Evaluation and Optimization of seal behavior through solid contamination of heat sealed films

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Evaluation and optimization of seal behaviour through solid contamination of heat-sealed films

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Abstract

A method is presented to apply solid powder/granulate contamination (ground coffee and blood powder) in between the heat conductive seals of flexible packaging materials. A response surface method is tested and validated to optimize seal strength of heat conductive sealing with and without solid contamination. In this study, a maximal seal

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Introduction and objectives

Materials and methods

Results

Conclusions

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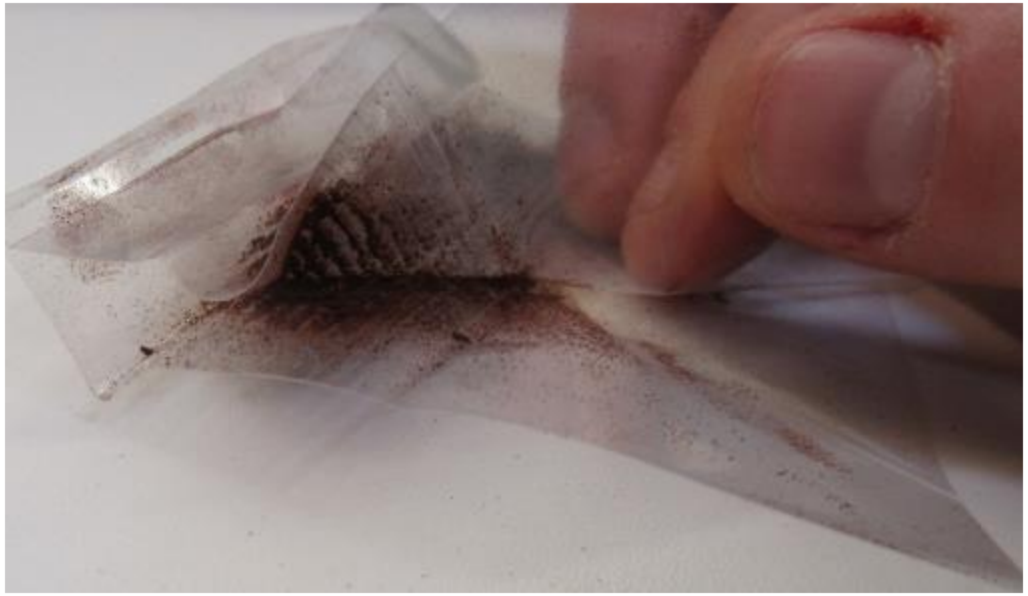
Introduction

- 1/3 sealed packages are of insufficient quality[1]
- In 65% of seal defects: Contamination is major cause[2]
- Prevention seal defects
  - Avoid contamination
  - Seal technology
    - **Parameters**
  - **Seal materials**



[1] Tauschitz B, Washüttl M, Wepner B, Tacker M. MAP-Verpackungen: ein Drittel nicht optimal. PACKaktuell, DE 2003; 04, pp. 6–8.
[2] Dudbridge M, Turner R. Seal integrity and the impact on food waste. http://www.wrap.org.uk/sites/files/wrap/Household_food_and_drink_waste_in_the_UK_-_report.pdf, date of access:22/11/2018. WRAP 2009. ISBN: 1-84405-430-6.

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Objectives

- Optimization granular contaminated seal strength of packaging films
  - Protocol to apply solid contamination
  - Optimization with response surface methodology

- Evaluation of variation in seal layer composition
  - Evaluation of hot tack test as predictive test for seal through contamination performance

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Materials

- Laminated films
  - 12µm PET + 50 µm seal layer
  - Seal layer: 3-layer blown film
    - Films differ mainly in lower 15 µm
    - 2% processing aid with films 1+2

Film 1

PET	12 µm
80% LDPE/ 20% mLLDPE	15 µm
80% LDPE/ 20% mLLDPE	20 µm
68% LDPE/ 30% mLLDPE	15 µm

Film 2

PET	12 µm
80% LDPE/ 20% mLLDPE	15 µm
80% LDPE/ 20% mLLDPE	20 µm
68% LDPE/ 30% plastomer	15 µm

