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A study into the hot tack and cooled seal performance of emerging coated papers for primary flexible food packaging

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1/ Motivation & objective

Why coated paper?

1. **EU 'Green deal': 100% reusable and/or recyclable packaging in 2030**
2. **Wood fibre**
   - Renewable resource
   - Mechanical recycling of paper: long history (+ 100 years)
   - Paper packaging: Consumer often prefers paper over plastic film
3. **Food packaging**
   - •Gas/moisture barrier, heat sealability, mechanical performance → plastic films combines all functionalities
   - •Paper: printable and stiff BUT low gas/moisture barrier, not heat sealable, brittle → Composite structures (lamination, coating) are needed to increase performance

Limitations of heat sealable paper

1. **Recyclability: Allowable thickness seal layer < 20 µm**
2. **Low thermal conductivity compared to plastic**
3. **Low dead fold → high spring-back force when seal jaws are opened**

Objective: analyze seal performance of commercial coated papers

1. **By correlating seal outcomes (hot tack and cooled down seal strength) with the coating composition and thermal properties**
2. **By evaluating the influences of various seal parameters, including jaw temperature, seal time, seal pressure, and cool time**

2 Materials and methods

Materials

16 food-grade, heat-sealable materials

1. **Vary in terms of barrier properties, production processes, and polymer origins in the coatings**
   - 12 dispersion coatings, two are coated by extrusion, and two possess a wax coating
   - 14 of these materials are existing commercial coated papers, the papers with codes II.a and IV.a were specially coated in a laboratory setting
2. **Stored ≥ 48 h in standard atmosphere (ISO 187): 23 °C ± 1°C and 50 % ± 2 % relative humidity**

Code – Thickness – Grammage Description	Code – Thickness – Grammage Description
I.a - 65 ± 1 µm - 67 ± 0 g/m² ethylene, metacrylic acid, acrylate copolymer dispersion	I.b - 72 ± 1 µm - 45 ± 0 g/m² acrylic, polyethylene vinyl acetate copolymer dispersion
I.c - 99 ± 1 µm -102 ± 2 g/m² acrylic acid copolymer dispersion	I.d - 70 ± 1 µm - 69 ± 0 g/m² acrylic copolymer dispersion
I.e - 86 ± 1 µm - 80 ± 1 g/m² proprietary polymeric component dispersion	II.a - 146 ± 3 µm - 03 ± 1 g/m² cellulose nanocrystals dispersion
II.b - 82 ± 2 µm - 71 ± 1 g/m² vacuum metalized dispersion	II.c - 60 ± 1 µm - 55 ± 1 g/m² vacuum metalized dispersion
II.d - 56 ± 1 µm - 67 ± 1 g/m² vacuum metalized dispersion	III.a - 92 ± 2 µm - 71 ± 1 g/m² proprietary vegetable wax
III.b - 73 ± 2 µm - 44 ± 1 g/m² ethylene copolymer and wax	IV.a - 73 ± 3 µm - 41 ± 2 g/m² polyvinylalcohol (PVOH) dispersion
IV.b - 55 ± 1 µm - 45 ± 0 g/m² PVOH dispersion	IV.c - 75 ± 1 µm - 65 ± 1 g/m² polyolefin dispersion
IV.d - 97 ± 1 µm - 98 ± 1 g/m² polyethylene (PE) and ethylene vinyl alcohol extrusion	IV.e - 126 ± 3 µm - 100 ± 1 g/m² polyolefin extrusion

2 Materials and methods

Methods

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Material characterization

Differential scanning calorimetry (DSC)

- To determine a glass transition temperature (T_g) and/or melting temperature (T_m) of the coated papers
- Heated between temperatures of -50 to 150°C, two heating runs at 10°C/min
- Results of second heating run are reported

Seal characterization

Hot tack strength (ASTM F1921)

- Four fixed seal settings to evaluate impact of jaw temperature
  - Seal time: 0.3 – 1.0 s
  - Seal pressure: 0.2 – 2.0 N/mm²
  - Cool time: 0.1 – 1.0 s

