Descriptive study and evaluation of shrink hoods with recycled content for regulatory compliance

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Overview

- **Introduction**
  - **General motivation MultiRec project**
  - **Description case study on shrink hoods**
- **Materials & Methods**
- Results
  - Chemical characterisation
  - Mechanical/thermal characterisation
  - Transport simulation
- Conclusion & next steps

Motivation & problem statement of MultiRec-project

- Stretch/shrink wrapping of pallets
  - The need: Shipping of packaging → vibration, shocks, handling operations → sliding + tipping over
  - Advantages (besides load stability): Cost-effective, versatile, protective, efficient, transparent
- Legislation & eco-modulation
  - Packaging and packaging waste regulation (PPWR) sets targets for recycling
  - Plastic tax
  - Bonus myRecycledContent
- Number of cycles x recycled content: Impact?
  - Cast/blown film extrusion, composition, mechanical/seal performance, life cycle assessment

Use of multi-processed PE in pallet films is inevitable

- Objective
  - Suitable material composition for cast/blown film extrusion + acceptable recyclate films (heat contact/ultrasonic sealing, transport film)
- A CORNET-collaboration of Flemish, German and Polish partners
  - Flanders (VLAIO): MPR&S, ACC
  - Germany (DLR): Fraunhofer-IVV, Fraunhofer-IGCV, IVLV
  - Poland (NCBR): WUST, Green Chemistry

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Today's presentation

Case study of MultiRec

- Why this case?
  - PPWR: 35% PCR in transport packaging by 2030
  - Commercial films with PCR already on the market
  - How do these materials perform in practice?

- What is being evaluated?
  - LDPE shrink hoods with 30–35% PCR-PE: extrusion blown tubular films that are sealed to form a hood → shrink process on pallet to stabilize loads
  - Used for heavy loads (1.3-ton brick pallets)

- Why is it relevant?
  - **Description of chemical composition + current performance**
  - Expose material variability

- Note:
  - No multi-recycled content (yet)

Materials

Shrink hoods with 30–35%

- Film types (LDPE-based):
  - 4 commercial shrink hood films: F-35PCR_A, F-35PCR_B: 35% post-consumer recyclate
  - F-30PCR_C, F-30PCR_D: 30% post-consumer recyclate
- Supplied by member supervisory group
- Tubular (blown) films (128 cm wide)
- Top is heat-sealed and applied to interlocked stacks of 1.3-ton bricks on wooden pallets
- Granulate analysed:
  - PCR A (used in F-35PCR_A): mixed light/dark
  - PCR C (used in F-30PCR_C): more homogeneous

Figure 1: Sealed hood (left) and palletised load with shrink hood applied (right)

Methods

Analytical approach: from chemistry to transport

- Chemical characterisation:
  - Differential scanning calorimetry (DSC): Thermal transitions & crystallinity (melting peaks, enthalpy)
  - Gel permeation chromatography (GPC): Molar mass (M_W, M_N) & dispersity
  - Gas chromatography – Mass spectrometry (GC-MS): Additive screening

- Thermal properties:
  - Sealability: Max. seal strength vs. temperature (ASTM F88)
  - Thermal shrinkage: Machine and cross direction (MD and CD) behavior vs. temperature (ASTM D2732)

- Mechanical properties of unshrunk films:
  - Coefficient of friction (COF, ISO 8295): Inner/outer surface to metal plate
  - Tensile (ISO 527-3), puncture (ASTM F1306), tear resistance (ISO 6383-2)

- Transport simulation
  - Swing tests + influence of vibrations, hot humid conditioning

Figure 2: Transport simulation equipment used in this study. (A) swing device to simulate horizontal collisions; (B) forklift for pallet transport; (C) vibration table; (D) walk-in climate chamber.

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Results chemical characterisation

DSC

- Cristallinity and melting behaviour
  - 1st vs. 2nd heating cycle suggests possible multilayer structures, but inconclusive due to similar PCR behavior
  - PCR A: Differences between different coloured granulate of same batch
    PCR C (other batch): higher melting point (~125.5 °C), narrower peak → more homogeneous, likely LLDPE-rich
  - Films with identical PCR levels show similar thermal profiles
  - Lower enthalpy values in PCR (95–103 J/g) vs. films (>108 J/g) → lower crystallinity, reduced chain packing