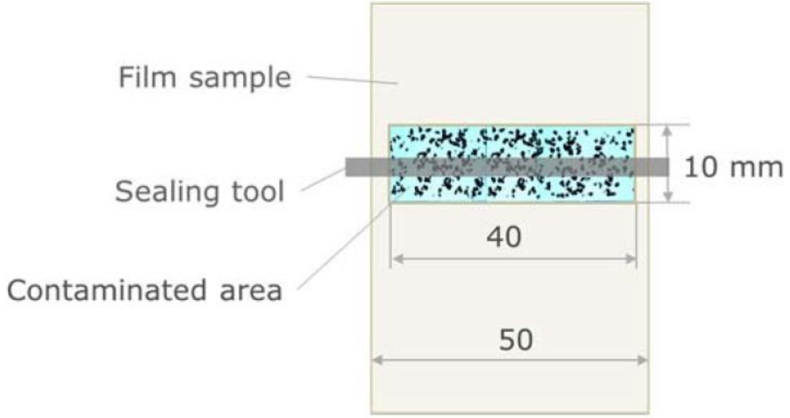
Film 3

PET	12 µm
80% LDPE/ 20% mLLDPE	35 µm
acid copolymer resin	5 µm
sodium ionomer	10 µm

- Contamination
  - Sieved ground coffee (particle size: 500-630 µm)
  - Dried blood powder (particle size: < 100 µm)

Methods

- Application of solid contamination*
  - 25 g.m^{-2} manually spread in marked area



- Seal technology
  - Heat conduction
  - Parameters
    - Temperature (2 flat hot jaws)
    - Time
    - Pressure

Labthink HST-H3

*IVLV Technical Bulletin No. 114/2019 “Method for analyzing the influence of contamination on seal properties of films for packaging applications”

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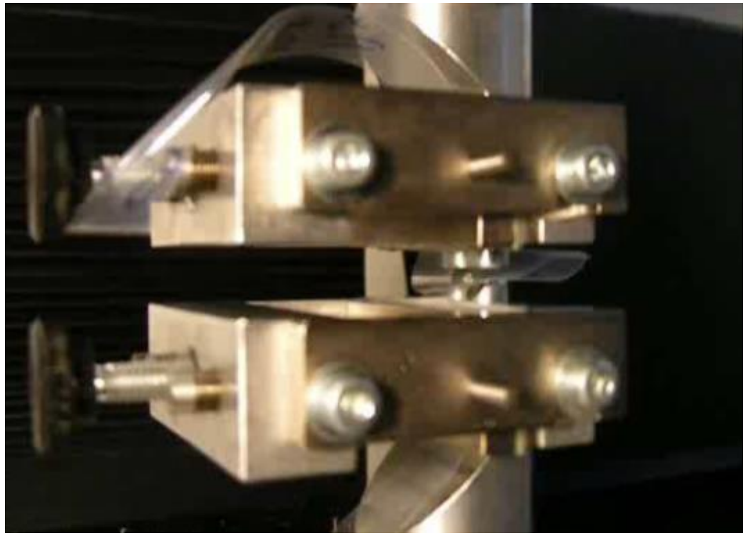
Methods: Film characterization

- Differential scanning calorimetry (DSC)
  - Within 10→200°C with a heating/cooling speed of 10°C.min^{-1}
  - Second heating cycle is used to obtain melting onset and peak temperature

- Hot tack
  - ASTM F1921
  - Width: 25 mm
  - Tensile speed: 200 mm.s^{-1}
  - Seal time: 1.0 s – seal pressure: 0.3 N.mm^{-2} - cooling time: 0.1 s
  - Variation of seal temperature
  - Hot tack strength = max. strength / width

Methods: Seal characterization

- Seal strength
  - ASTM F88
  - Width: 15 mm
  - Tensile speed: 300 mm.min^{-1}
  - Unsupported T-peel test
  - Seal strength = max. strength / width



