Summary for the final report
Simulation-based strength and failure analysis of peelable and tightly sealed seams (Seal Strength Simulation)

The plastic film material, sealing tools and processing parameters of heat conduct sealing affects the seal seam formation. On the other hand the seal seam formation affects the seal strength of a sealed polymer film. Modern packaging concepts reduce common seal and carrier layers or substitute them by mono-material films, respectively. The effects on seal seam formation and seal strength of substitution of common material concepts by modern packaging concepts are complex and partly unknown.

Furthermore, in practical application high sealing pressures are usual. High sealing pressures increase the meltflow. In previous scientific studies the influence of the sealing pressure and distinctive seal seam formations were neglected.
In this research project a simulation process was implemented to analyze the strength and fail of seal seams. By means of the simulation modell geometric and material influence oft the seal strength were analysed.

Keywords: heat contact sealing, seal seam formation, material characterization, LS-DYNA, finite-element-methode cohesive elements, T-peel-test

Introduction

Heat contact sealing is the most commonly used method in the packaging industry to join polymer films. In this processing technology, two films are pressed together by two movable heated seal jaws. A heat transfer from the heated sealing jaws through the film is etablished to achieve a fusion at the interface between the films. In industrial application high sealing pressures are necessary to achieve a safety packaging by compensating layer jumps, side folds or contaminations of the seal seam with packaged goods.

Practice-relevant sealing pressures result in pronounced melt flows which leads to different seal seam formations. As a result peelable films may lose their peelability. However, the sealing pressure is not taken into account in the scientific literature to date. Previous scientific literature on heat contact sealing processes has been limited to studies without pronounced melt flow. ([1], [6],[11]).

The seal strength, toughness, failure mode, and appearance of such seals after cooling to room temperature are important seal properties. Testing of heat seals between thin films has generally been done using T-peel-tests [13].

In this research a PET-PE (12/50µm) peelable film was sealed by 10mm flat sealing jaws with different sealing parameters. In particular the sealing pressure was varied and its effects on the seal seam formation were investigated. Finally, a finite element simulation of T-peel-test, taking into account the seal seam formation, and a comparison was made with the experimental results carried out and compared with the experimental results of T-peel-test.

1. Material characterization

The main objective of the material characterisation is to parameterise a material model in the finite element simulation method in order to describe the material behavior in the T-peel-test simulation as acurately as possible. Figure 1 describes the film structure of peelable PET-PE (12/50µm) composite and the associated individual films PET (BoPET12) and PE (LDPE50 (Peel)).

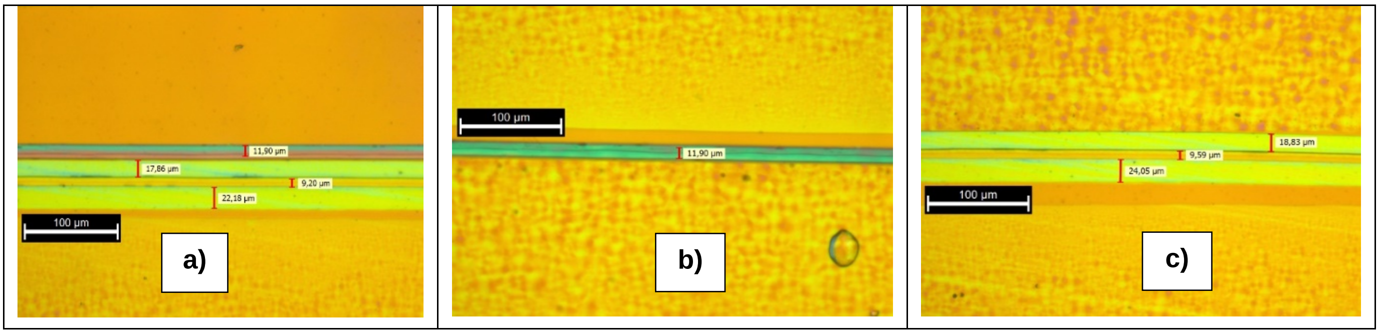


Figure 1: Composite with its individual layers: a) PET-PE (12/50 µm) peelable composite, b) PET-Layer BoPET12 and c) PE-Layer LDPE50 (Peel)

Tensile tests of the PET-PE-Peel (12/50µm) peelable composite and the individual layers BoPET12 and LDPE50 (Peel) were carried out in machine direction according to DIN 527-3 [12] with a clamping length 100mm and test speed of 100mm/min. The test-specimen geometry was 15mm wide and 150mm long.