Seal time (s)	Seal pressure (N/mm²)	Cool time (s)
0.3	0.2	0.1
0.3	2	0.1
1.0	2	0.1
0.3	2	1.0

Cooled seal strength (ASTM F88)

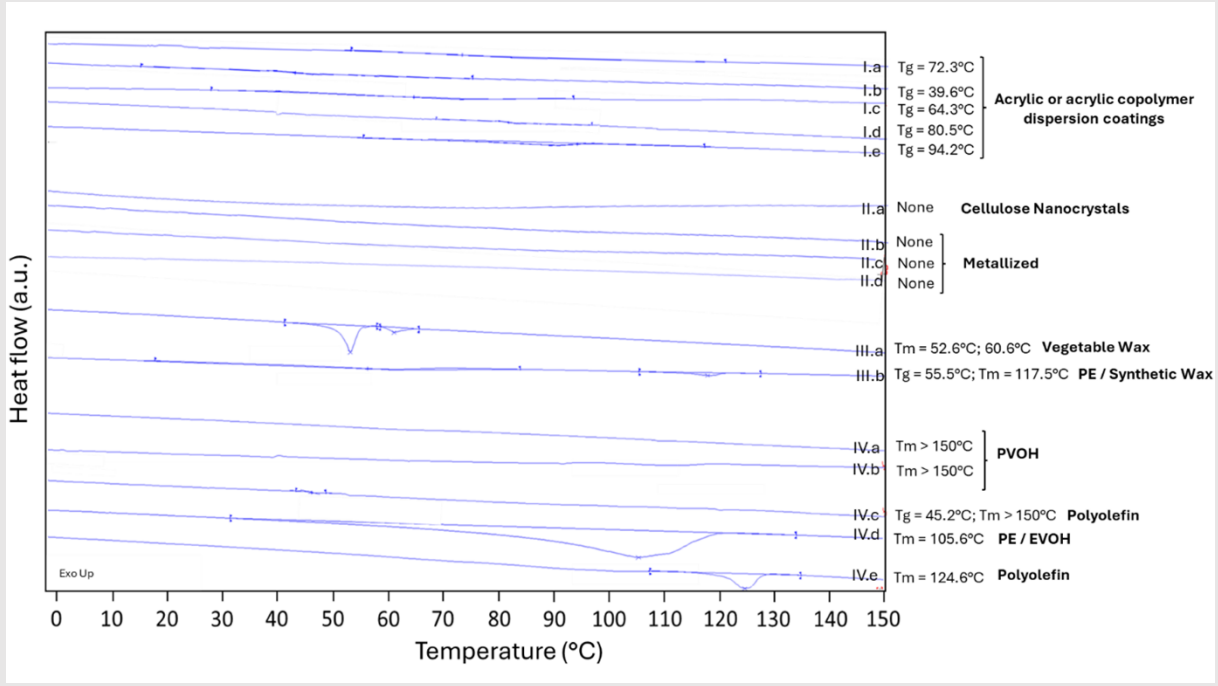
- Single fixed seal setting to evaluate impact of jaw temperature: 0.3 s seal time – 2.0 N/mm² seal pressure – 4 h cool time

Seal interface temperature measurements

- Using a Type K precision membrane thermocouple

3 / Results & discussion

DSC thermograms



- **Class I**
  - acrylic or acrylic copolymer (e.g. acrylic/styrene- or acrylic/vinyl-based) polymer coatings
  - T_g
- **Class II**
  - metallized papers or paper coatings with cellulose nanocrystals
  - No thermal transitions in scanned range
- **Class III**
  - wax coatings
  - T_m's, corresponding to the composition of the specific wax
- **Class IV**
  - polyolefins or PVOH
  - T_m at expected melting intervals of polyolefins or with melting temperatures beyond the temperature limits

3 Results & discussion

Hot tack curves, n=3

Seal time (s)	Seal pressure (N/mm²)	Cool time (s)
0.3	0.2	0.1
0.3	2	0.1
1.0	2	0.1
0.3	2	1.0