Methods: Seal strength optimization → maximization

- Define design space
  - Temperature: 105-120 (seal initiation) → 180°C (high maximum)
  - Time: 0.4 → 1.0 s (relevant time range for seal process of flowpack films)
  - Pressure: 1.0 → 4.0 $N.mm^{-2}$ (full working range lab sealer)
- Set up experimental design: I-optimal design
- Fit a response surface model with three parameters (T, t, p) to seal strength values, obtained at 20 experimental runs
  - $y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{23} x_2 x_3 + \beta_{13} x_1 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{333} x_3^3 + \varepsilon$
  - $x_{1,2,3}$: seal parameters – y: seal strength – ε: error term
- Optimize seal parameters
  - A process window was generated by excluding seal strengths below 90% of the maximum
- Validation of maximum seal strength (n=10)

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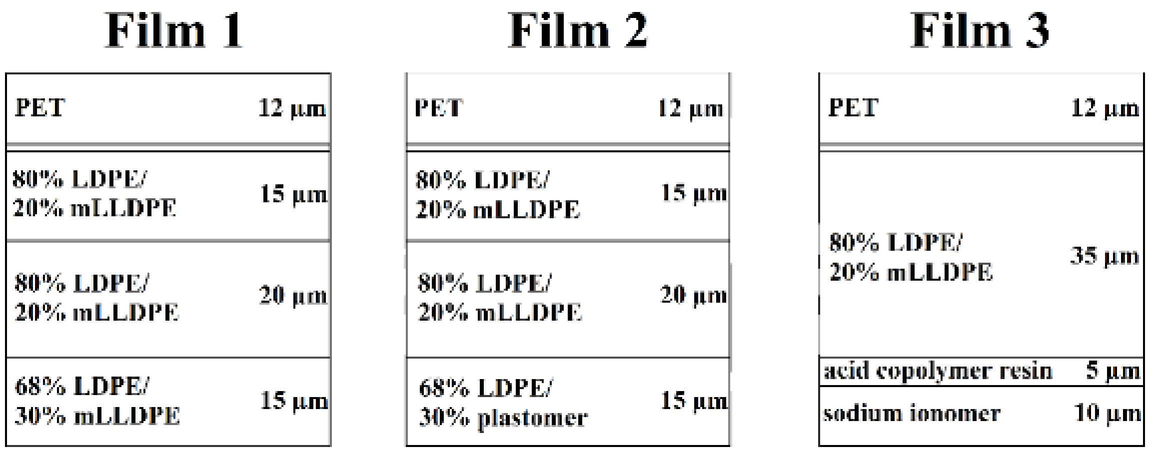
Results: Film characterization: DSC



	Film			Granulate of film component				
	1	2	3	LDPE	mLLDPE	plastomer	Acid copolymer	Sodium ionomer
$T_{melt\ onset}$ (°C)	100	95	98	102	95	87	77	70
$T_{melt\ peak}$ (°C)	112	113	112	112	111	102	98	90

- Values film 1: in between main components LDPE and mLLDPE in granulate form
- Values film 2: melting onset temperature 5°C lower as film 1 → possible explanation: presence of plastomer in lower 15 µm
- Values film 3: no decrease in melting onset temperature → possible explanation: melting temperatures of acid copolymer and sodium ionomer are too low to influence the tangent line, used to obtain the onset temperature