In order to use the data in the nonlinear finite element simulation, they have to be transferred into true-strain-true-stress curve under the assumption of volume constancy.

However, the true strain-true-stress curve of the materials cannot directly used for the simulation as this could lead to numerical instabilities due to the smoothness of the curves. Therefore, the data must be fitted with the analytical G'sell-Jonas function [5].

$$\sigma_t(\varepsilon_t) = k * \left(1 - e^{-\left(\frac{\varepsilon_t}{\varepsilon_v}\right)^t}\right) * e^{h\varepsilon_t{}^u} * \left(1 - p * e^{-q*(\varepsilon_t - \varepsilon_D)^2}\right).$$

In the G'sell-Jonas function k, ε_v, t, h, u, p, q and ε_D are curve parameters [3]. The fitting was carried out using an optimisation algorithm. As a result a set of G'sell-Jonas curve parameter was found for every film (see. Table 1).

Table 1 Curve parameters of the G'sell-Jonas function for all films

	k	ε_v	t	h	u	p	q	ε_D
BoPET 12	0.11	0.016	1.38	1.95	0.95	9.98	12.38	1.29
LDPE 50 (Peel)	0.016	0.0201	1.05	1.36	1.03	0.22	9.0E-06	9.83
PET-PE (12/50µm) peelable	0.034	0.016	1.31	1.76	1.04	20.05	27.29	0.91

Furthermore, the elasto-plastic matertial parameters such as modulus of elasticity E and yield stress σ_y were also determined (see. Table 2) from the optimisation according to DIN527-3.

Table 2 Elasto-plastic material parameters of film material

	$E\ \left[\frac{kN}{mm^2}\right]$	$\sigma_y\ \left[\frac{kN}{mm^2}\right]$	ν [-] *
BoPET 12	4.25	0.021	0.4
LDPE 50 (Peel)	0.61	0.0015	0.42
PET-PE (12/50µm) peelable	1.14	0.0028	0.4

Using the curve parameters in Table 1 and the elasto-plastic material parameters from Table 2, the flow curves were calculated of each film. The Poissons ratios from Table 2 were from literature [7] and [8]

2. Sealing experiments

A design of experiment with a full factorial test plan was carried out to investigate the effects of the heat contact sealing parameters sealing pressure p_S, dwell time t_S and sealing temperature T_S on the seal seam formation and the seal strength. The sealing jaws were flat and had a width of 10mm. The parameter spaces of sealing temperature, sealing pressure and dwell time were 110-150°C, 0.5- 5 MPa, and 0.2- 0.75 s, repectively. Different seal seam formations with different sealing parameters were measured (see. Figure 2).