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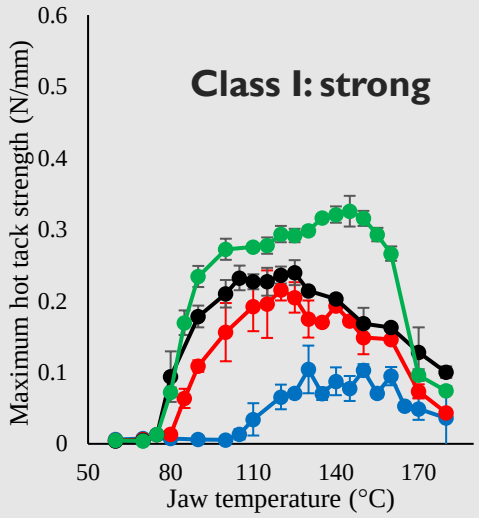
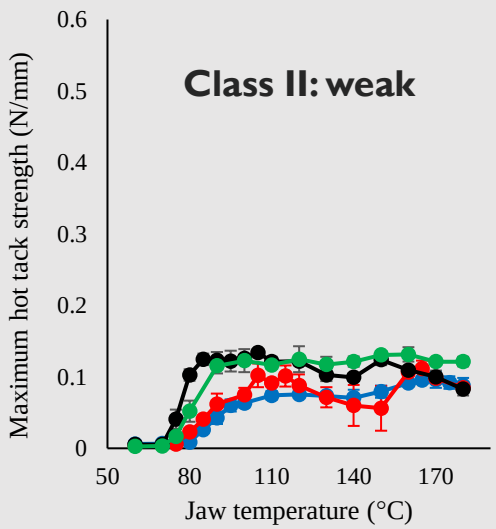
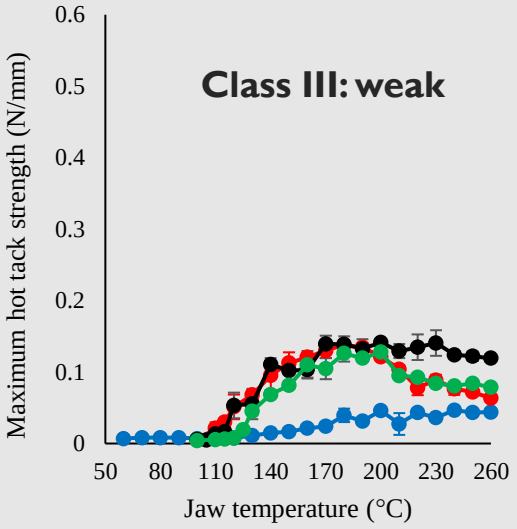
I.d



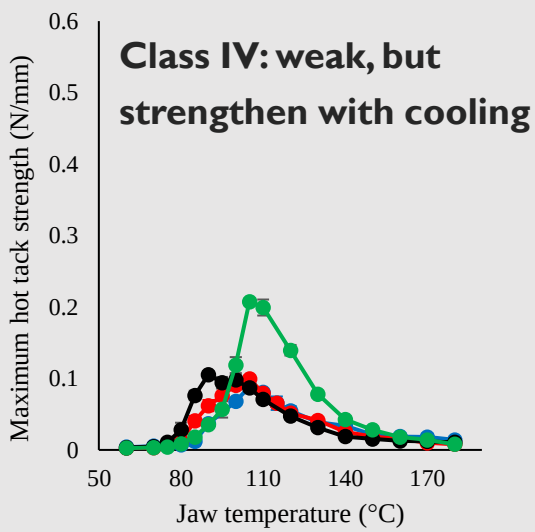
II.b



III.a



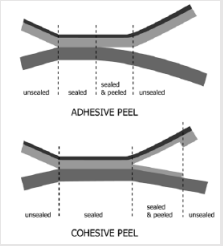
IV.b



General

- Clear relationship between hot tack strength and seal failure mechanism: fibre tear > adhesive failure
- Influence of seal parameters
  - Seal time (red-black curves): limited to no impact of seal time (most pronounced in II.b)
  - Seal pressure (red-blue curves): influences hot tack characteristics in many coated papers, exceptional positive effect in I.d and III.a
  - Cool time (red-green curves): hot tack strength generally enhanced through longer cooling, e.g. IV.b double in strength after 1.0 s