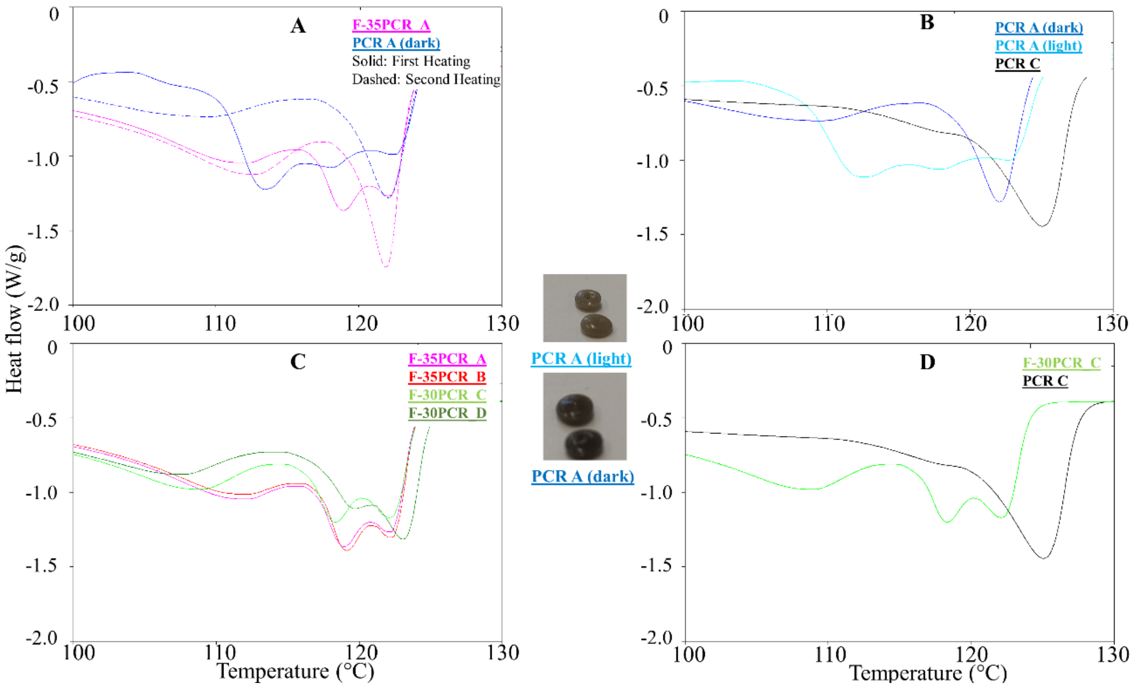

Figure 3: DSC thermograms: (A) two heating cycles of F-35PCR and PCR A; (B) first heating of two granulate types, with PCR A split by colour (dark and light); (C) first heating of four films compared; (D) first heating of F30PCR A vs. PCR 2.

Results chemical characterisation

GPC

- Molecular weight (distribution)
  - Films A, B and C show high dispersity (Đ 6.4–7.1) F-30PCR_D shows lowest dispersity (Đ = 4.8) possible shrink performance limitation Dispersity affects bubble stability + shrinkage correlates with blown processing-induced orientation.
  - Chain length is also relevant, as it affects melting point and sealing behaviour
  - PCR A (light) has lower M_N, higher Đ than PCR C → greater heterogeneity

	M_n (kg/mol)	M_w (kg/mol)	Đ
F-35PCR_A	38.0	270.4	7.1
F-35PCR_B	40.5	257.6	6.4
F-30PCR_C	40.8	274.1	6.7
F-30PCR_D	50.5	242.2	4.8
PCR A - dark coloured	46.7	275.3	5.9
PCR A - light coloured	24.9	199.6	8.0
PCR C	44.3	282.1	6.4

Table 1: Number- and weight- average molecular weight (M_N, M_W) and dispersity (Đ) of films and PCR granulates.

Results chemical characterisation

GC-MS

- Additive screening
  - Identifies Irganox 1076, oxidised Irgafos 168, and erucamide in films and PCR
  - Similar profiles suggest monolayer blends rather than coextrusions
  - Lower erucamide in PCR A (compared to PCR C) highlights need for additive compensation
  - Oxidation markers indicate prior degradation, especially in PCR