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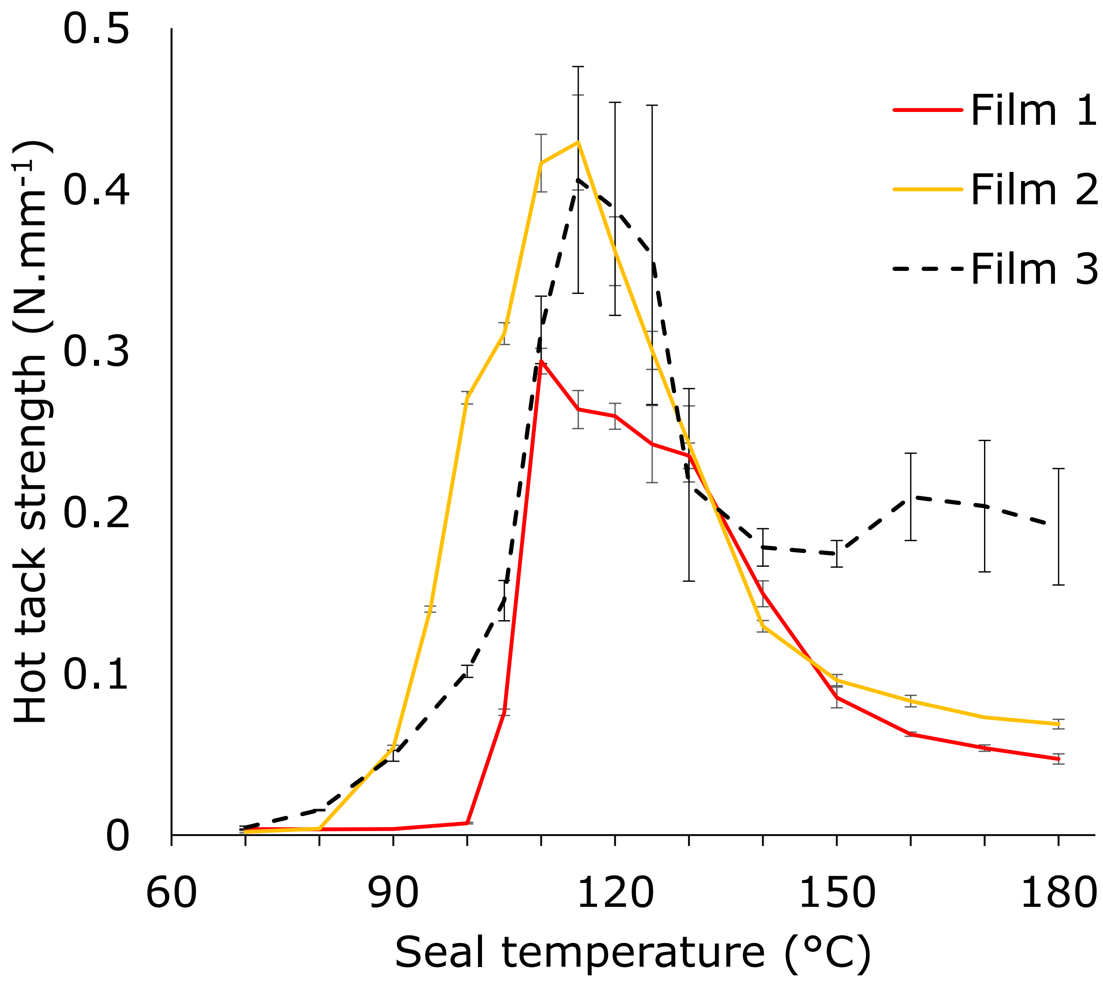
Results: Film characterization: hot tack



Film 1

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80% LDPE/ 20% mLLDPE	20 µm
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Film 3

PET	12 µm
80% LDPE/ 20% mLLDPE	35 µm
acid copolymer resin	5 µm
sodium ionomer	10 µm

➔ Films 2 and 3 have good hot tack performance (low initiation temperature, high peak value and wide window)

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Results: Seal strength maximization