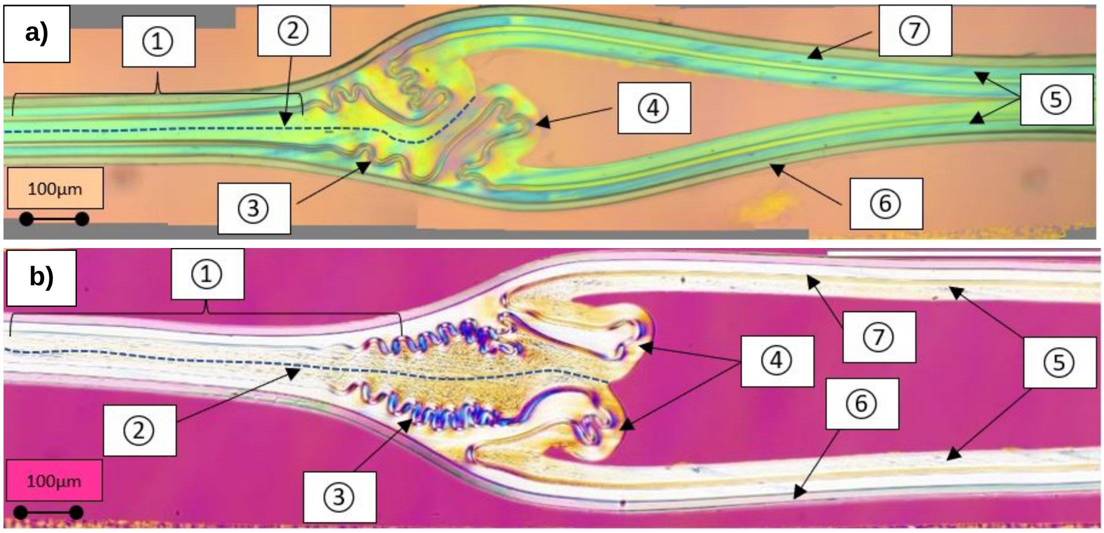
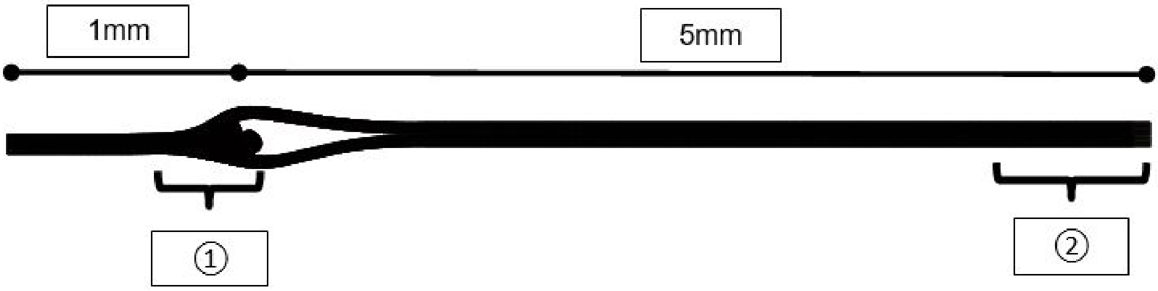


Figure 2: Seal seam formations from PET-PE (12/50µm) peelable. a) sealing parameters 150°C-3MPa-500ms, b) sealing parameters 150°C-5MPa-750ms. ①: seal seam, ② peel area, ③ EVOH layer with wrinkles, ④ sealing bead, ⑤ peel arms, ⑥ PET-layer (BoPET12), ⑦ PE-layer (LDPE50 (Peel))

3. Implementing T-peel-test simulation and validation

In the next step, a finite element simulation model of the T-peel-test was implemented, taking into account the seal seam formation (see. Figure 3). The simulation was carried out with the finite element software LS-DYNA® R11.1 double precision and solved using non-linear implicit solver.

By means of spline geometries the seal seam formation could be reproduced in detail with its contrusions and beads. To the right of the seal seam, the bead merges into the peel arms, to the left o fit the seal seam folding merges into the seal seam in which the foils are welded together. The geometry was then meshed in the longitudinal and thickness direction with an element size of 0.005mm and 0.01mm repectively (see. Figure 4). With the geometric dimensions of 1mm length of the seal seam and 5mm for the peel arms, the proportions of the experimental T-peel-test samples were taken into account in the simulation model.



3: simulation model of T-peel-test with the seal seam formation

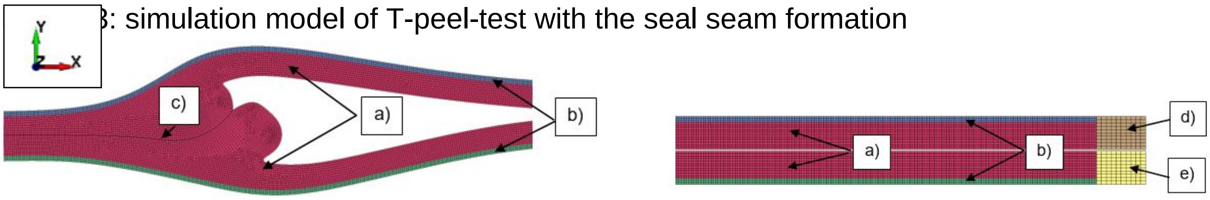


Figure 4: detailed view of the simulation model. ① seal seam and seal seam formation: a) PE-layer (LDPE50 (Peel)), b) PET-layer (BoPET12), c) peel region (cohesive zone), ② peel arms and clamps: d) clamp top, e) clamp bottom

The material description of the film material has been done by the elastic-plastic material model *MAT24 [2] in LS-DYNA®. Its material parameters such as modulus of elasticity E, yield stress σ_y and flow curve were determined in 1. The peel region c) of the simulation (see Figure 4 ①) was modeled with cohesive elements in *MAT138 [9]. The required material parameters of *MAT138 were optimised based on the averaged peel force of the T-peel-test experiments (see. [4]). In Table 3 the optimised material parameters of *MAT138 are listed. For reasons of simplification, no distiction was made between normal an tangential material parameters (see. [10]).

