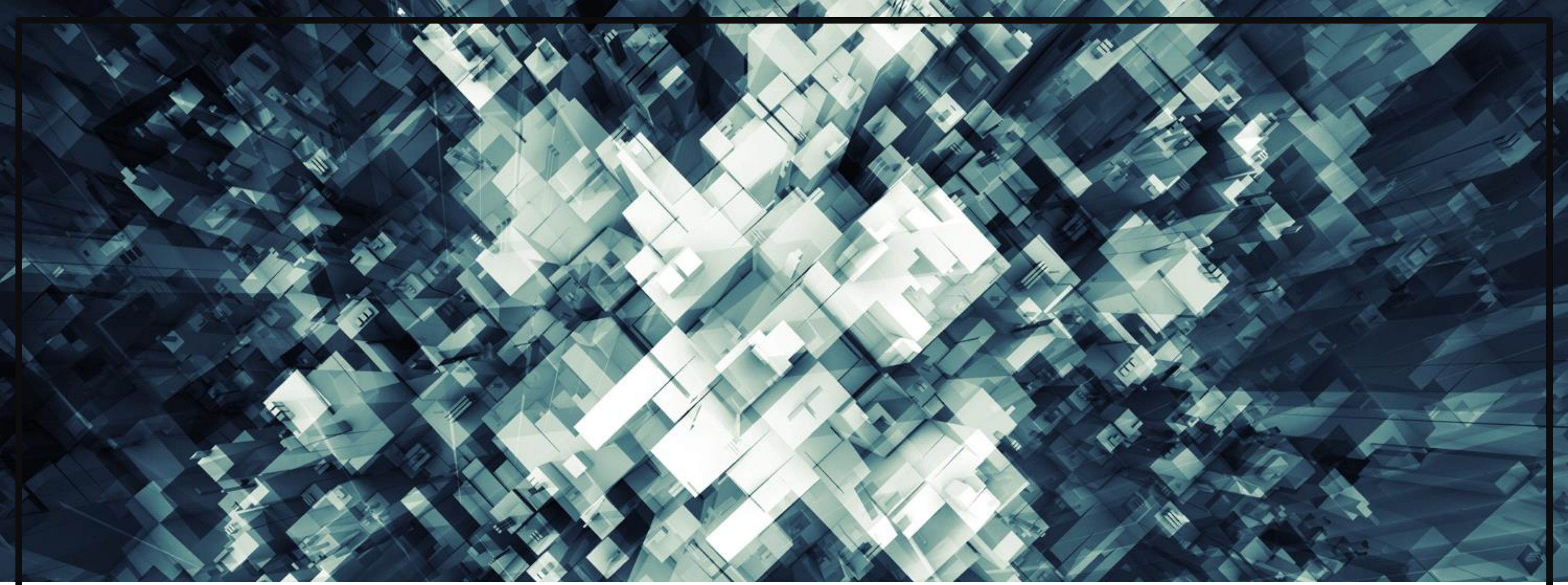

Evaluation of the ultrasonic sealing performance of flexible films with polyolefin seal layer

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Packaging technology center

- Gas permeability
- Material characterization
- Transport simulation
- Environmental influences
- Packaging optimization

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Outline

Introduction

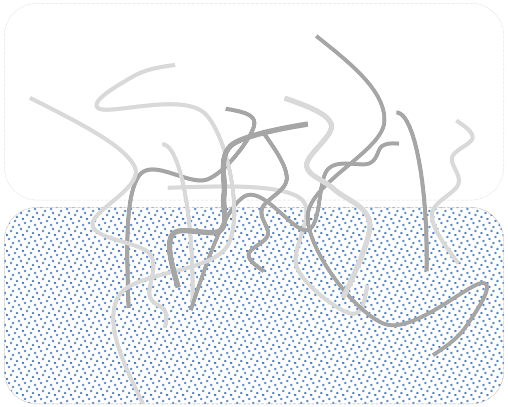
Methods

Materials

Results

Conclusion

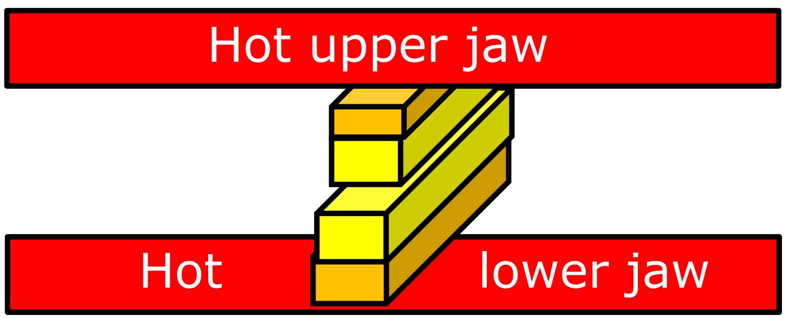
Introduction



- Flexible packaging:
  - VFFS, HFFS
- Closure: heat seal
  - Melting of thermoplastics → Entanglement of polymer molecules
- Heat seal:
  - **conductive**,
  - impulse,
  - hot air,
  - **ultrasonic**,
  - induction current,
  - electrical field loss
  - and hot wire heating