Schematic representations in ASTM F88



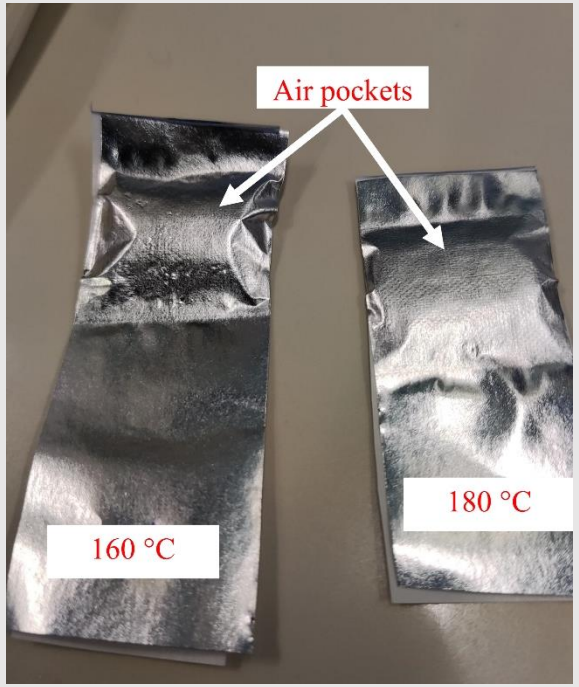
Fibre tear

3 Results & discussion

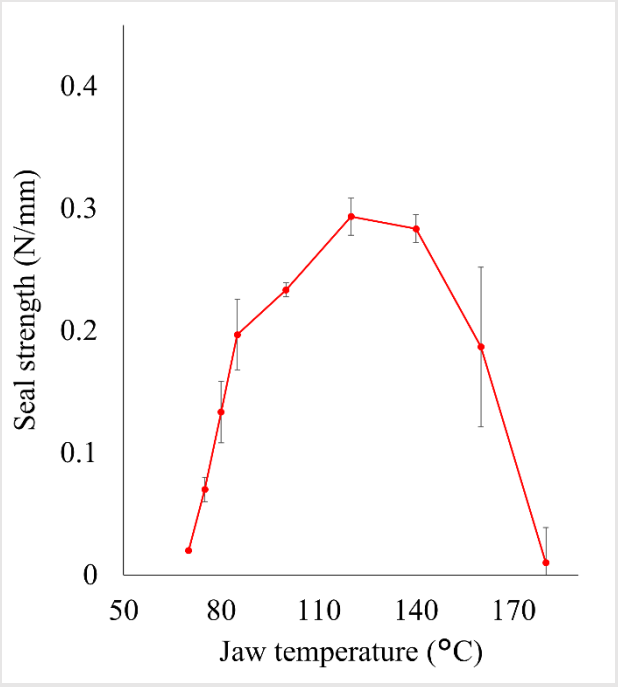
Cooled seal strength, n=3

Code	Seal strength characteristic	
	Peak value (N/mm)	Seal failure mechanism
I.a	0.22 ± 0.01	Mainly fibre tear
I.b	0.19 ± 0.02	Mainly fibre tear
I.c	0.56 ± 0.05	Mainly fibre tear
I.d	0.29 ± 0.01	Mainly fibre tear
I.e	0.69 ± 0.04	Mainly fibre tear
II.a	0.06 ± 0.01	Adhesive peel
II.b	0.06 ± 0.01	Mainly cohesive peel
II.c	0.15 ± 0.01	Mainly cohesive peel
II.d	0.27 ± 0.01	Mainly fibre tear
III.a	0.24 ± 0.01	Mainly fibre tear
III.b	0.29 ± 0.02	Mainly fibre tear
IV.a	0.16 ± 0.05	Mainly fibre tear
IV.b	0.28 ± 0.02	Mainly fibre tear
IV.c	0.28 ± 0.04	Mainly fibre tear
IV.d	0.74 ± 0.03	Mainly fibre tear
IV.e	1.14 ± 0.06	Mainly fibre tear

