with additive (21x21 cm):**

60% PB3000 : 40% PB3430:

45% GS2090
C1



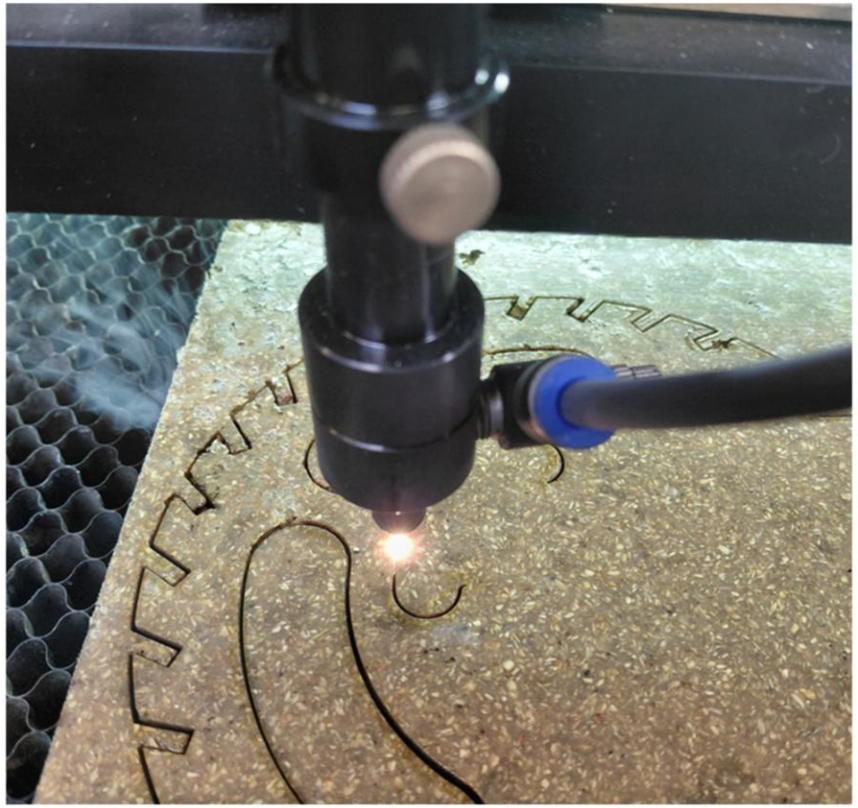
45% GS2090, **3% additive**
C2

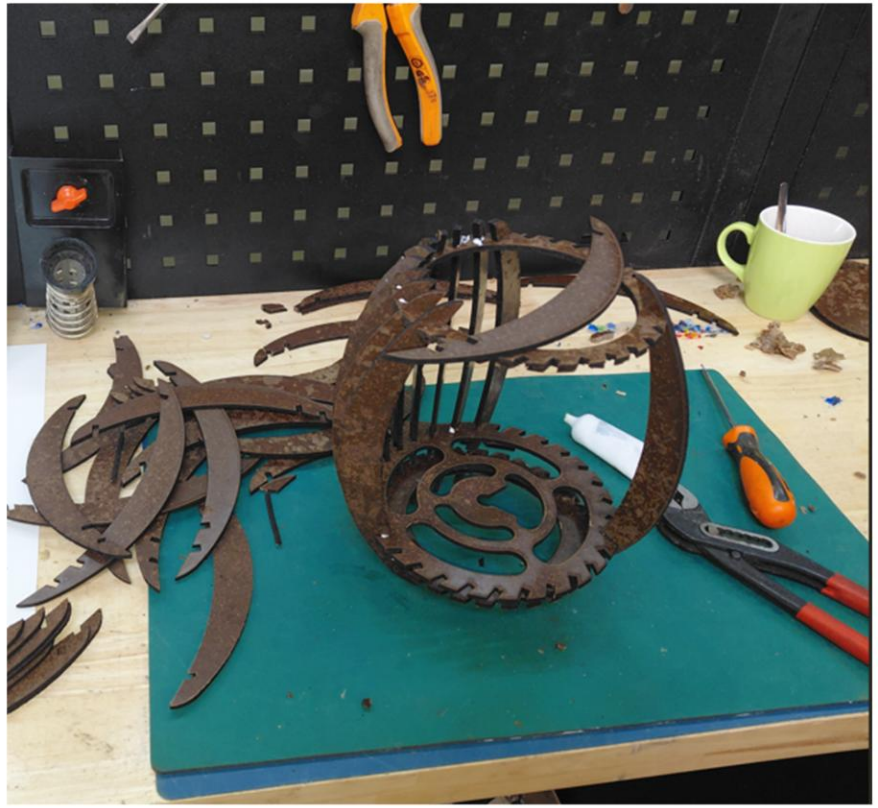


***No additive needed***

# Demonstrator lamp

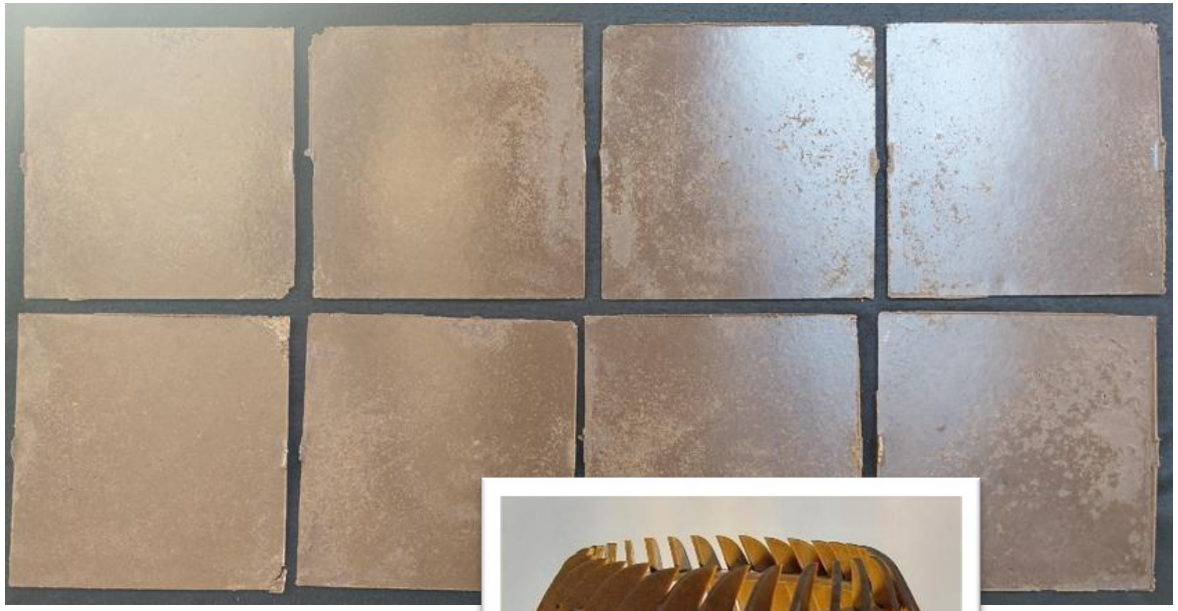
Cutting & assembly



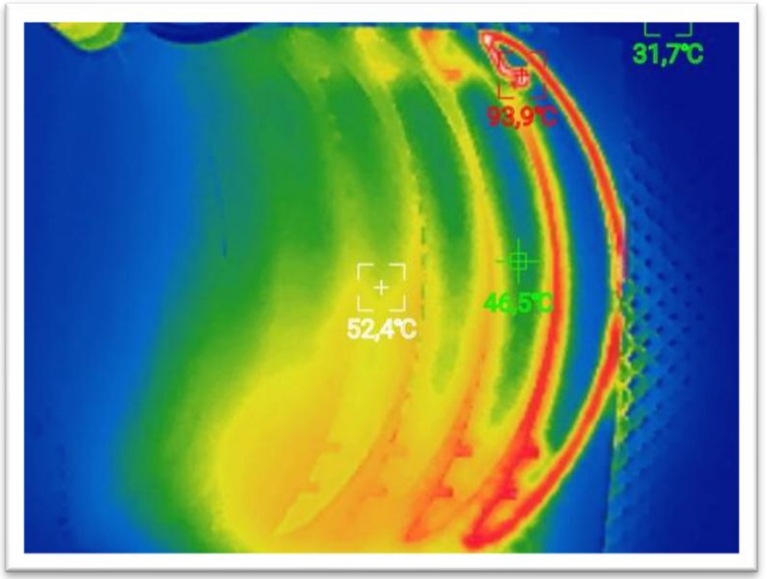