Table 3 material parameters of *MAT138

	EN	GIC	T	UND
*MAT138	10	1.595E-04	0.0058	0.058

In order to perform and validate the T-peel-test e.g. to obtain reaction forces between the clamps and the foil, a contact *TIED_SURFACE_TO_SURFACE_OFFSET was defined. For the material description and the moving of the clamps the *MAT20 was used ([14], [15]).

The first step of the simulation is to unfold the peel arms (see.Figure 5a)). The upper clamp then moves in y-direction at a constant velocity 0.0016mm/ms. The lower clamp, on the other hand, was fixed after the unfolding process. Thus the T-peel-test sample was separated along the cohesive zone (see. Figure 5 b)- e)).

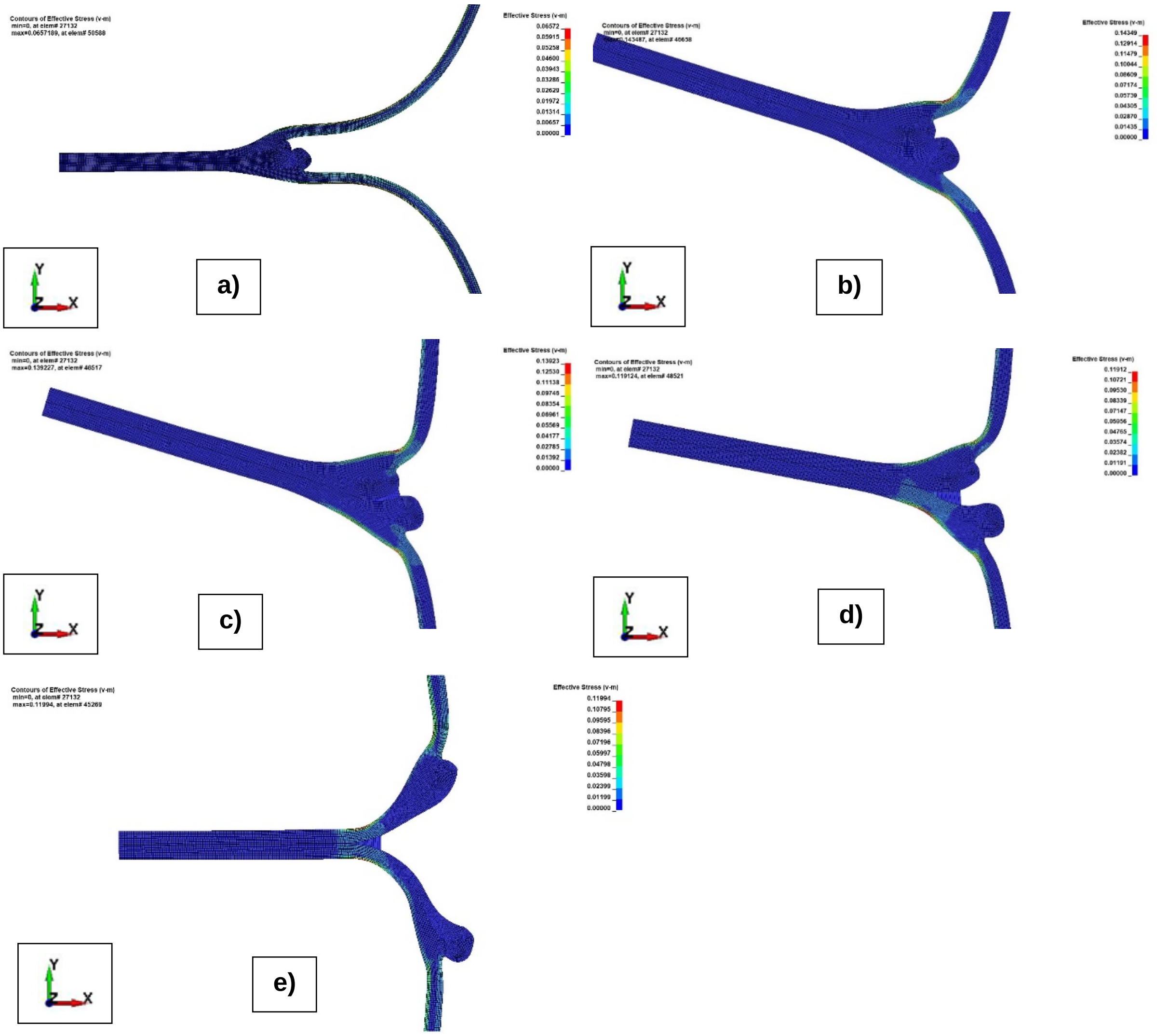


Figure 5: a) unfold simulation model, b) -e) simulation progress

After the simulation process the reaction forces resulting from the contact between the film and the upper clamp were compared with the experimentally measured force-displacement curves (see. Figure 6). Figure 6 illustrates that the maximum force in the simulation is within the standard deviation of the experimetally measured maximum force (sd. Max. force). The peel force of the simulation is outside the standard deviation of experimental peel force (sd peel force). However, the peel force of the simulation is not below the smallest experimentally measured peel force from T-peel-test 2.