II.c



III.b



Strength – failure mechanism

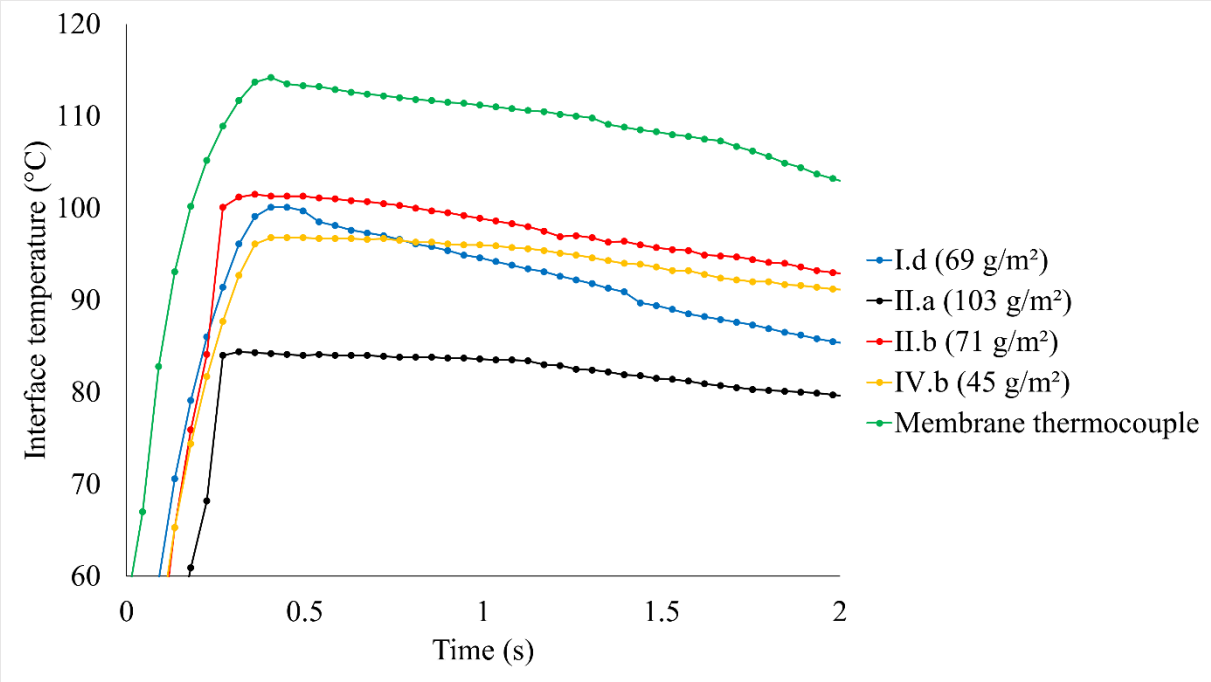
- Most coated papers fail via fibre tear after extended cooling
- Papers with peel failure (class II) have low seal strength
- No clear trends for class I, III and IV papers

Other observations

- Air pocket formation in some papers at high jaw temperatures (e.g. air pockets in II.c at 160 and 180°C)
- In some papers the seal strength decreases at high temperatures (e.g. seal curve III.b)

3 Results & discussion

Seal interface temperature, n=5; Settings: seal temperature 120 °C and seal time 0.3 s (cooling down after sealing