# Demonstrator: Lamp

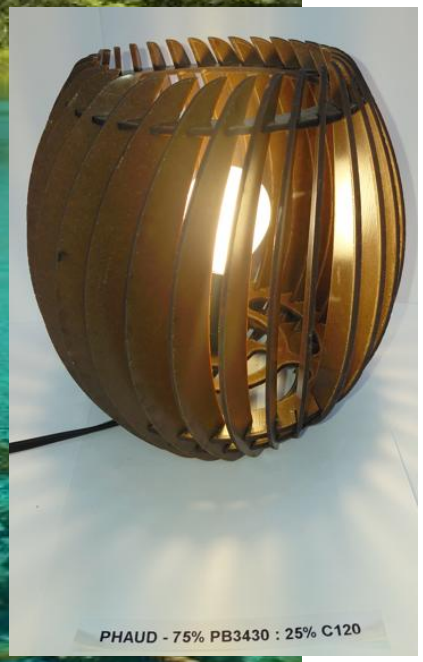






# Demonstrator: Lamp

- Grade #1: 75% PB3430G : 25% C120 — good
- Grade #3: 75% PB3430G : 25% GS8020 — good
- Grade #0: 50% PB3430G : 50% GS8020 — weak
- Grade A2: 38% PB3000G : 17% PB3430G : 45% C2 — extremely fragile
- Grade C3: 33% PB3000G : 22% PB3430G : 45% C2 — good