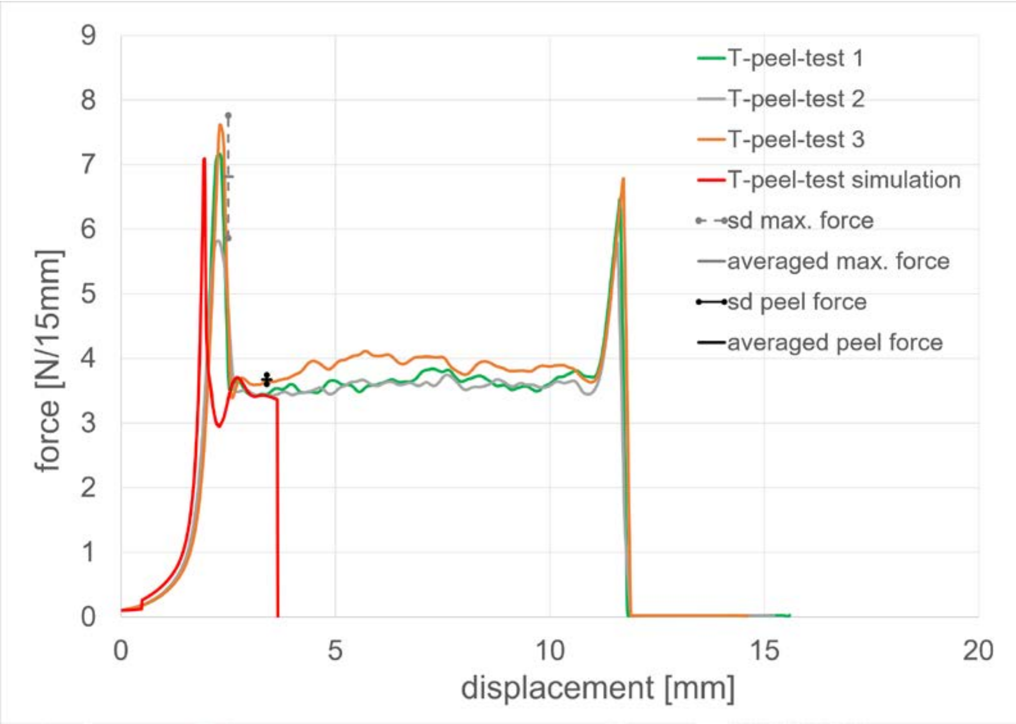


Figure 6: Comparision between force-displacement curves from experiment (sealing parameters 150°C-3MPa-500ms) and simulation

4. Conclusion

In this project the influence of seal seam formation with its beads and notches on the characteristic force-displacement curves in the T-peel-test was shown. Furthermore a finite element simulation of T-peel-test could be implemented and carried out, taking into account the seal seam formation. The influence of the seal seam formation could be proven with finite element simulation. since the characteristic force displacement curve of the experimental T-peel-test could be reproduced using the finite element simulation.

5. References

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[12] DIN 527 Bestimmung der Zugeigenschaften.

[13] DIN 55529 Bestimmung der Siegelnahtfestigkeit von Siegelungen aus flexiblen Packstoffen.

[14] LS-DYNA Keyword-Manual I r11.

[15] LS-DYNA Keyword-Manual II r11.

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