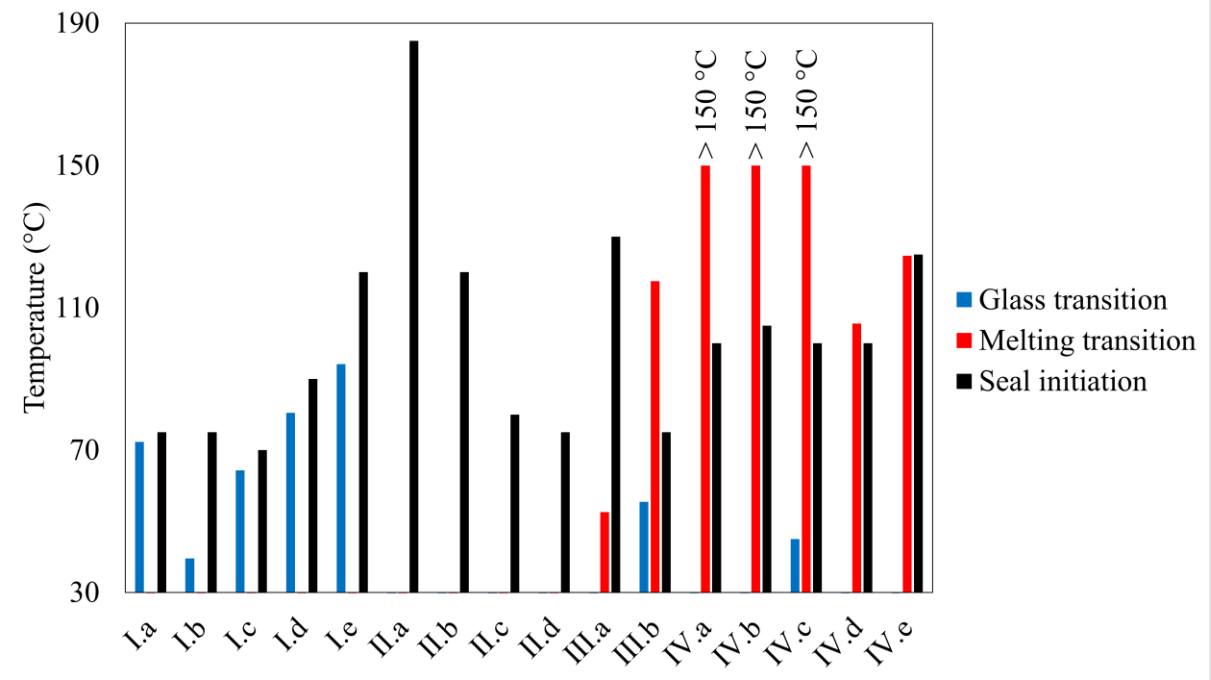


Observations

- Without a paper sandwiched around the membrane thermocouple (green curve), setpoint value is not achieved after brief seal time
- High grammage paper achieves lowest seal interface temperature
- Low grammage papers achieve higher interface temperatures. No clear trend: 45 g/m² paper (IV.b) achieves lower maximum than 70 g/m² papers (can be influenced by consumption of energy by thermoplastic material)

3 Results & discussion

Correlating DSC transition temperatures with seal initiation



Observations

- Class I: T_g's are slightly lower than seal initiation temperatures
- Class II: no thermal transitions
- Class III and IV: less sensitive in determining seal initiation temperature
- Nuances: influence of coating thickness + type (consumes energy), coating contains also gas/liquid barrier thermoplastics

3 Results and discussion

Polymer composition and seal performance dynamics

Class II: apparent thermal inertia in DSC → very low hot tack and cooled seal strengths, likely due to insufficient thermoplastic presence

Seal initiation requires mobile chains

Acrylic copolymers (class I) are largely amorphous, T_g needs to be exceeded to allow diffusion and entanglement across the seal interface

Wax (class III) and PVOH, polyolefins (class IV) are semi-crystalline, T_m needs to be exceeded to allow participation of long chains in seal process

Hot tack: melt strength and/or recrystallization

Acrylic copolymers (class I) are held together with hydrogen bonding (besides chain entanglement) → increases melt strength → strong hot tack

Wax (class III) and class IV papers require adequate cooling (recrystallization) to increase strength

- Non polar nature of wax, chains predominantly held together by chain diffusion
- Polyolefins (class IV) have no additional bonds
- PVOH (class IV): can form hydrogen bonds, they appear to play a less notable role in melt strength development

4 Conclusion

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Correlating seal performance with coating composition and thermal properties

DSC results inform seal performance → selection of coated paper to enhance packaging integrity

Influences of seal parameters

Critical role of jaw temperature, dictating efficacy other parameters

Impact of cool time and seal pressure (seal time to a lesser extent)

Thank you for your attention!

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