# Larger panels 60x60 cm



3 mm, Mixed recyclate



11 mm, Mixed recyclate



8 mm, (Grade C2)

38% PB3000G : 17% PB3430G : 45% GS2090

# Panel 60x60 cm

Panel from Grade C2

Grade: C2 (60:40, 45% GS2090)

8 mm, 12 min, 190º C, Pressure 15 ton





# Demonstrator: Stool

From 8 mm grade C2



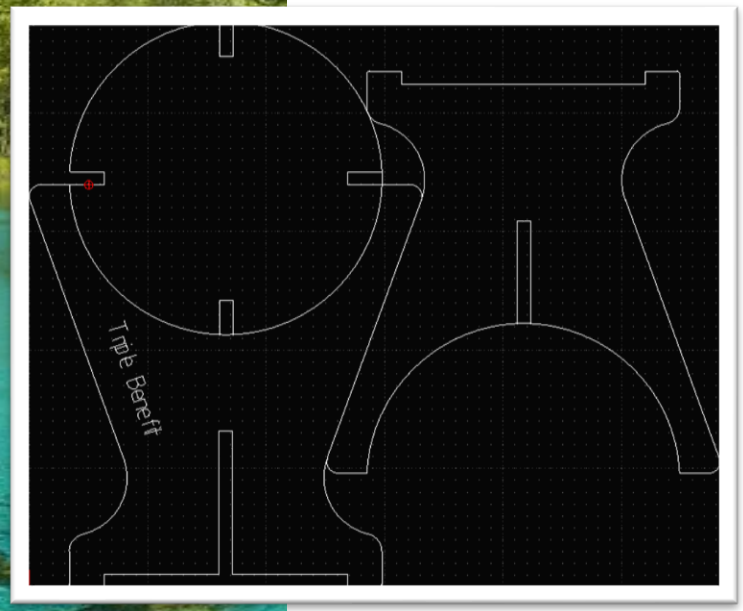




*File: Stool 8mm.pdf*

# Demonstrator: Stool

From 11 mm mixed recyclate panel





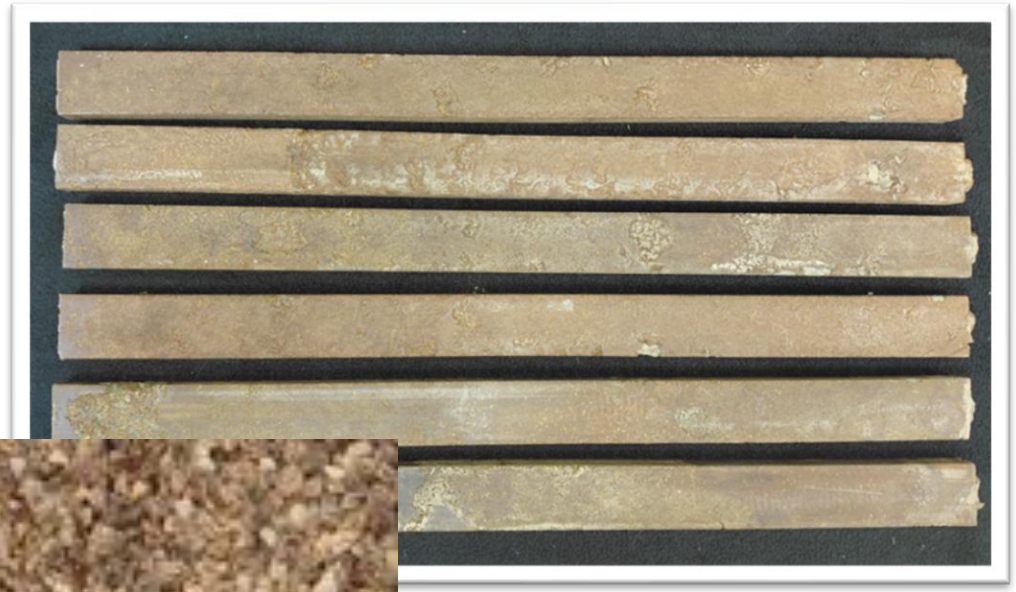



*File: Stool 11mm.pdf*

# Prototype: Flow moulded beams

**Recycled wood-PHA (cut-offs from other panels)**

16x36 mm









# Conclusions

1. High wood content is limited by both processability and mechanical strength
2. A maximum is around 45%, depending on polymer blend and type of wood filler used
3. Within 3 weeks material degradation is evident for all grades under compost/soil conditions
4. Injection moulding works well with compound C3 (45% flour)
5. Fast sintering works best with compound C3 (45% flour)

# Thank you for your attention



Further info:
rikvoerman@triplebenefit.nl

Interreg
Co-funded by the European Union