➔ Essential to monitor additive levels to ensure processability and stability

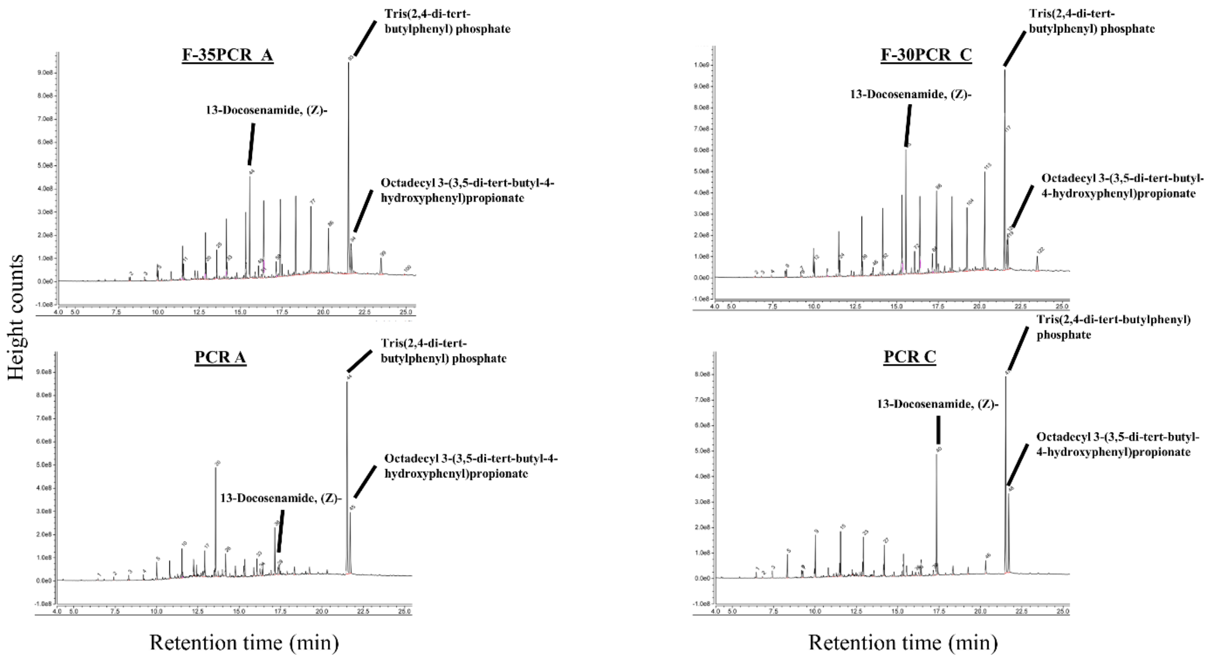

Figure 4: Mass spectra of F-35PCR_A and F-30PCR_C, alongside the spectra of their respective PCR granulates.

Results thermal characterisation

Heat seal performance

- Seal strength increases with bar temperature in a sigmoidal trend
  - All films show similar sealability and failure behavior
    Minor variation: F-30PCR_C seals at slightly higher temperature
  - Sharp transition from peel to tear failure occurs around 125 °C
    Slope: driven by interfacial adhesion (chain mobility + interdiffusion explain temperature–strength relation)
    Plateau height reflects film strength