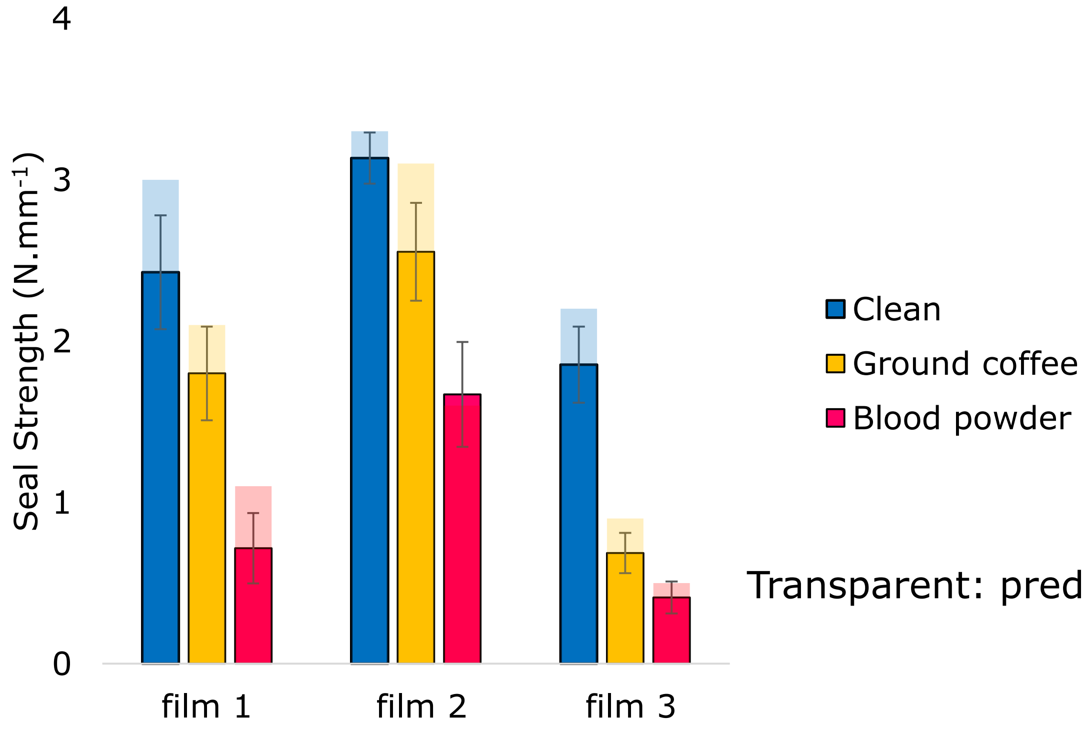
Run	T_{jaw} (°C) F1	T_{jaw} (°C) F2	T_{jaw} (°C) F3	t_{seal} (s)	p_{seal} ($N.mm^{-2}$)	Response: Seal strength ($N.mm^{-1}$)								
						Clean			Ground coffee Contamination (25 $g.m^{-2}$)			Blood powder contamination (25 $g.m^{-2}$)		
						F1	F2	F3	F1	F2	F3	F1	F2	F3
1	149.3	141.2	143.9	0.7	1.9	2.4	3.0	1.4	1.4	2.3	0.6	0.7	1.4	0.3
2	181.5	181.5	181.5	0.4	3.2	2.3	3.1	1.8	1.9	2.0	0.3	0.3	0.4	0.3
3	119.6	104.1	109.2	0.5	1.6	0.6	1.9	0.1	0.0	0.0	0.0	0.0	0.0	0.0
4	150.5	142.7	145.3	0.7	3.3	2.6	2.8	1.7	1.4	1.9	0.6	0.7	1.7	0.3
5	150.5	142.8	145.4	0.7	3.2	2.5	3.1	1.8	1.5	2.1	0.5	0.7	1.5	0.6
6	162.6	157.8	159.4	1.0	3.4	2.2	2.6	1.3	2.2	2.3	0.8	0.4	0.8	0.5
7	144.1	134.7	137.9	1.0	1.9	2.5	3.0	1.5	1.4	2.6	0.6	1.1	1.4	0.5
8	119.6	104.1	109.2	0.7	3.1	2.3	2.9	0.4	0.6	0.9	0.0	0.5	0.1	0.0
9	181.5	181.5	181.5	0.7	1.0	2.2	2.9	1.8	1.9	2.9	0.5	0.9	0.6	0.2
10	148.8	140.6	143.3	0.7	1.8	2.4	2.9	1.7	2.0	2.9	0.6	0.7	0.9	0.3
11	144.3	135.0	138.1	0.4	4.0	2.3	3.2	0.5	1.2	1.7	0.1	0.7	1.0	0.2
12	119.6	104.1	109.2	1.0	4.0	2.2	2.9	0.4	1.4	1.5	0.1	1.1	0.6	0.3
13	181.5	181.5	181.5	0.4	1.9	2.3	2.9	1.7	1.1	1.4	0.5	0.3	0.3	0.4
14	181.5	181.5	181.5	1.0	1.0	2.2	2.9	1.7	1.3	3.0	0.5	0.6	0.5	0.4
15	150.5	142.8	145.4	0.4	1.0	2.4	3.1	0.7	1.0	2.1	0.3	0.4	1.4	0.2
16	119.6	104.1	109.2	1.0	1.0	2.1	3.0	0.3	1.6	1.1	0.0	0.8	0.3	0.1
17	181.5	181.5	181.5	1.0	2.4	2.2	3.6	1.8	2.0	3.2	0.5	0.4	1.6	0.4
18	181.5	181.5	181.5	0.7	4.0	3.1	2.6	2.2	2.0	2.9	0.7	0.3	0.3	0.4
19	119.6	104.1	109.2	0.4	3.3	0.7	1.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
20	150.8	143.1	145.6	0.7	1.8	2.3	2.9	1.5	1.2	2.5	0.5	0.6	2.0	0.3