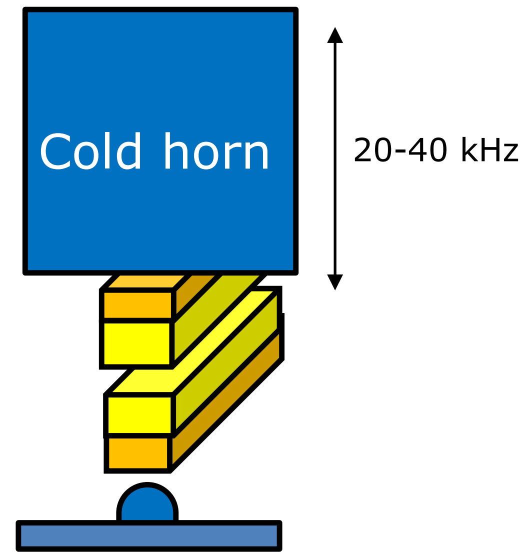
Introduction

- Heat conductive sealing (HCS)



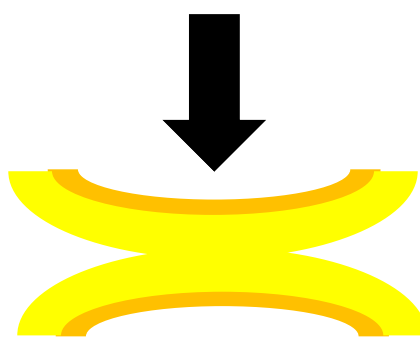
Conductive heating: hot jaw → film layers → seal interface

- Ultrasonic sealing (USS)



Cold anvil with energy director
semi cilinder r = 2.5 mm

Ultrasonic heating: mainly intermolecular friction at seal interface: $Q = \pi \cdot f \cdot \varepsilon_0^2 \cdot E''$



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Methods

- HCS

Seal time: 1.0 s

Seal pressure: 2.46 N.mm^{-2}

Seal temperature: 90 – 200°C

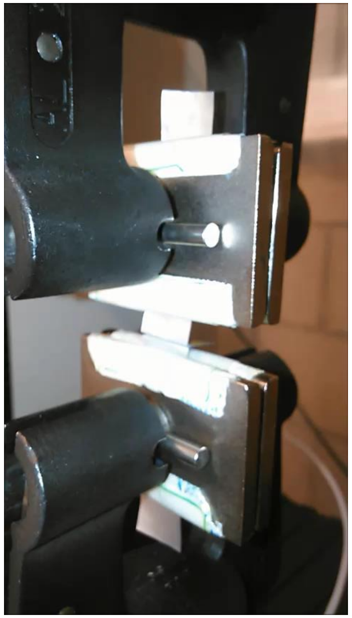
Sample width: 15 mm

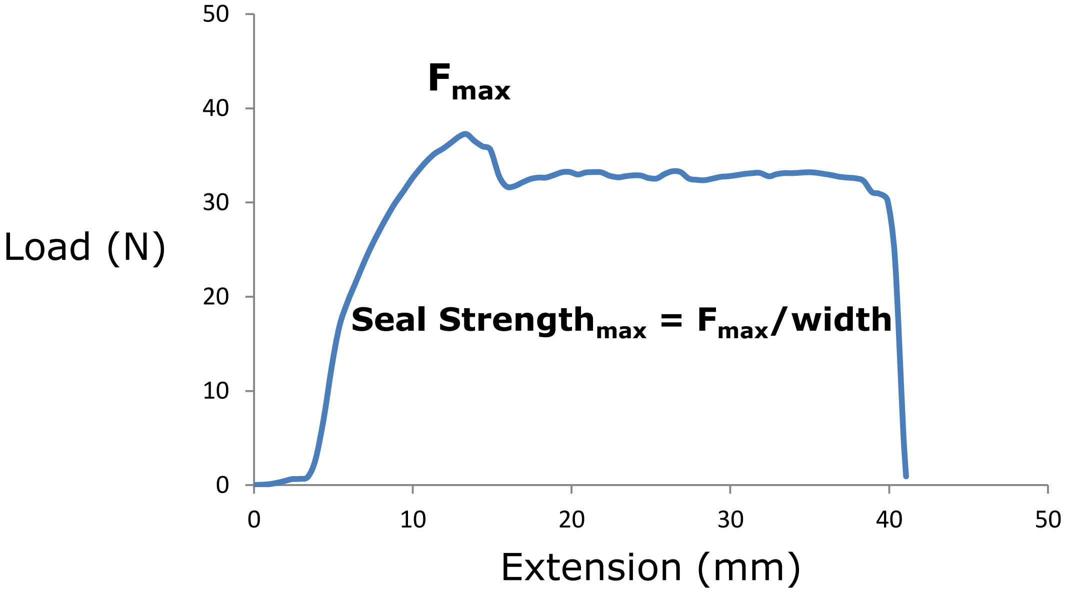
+ silicone film to prevent sticking against the sealing jaws