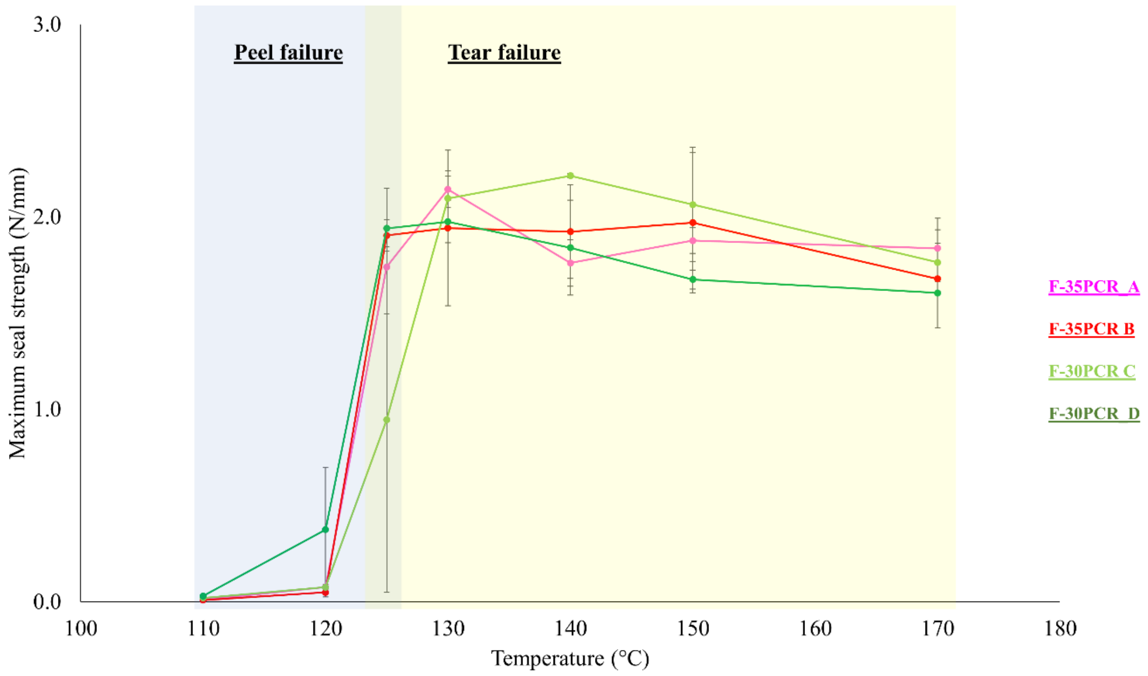

Figure 5: Evolution of maximum seal strength and failure mechanisms (peel, tear) of the inner side of films as a function of bar temperature.

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Results thermal characterisation

Thermal shrinkage

- Sigmoidal trend
  - Sharp increase between 110 °C and 130 °C, followed by a plateau beyond melting point
- Plateau values
  - ~60% in machine direction (MD)
    ~40% in cross direction (CD)
  - Lower shrinkage in CD can be related to limited orientation due to low blow-up ratio, while high MD shrinkage can be related to a higher drawdown ratio
  - Minor differences among films (e.g., F-30PCR_D shrinks more; F-30PCR_C less)

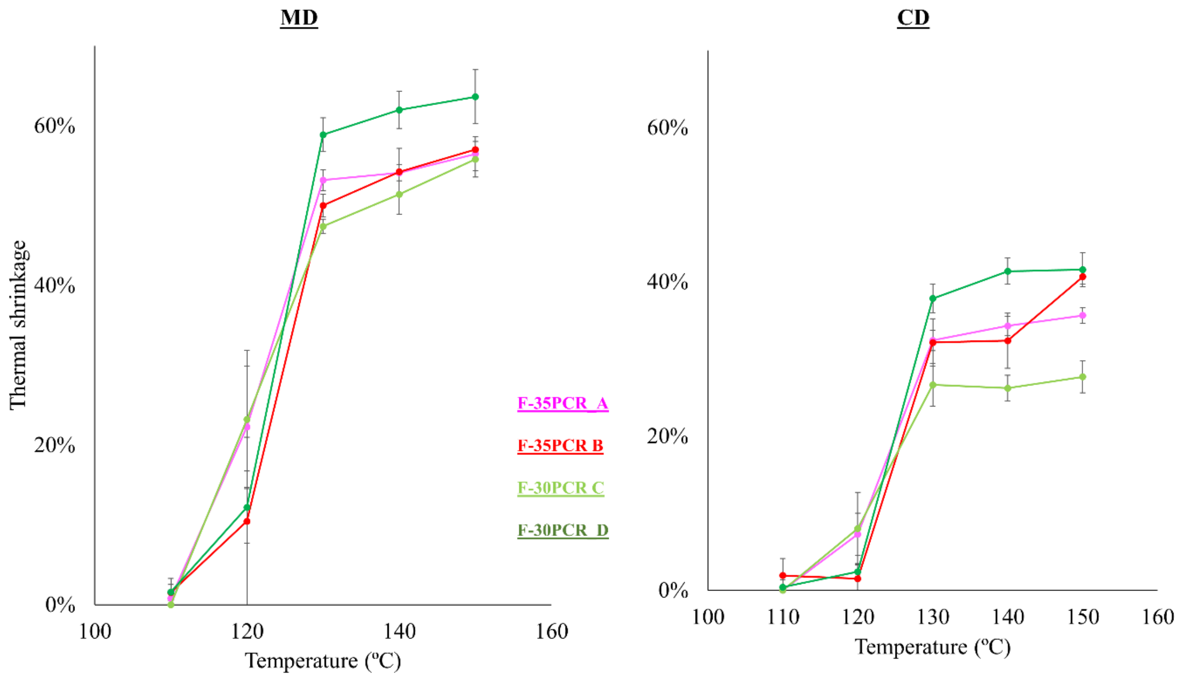


Figure 6: Thermal shrinkage of films in machine direction (MD, left) and cross direction (CD, right).