= Input to build a model that predicts the clean and contaminated seal strength at all possible parameter settings within the defined design space

- Coefficients of terms included in the selected model: not shown

Results: Seal strength maximization: validation of maxima (n=10)

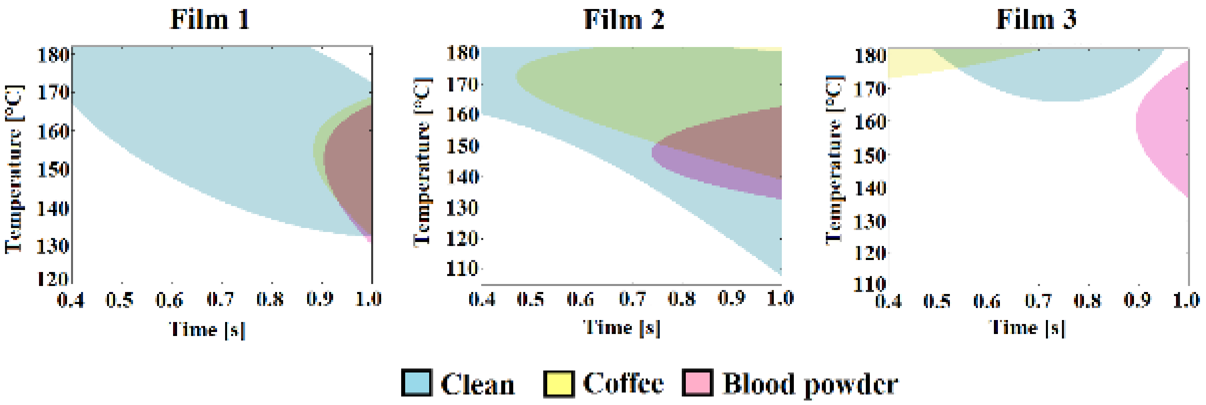
	Clean	Ground coffee contamination (25 g.m^{-2})	Blood powder contamination (25 g.m^{-2})
Optimal settings			
Film 1	165°C_0.7s_4.0N.mm^{-2}	151°C_1.0s_1.0N.mm^{-2}	150°C_1.0s_1.0N.mm^{-2}
Film 2	144°C_1.0s_1.0N.mm^{-2}	161°C_1.0s_4.0N.mm^{-2}	147°C_1.0s_2.0N.mm^{-2}
Film 3	182°C_0.7s_2.7N.mm^{-2}	182°C_0.4s_1.2N.mm^{-2}	157°C_1.0s_3.4N.mm^{-2}



Transparent: predicted value

- Good indication but model tends to slightly overestimate seal strength
- Contamination decreases seal strength, even when maximized
  - Rate of decrease is dependent on seal material and applied contamination
    - Based on measured average values: degree of decrease for film 1, 2 and 3 are respectively 25, 16 and 63 % for ground coffee and 71, 45 and 79% for blood powder contamination compared to the clean seal strength.

Result: Seal strength maximization: process windows



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sodium ionomer	10 µm

- Film 1 vs. Film 2
  - Process window
    - Wide for clean seals, narrowed down with contamination - overlap
    - Clean and coffee: wider for film 2
  - Process window + validation results
    - Film 1 less tolerant for solid contamination
    - Results are in line with hot tack performance: lower initiation, wider window
- Film 3
  - Process window
    - Narrow compared to films 1 and 2 – almost no overlap
  - Process window + validation results
    - Worst tolerance for solid contamination
    - Results are inconsistent with good hot tack performance

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Conclusions

- Method to optimize granular contaminated seal strength is presented
  - Predicted values are good indication of clean and contaminated seal strength
  - Process windows for clean and contaminated seal strength can be obtained
- Film with plastomer based seal layer outperformed other films
  - Higher seal strength
  - Wider process windows
- Hot tack test not predictive for contaminated seal strength
  - Similarities in comparison of films with metallocene and plastomer based seal layer, results with film with sodium ionomer were not predictive

Questions?

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