- USS

Seal time: 0.1 – 0.3 s
Seal pressure: 2 – 6 N.mm^{-1}
Seal amplitude: 18 – 36 µm
Cooling under pressure: 2 N.mm^{-1} – 0.5 s
Radius semi-cilindric energy director: 2.5 mm
Frequency: 35 kHz

Methods



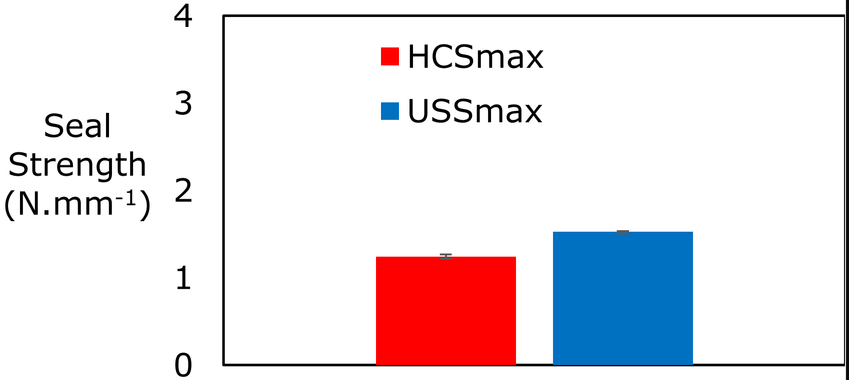


- Seal strength ($N.mm^{-1}$) based on ASTM F88
  - Sample width: 15 mm
  - Clamp distance: 10 mm
  - Speed: 300 $mm.min^{-1}$
- Comparison maximum strength: HCS vs. USS

Methods

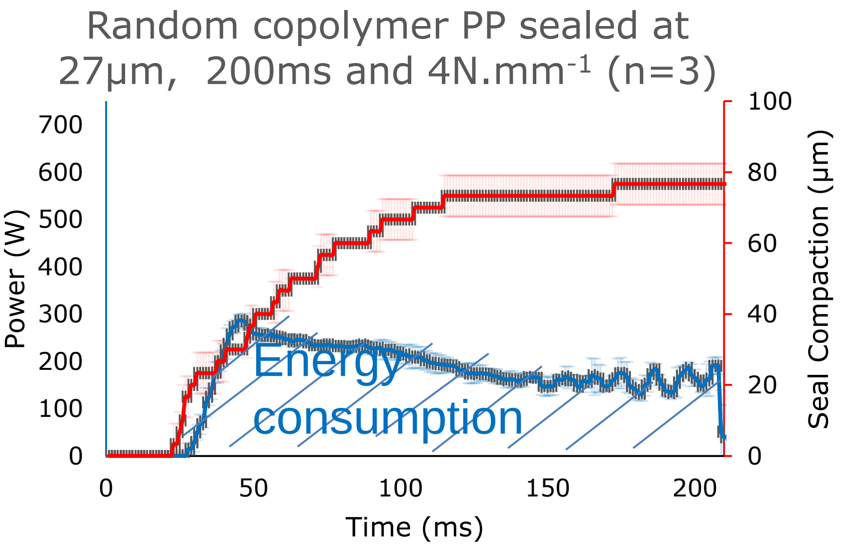
- Ultrasonic seal performance

  - Comparison maximum strength: HCS vs. USS



+ Seal compaction (µm)
+ Energy consumption (W.s)
+ Seal window (#seals with strength > 0.05 N.mm^{-1})

→ Selection of best film



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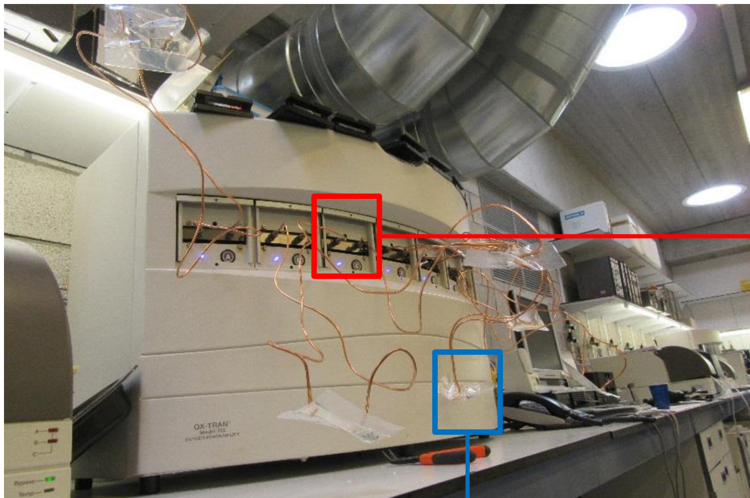
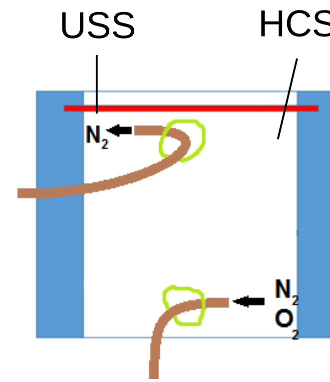
Methods