Results mechanical characterisation

Coefficient of friction / other mechanical properties

- μ_d: 0.189–0.251 | μ_s: 0.255–0.308
  - Higher than in other study (10.1177/07316844241272979)
- Substantial variation between films for the same application
  - Up to 33% difference in outer layer μ_d (e.g., 0.189 vs. 0.251)
  - Likely caused by differences in PCR composition, slip agent content
  - May affect machine handling (e.g. film guidance, roll uniformity)
- Other mechanical properties
  - Tensile stress shows clear variation in MD
F-30PCR_D is notably weaker despite identical application (14 MPa vs. 20 MPa for F-30PCR_C)
  - Large variations also observed in tensile elongation in MD
  - Minor variations in puncture force and tear resistance

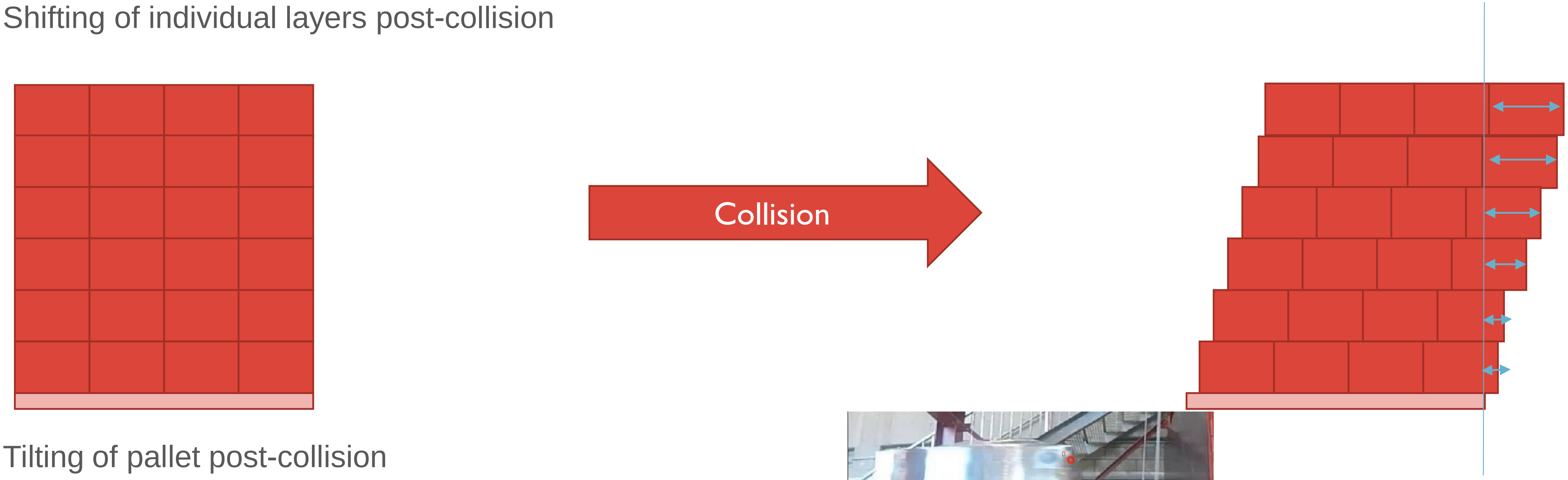
Film	$\mu_{d\text{-inside}}$	$\mu_{s\text{-inside}}$	$\mu_{d\text{-outside}}$	$\mu_{s\text{-outside}}$
F-35PCR_A	0.197 ± 0.008	0.274 ± 0.005	0.189 ± 0.002	0.292 ± 0.009
F-35PCR_B	0.186 ± 0.007	0.255 ± 0.008	0.188 ± 0.003	0.270 ± 0.013
F-30PCR_C	0.209 ± 0.003	0.285 ± 0.015	0.205 ± 0.006	0.302 ± 0.018
F-30PCR_D	0.237 ± 0.007	0.283 ± 0.013	0.251 ± 0.012	0.308 ± 0.019

Table 2: Dynamic and static coefficients of friction (µ) for the inner and outer surfaces of the films

Transport simulation

Swing test: evaluating the outcomes

- Shifting of individual layers post-collision



- Tilting of pallet post-collision
  - Tracking movement edges (https://physlets.org/tracker/), relative to fixed component (pink circles below)

- +influence 3h random vibrations (ISTA 3E)
  - Not possible because of load instability
- +influence hot humid conditioning
  - 72 h at 38°C/50% RH, then 6 h at 60°C/30% RH