- Seal permeation (cc/[package.day])





ASTM F1927: flat films
ASTM F1307: sealed packages

Flat films vs. sealed pouches
Seal settings
HCS: 1000 ms – 150°C – 1 $N.mm^{-2}$
USS: 300 ms – 36 µm – 4 $N.mm^{-1}$

Materials

Table 1: Composition, measured total thickness and production process of flexible films

Composition	Measured Total Thickness (µm) (n=10)	Production process
	Monolayers	
LDPE 60	63 ± 2	Blown extrusion
mLLDPE-C6 60	64 ± 2	
LLDPE-C6 60	58 ± 3	
LLDPE-C4 60	63 ± 2	
Homopolymer PP (=homo PP) 60	61 ± 3	Cast extrusion
Random copolymer PP (=raco PP) 60	58 ± 3	
	Plastic Laminates	
PET/LLDPE-C4 24/40	69 ± 1	Blown extrusion, corona pretreatment and lamination with Adcote 301/350
OPA/LLDPE-C4 23/40	69 ± 2	
PET/ mLLDPE-C6 24/40	69 ± 2	
OPA/mLLDPE-C6 23/40	71 ± 2	
PET/PE 12/60	76 ± 2	Commercial films, production process and specific composition is not known
PET/PE-EVOH-PE 12/40	55 ± 2	
PET/ALU/PE 12/9/75	105 ± 4	

Results and conclusions

Monolayers

- PE: LDPE vs. LLDPE-C4 vs. LLDPE-C6 vs. mLLDPE-C6
- PP: homo PP vs. raco PP
- PE vs. PP

Plastic laminates

- OPA vs. PET
- Plastic laminates vs. monolayers

Oxygen permeability

- Flat film vs. sealed pouch (full HCS)
- Full HCS vs. HCS+USS sealed pouch

Results - monolayers

Table 2: Comparison of size sealing window and max. seal strengths of polyolefin monolayers

	USS_{window}	$USS_{max\ parameters}$ (N.mm^{-1})	$USS_{max\ Seal}$ Strength (N.mm^{-1})	$HCS_{max\ parameters}$ (N.mm^{-1})	$HCS_{max\ Seal}$ Strength (N.mm^{-1})
LDPE	11/15	300ms_4N/mm_36µm	0.77 ± 0.01	1000ms_2.46N.mm^{-2}_130°C	0.81 ± 0.02
mLLDPE-C6	11/15	100ms_6N/mm_27µm	0.90 ± 0.03	1000ms_2.46N.mm^{-2}_120°C	0.86 ± 0.01
LLDPE-C6	11/15	100ms_6N/mm_27µm	0.89 ± 0.07	1000ms_2.46N.mm^{-2}_190°C	0.94 ± 0.05
LLDPE-C4	9/15	300ms_6N/mm_27µm	0.98 ± 0.06	1000ms_2.46N.mm^{-2}_170°C	0.90 ± 0.09
homo PP	9/15	100ms_6N/mm_27µm	1.73 ± 0.09	1000ms_2.46N.mm^{-2}_160°C	1.59 ± 0.05
raco PP	13/15	100ms_6N/mm_27µm	1.52 ± 0.07	1000ms_2.46N.mm^{-2}_160°C	1.24 ± 0.14

Results - monolayers

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raco PP	13/15	100ms_6N/mm_27µm	**1.52 ± 0.07**	1000ms_2,46N.mm⁻²_160°C	**1.24 ± 0.14**

- Comparison maximum seal strength: HCS vs. USS
  - PE: LDPE < LLDPE-C4 ~ LLDPE-C6 ~ mLLDPE-C6
  - PP: homo PP > raco PP
  - PE < PP

Results - monolayers

Table 2: Comparison of size sealing window and max. seal strengths of polyolefin monolayers

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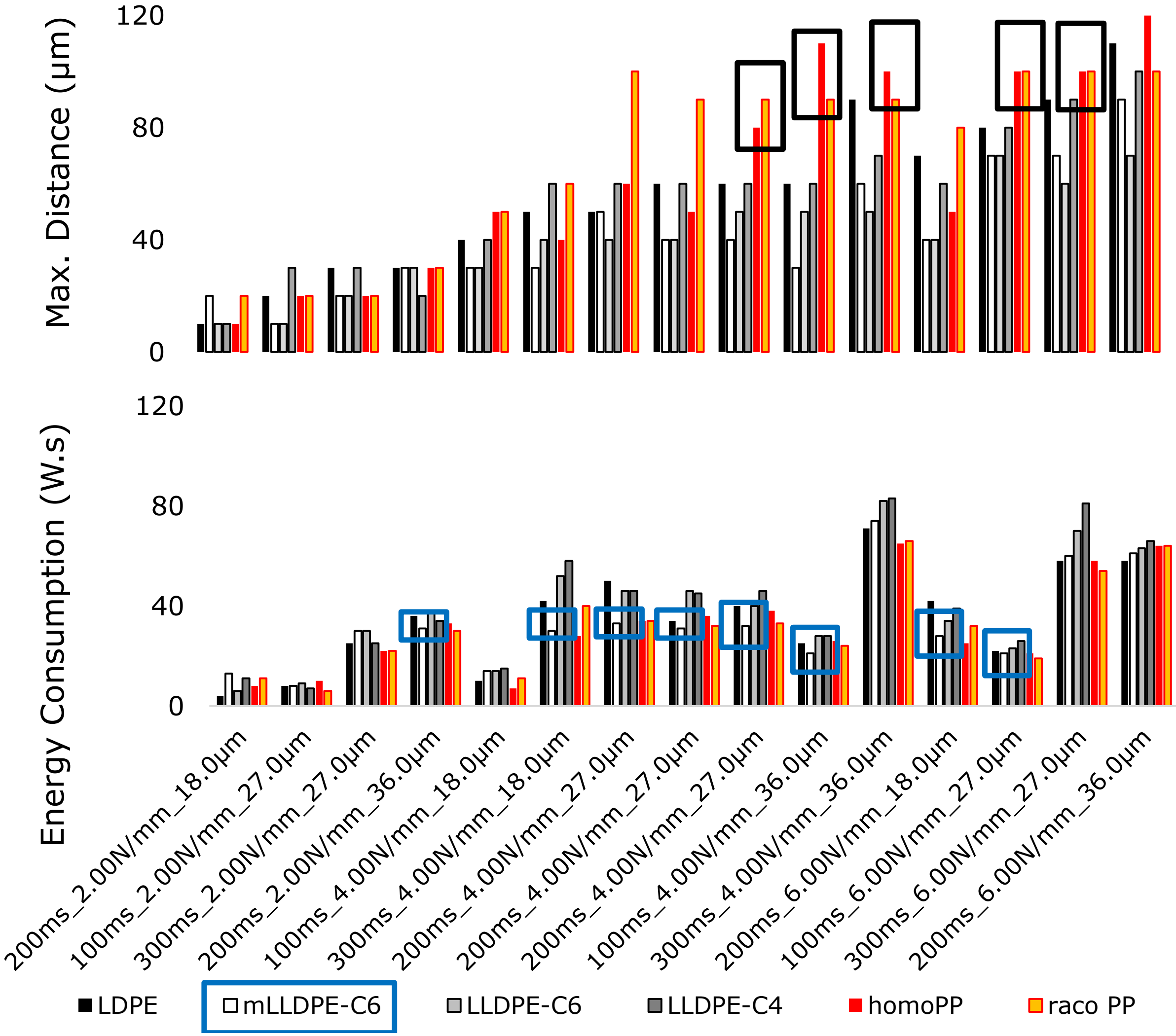
homo PP	*9/15*	100ms_6N/mm_27µm	**1.73 ± 0.09**	1000ms_2,46N.mm⁻²_160°C	**1.59 ± 0.05**
raco PP	***13/15***	100ms_6N/mm_27µm	**1.52 ± 0.07**	1000ms_2,46N.mm⁻²_160°C	**1.24 ± 0.14**

- Comparison maximum seal strength: HCS vs. USS
  - PE: LDPE < LLDPE-C4, LLDPE-C6 and mLLDPE-C6
  - PP: homo PP > raco PP
  - PE < PP
- Seal window
  - PE: LLDPE-C4 < **LDPE, mLLDPE-C6 and LLDPE-C6**
  - PP: homo PP << **raco PP**

Results - monolayers

Figure 1: Comparison of seal compaction and energy consumption of polyolefin monolayers



- Seal compaction
  - PP is slightly more compacted
- Energy consumption
  - PE
    - mLLDPE < LDPE, LLDPE-C6 and LLDPE-C4

Conclusions monolayers

- PE: mLLDPE-C6 is selected as best film
  - High seal strength
  - Low energy consumption
- PP: random copolymer is selected as best film
  - Good seal strength (slightly lower than homo PP)
  - Large seal window
- PP vs. PE
  - PP reaches higher maximal seal strength
  - PP is slightly more compacted
  - Small differences in energy consumption

Results - plastic laminates

Table 3: Comparison of size sealing window and max. seal strengths of plastic laminates