Results transport simulation

Swing test

- F-35PCR_B outperformed F-30PCR_C in swing tests
  - Less horizontal displacement and tilt (0.12 m vs. 0.16 m after 2 s) → Potentially related to tighter wrap due to higher shrinkage
- Tearing at rear corners observed in all cases, yet loads remained partially contained
- Hot humid conditioning improved stability
  - Suggests enhanced ductility and brick friction under elevated temperature
- Vibration caused partial collapse, but films held load together

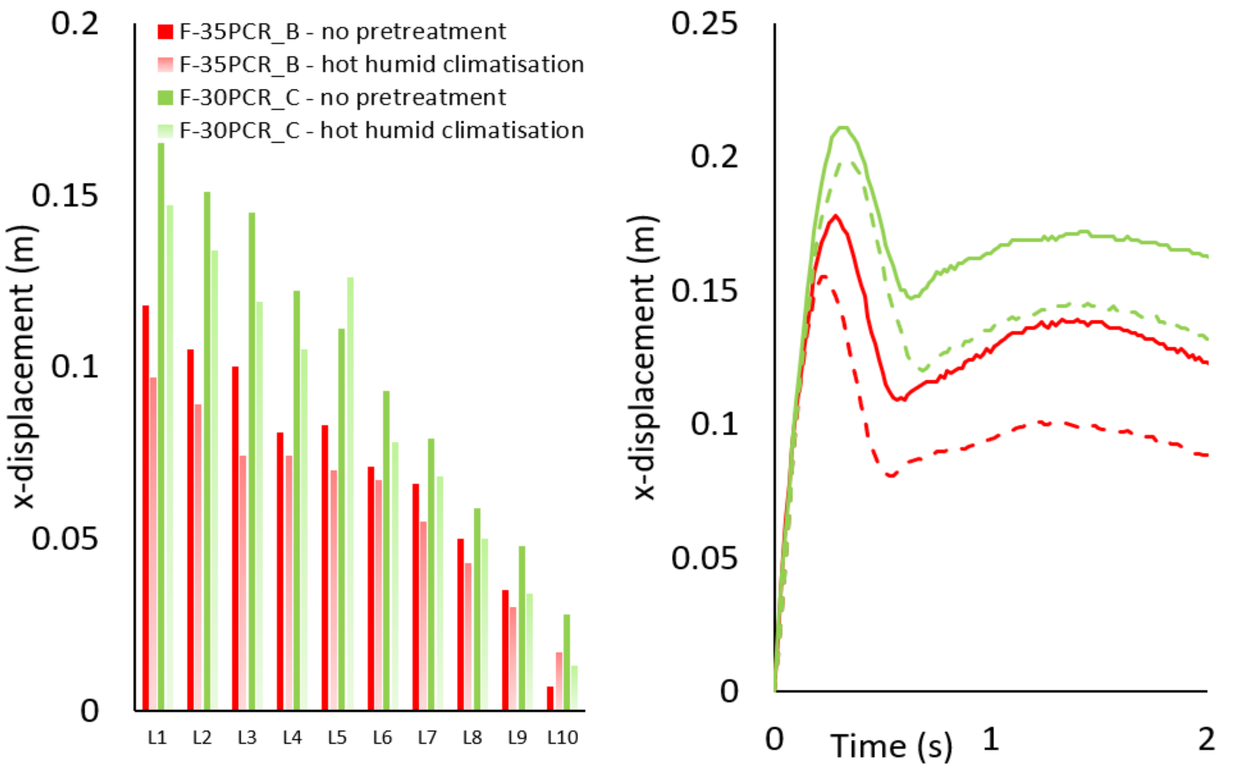


Figure 7: Horizontal displacements of the 10 brick layers after the swing test (left), with L1 as the top layer and L10 as the bottom, and during the swing test (right, only the top layer), caused by tilting.

Figure 8: (A) Rear view of the pallet showing a side tear after the swing test. (B) Side view of the pallet with a tear after the swing test. (C, D) Bulging observed after >15 min vibration. (D) 26° tilt test. Labels and logos have been covered with white rectangles for confidentiality.

Conclusions

- Shrink hoods for identical use (1.3-ton brick pallets) show clear variability in mechanical and thermal properties

- Chemical analysis revealed:
  - Variability within PCR types (e.g., light vs. dark granules)
  - Lower melt enthalpy in PCR (95–103 J/g) + reduced crystallinity
  - Additive content

- Consistent film performance requires:
  - Better control of PCR quality → Targeted adjustments in virgin blends and processing

- Open, systematic research is essential to ensure reliable circular packaging in demanding transport conditions

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Thank you for your attention!

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