	USS_{window}	$USS_{max\ parameters}$ ($N.mm^{-1}$)	USS_{max} Seal Strength ($N.mm^{-1}$)	$HCS_{max\ parameters}$ ($N.mm^{-1}$)	HCS_{max} Seal Strength ($N.mm^{-1}$)
OPA/LLDPE-C4	14/15	200ms_6.00N/mm_36.0µm	1.98 ± 0.43	1000ms_2.46N.mm^{-2}_200°C	3.62 ± 0.17
PET/LLDPE-C4	10/15	300ms_4.00N/mm_36.0µm	2.73 ± 0.31	1000ms_2.46N.mm^{-2}_180°C	2.66 ± 0.06
LLDPE-C4	9/15	300ms_6N/mm_27µm	0.98 ± 0.06	1000ms_2,46N.mm^{-2}_170°C	0.90 ± 0.09
OPA/mLLDPE-C6	13/15	300ms_6.00N/mm_27.0µm	2.94 ± 1.08	1000ms_2.46N.mm^{-2}_200°C	3.70 ± 0.47
PET/mLLDPE-C6	15/15	300ms_4.00N/mm_36.0µm	2.59 ± 0.06	1000ms_2.46N.mm^{-2}_200°C	2.81 ± 0.01
mLLDPE-C6	11/15	100ms_6N/mm_27µm	0.90 ± 0.03	1000ms_2,46N.mm^{-2}_120°C	0.86 ± 0.01

Results - plastic laminates

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LLDPE-C4	9/15	300ms_6N/mm_27µm	0.98 ± 0.06	1000ms_2,46N.mm^{-2}_170°C	0.90 ± 0.09
OPA/mLLDPE-C6	13/15	300ms_6.00N/mm_27.0µm	**2.94 ± 1.08**	1000ms_2.46N.mm^{-2}_200°C	**3.70 ± 0.47**
PET/mLLDPE-C6	15/15	300ms_4.00N/mm_36.0µm	**2.59 ± 0.06**	1000ms_2.46N.mm^{-2}_200°C	**2.81 ± 0.01**
mLLDPE-C6	11/15	100ms_6N/mm_27µm	0.90 ± 0.03	1000ms_2,46N.mm^{-2}_120°C	0.86 ± 0.01

- Comparison maximum seal strength: HCS vs. USS
  - **PET**: reaches high ultrasonic seal strength. Results are comparable with heat conductive values. Standard deviations are low.
  - **OPA**: reaches high ultrasonic seal strength. Averages are lower than heat conductive values but standard deviations are high.

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Results - plastic laminates

Table 3: Comparison of size sealing window and max. seal strengths of plastic laminates

	USS_{window}	$USS_{max\ parameters}$ ($N.mm^{-1}$)	USS_{max} Seal Strength ($N.mm^{-1}$)	$HCS_{max\ parameters}$ ($N.mm^{-1}$)	HCS_{max} Seal Strength ($N.mm^{-1}$)
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PET/LLDPE-C4	***10/15***	300ms_4.00N/mm_36.0µm	**2.73 ± 0.31**	1000ms_2.46N.mm⁻²_180°C	**2.66 ± 0.06**
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OPA/mLLDPE-C6	***13/15***	300ms_6.00N/mm_27.0µm	**2.94 ± 1.08**	1000ms_2.46N.mm⁻²_200°C	**3.70 ± 0.47**
PET/mLLDPE-C6	***15/15***	300ms_4.00N/mm_36.0µm	**2.59 ± 0.06**	1000ms_2.46N.mm⁻²_200°C	**2.81 ± 0.01**
mLLDPE-C6	***11/15***	100ms_6N/mm_27µm	0.90 ± 0.03	1000ms_2,46N.mm⁻²_120°C	0.86 ± 0.01

- Comparison seal window
    - Laminated films have a larger seal window than monolayer films

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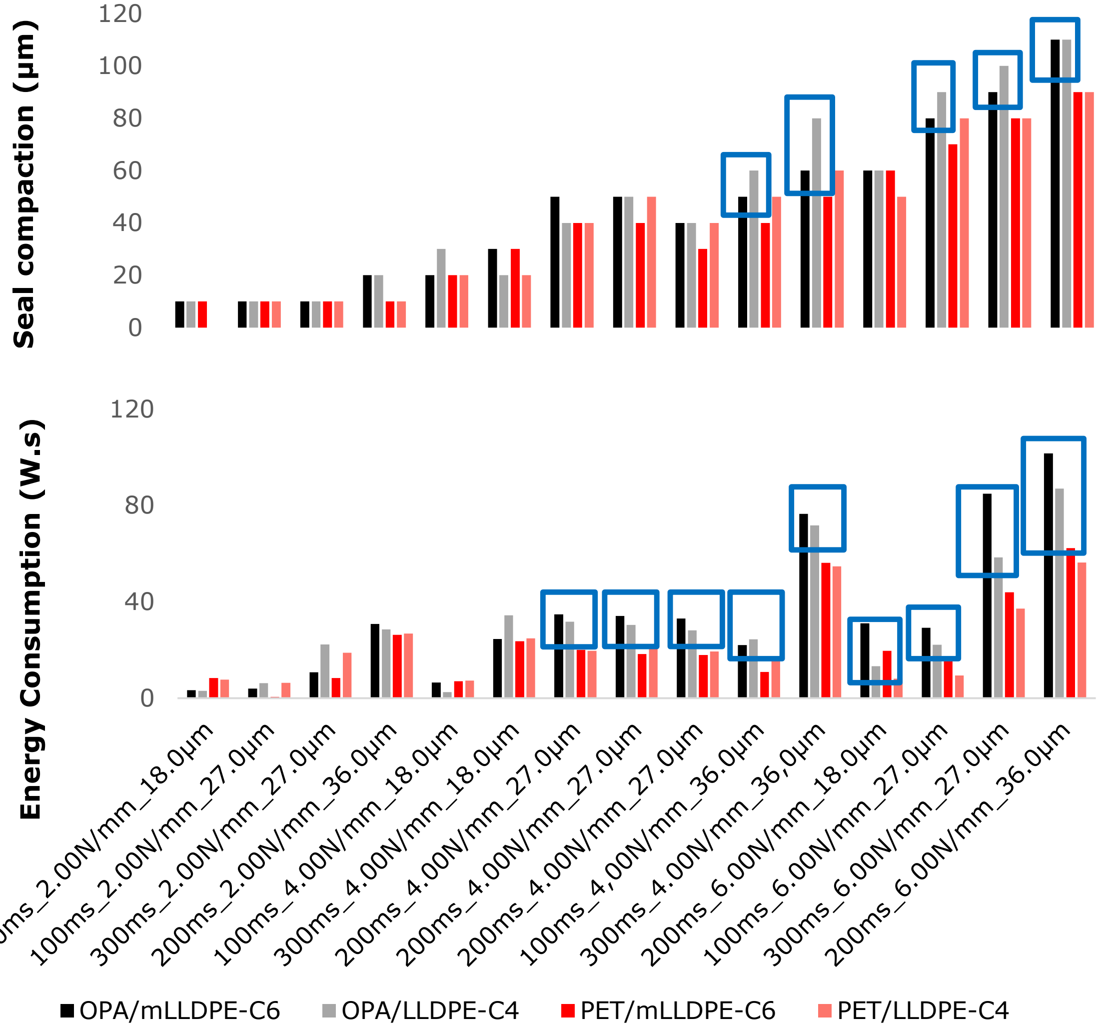
Results – plastic laminates

Figure 2: Comparison of seal compaction and energy consumption of plastic laminates



- Seal compaction
  - OPA is slightly more compacted
- Energy consumption
  - OPA consumes more energy than PET

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Results - plastic laminates

Table 4: Comparison of proportion of the energy consumption of ultrasonic sealing of the laminated over the monolayer structure

	OPA/LLDPE-C4	OPA/mLLDPE-C6	PET/LLDPE-C4	PET/mLLDPE-C6
200ms_2.00N/mm_18.0µm	27%	25%	69%	64%
100ms_2.00N/mm_27.0µm	90%	49%	90%	6%
300ms_2.00N/mm_27.0µm	89%	36%	76%	28%
200ms_2.00N/mm_36.0µm	84%	100%	79%	85%
100ms_4.00N/mm_18.0µm	17%	46%	49%	50%
300ms_4.00N/mm_18.0µm	59%	82%	43%	79%
200ms_4.00N/mm_27.0µm	69%	105%	43%	61%
200ms_4.00N/mm_27.0µm	68%	110%	46%	59%
200ms_4.00N/mm_27.0µm	61%	103%	42%	56%
100ms_4.00N/mm_36.0µm	87%	105%	61%	52%
300ms_4.00N/mm_36.0µm	86%	103%	66%	76%
200ms_6.00N/mm_18.0µm	34%	111%	21%	70%
100ms_6.00N/mm_27.0µm	85%	139%	36%	73%
300ms_6.00N/mm_27.0µm	72%	141%	46%	73%
200ms_6.00N/mm_36.0µm	132%	166%	85%	102%

→ PET laminates have lower energy consumption than the monolayers
Possibly due to better conduction of the ultrasonic vibrations

Conclusions plastic laminates

- PET is selected as better outer layer over OPA
  - High ultrasonic seal strength (low standard deviation, comparable with heat conductive seal strength)
  - Is slightly less compacted
  - Consumes less energy

- Plastic laminates vs. monolayers
  - PET laminates have lower energy consumption than the monolayers

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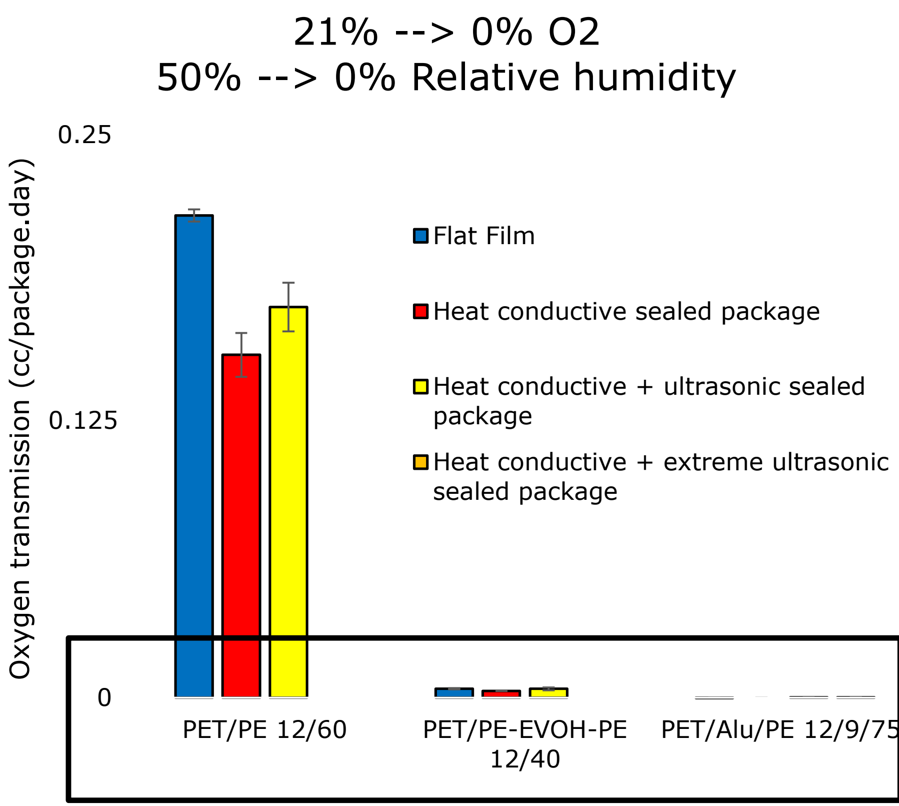
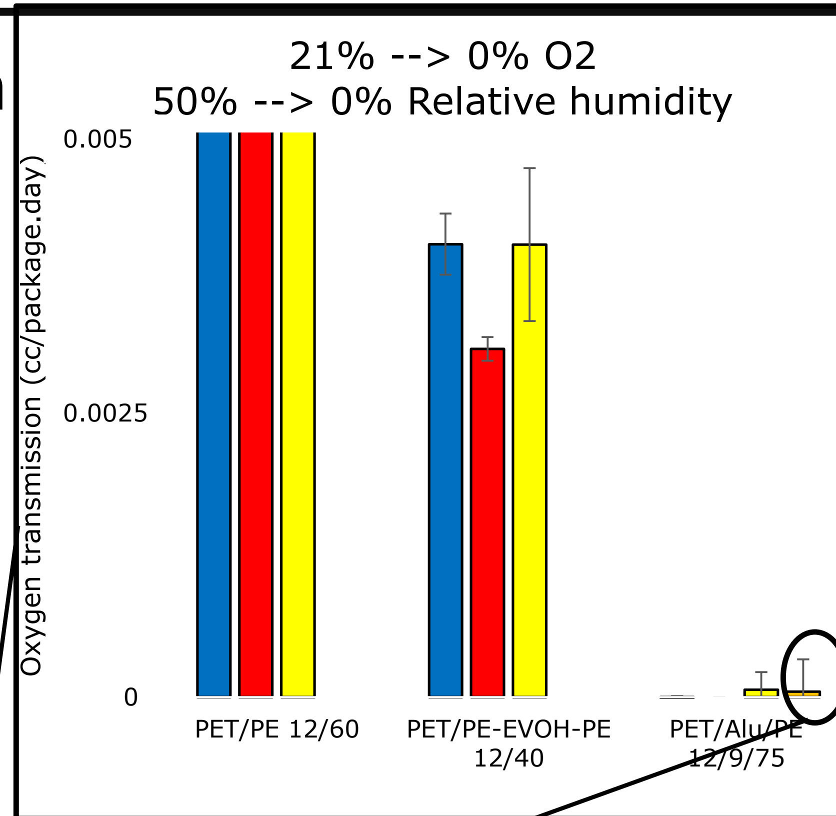
Results - oxygen permeation





- ≠ method, ≠ Oxygen transmission: better to evaluate samples with same method
- Oxygen transmission$_{HCS}$ ≠ Oxygen transmission$_{US+HCS}$ but same order of magnitude
- Oxygen transmission$_{ALU\text{-}film}$ = Oxygen transmission$_{ALU\text{-}sealedpouch}$ = Oxygen transmission$_{ALU\text{-}extremesealedpouch}$ < 0,00005 cc/[package.day]

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