Experimental investigation towards the transport-optimized design of peelable polymer tray packaging

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Funding information
Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.

Demands of peelable food packaging require a design to ensure both ease of usage as well as sturdiness in order to endure multiple loadings during transport. To aid the design processes in addressing these criteria, this paper aims to present factors influencing the closure safety and damaging behaviour during transport. Regarding this, we first present a methodology for the experimental investigation of transport safety, based on a substitute test, which aims to reflect the effects of vertical impact during transport. To achieve these conditions, we propose both the construction of a test rig and subsequent evaluation parameters to assess the damage of the packaging's sealed seam. Following that, the specific parameters of the experimental study based on the proposed method are presented. These include strength of a sealed seam, the thicknesses of used polymer films and the tray geometry itself. The results of this study and limitations are addressed in the final chapter, whereby first qualitative influences of the parameters become assessable, along with suggestions for further scientific work on the subject matter.

KEYWORDS
peelable packaging, packaging design, transport

1 | INTRODUCTION

Just as the products themselves, the requirements and complexity of packaging have grown exponentially in recent years. In addition to the protective function that packaging must provide for the packed goods, they make a decisive contribution to the individualization and successful advertising of the products. Related to this, the ease of handling and the opening behaviour of the packaging is crucial. Not only in regards of an everaging society, easy to open is indispensable nowadays, especially in the field of food products.\textsuperscript{3} For instance, in a German study, 92% of the people questioned stated that they had problems opening packaging. Forty-six percent criticized the excessive needed opening forces.\textsuperscript{2} This may lead to high dissatisfaction, partly even to injuries of the consumers, which has a negative impact on their future purchase decisions. Polymer packaging with peelable sealing seams meets the requirement of easy opening and thus enables convenient handling of the product. This has enabled their wide distribution in the market.\textsuperscript{5} The peelable sealed seams, which form a bond between the top film and tray, are usually produced with heat contact sealing technology during the packaging process through the application of heat and pressure.\textsuperscript{4} Unlike firmly sealed seams, they can be opened by hand without risking damage to the packaging materials, thus ensuring the easy opening.\textsuperscript{5} To produce the peelable sealed seam, the parameters for the heat contact process, for example, temperature, pressure and sealing time, have to be aligned with the attributes of given film packaging materials, which are mostly composites with a sealing layer of polyethylene. Test methods\textsuperscript{6,7} developed in the past allow the determination of forces required to open packaging. Furthermore, correspondingly defined reference values\textsuperscript{5,8} allow the subsequent investigation and assessment of the influence which process and material parameters pose on the opening behaviour. In addition to these recommended guideline values, a second major...
challenge is to ensure the integrity of a packaging, in particular its sealed seam, being able to withstand loads during transport from the manufacturer to the consumer. Ensuring packaging to be easy to open and yet securely closed results in higher process complexity, resulting in more elaborate process and quality monitoring, as well as additional requirements to the material needing a low seam strength range. Furthermore, current types of tests in industry which address sturdiness (e.g., burst pressure test in a water tank) do not cover loads of transport chains. Nevertheless, manufacturers are required to ensure that the packed product always reaches the consumer in perfect condition. The listed challenges therefore pose the following questions: How strong should a peelable seam be to withstand storage and transport loads? And which control variables are subsequently given to reduce resulting stresses? Currently, due to the points listed below, these questions either cannot be addressed or can only be answered for specific tasks with a disproportionately high effort:

- A single packaging has to be produced in its entirety to evaluate the ease of opening and product safety.
- Loads put on the sealed seam during transport, handling and storage processes are unknown.
- Transport safety tests are costly and resource-intensive, resulting in them rarely being used in industry.
- The individual properties of packaging (volume, sealed seam contour, contour width, stability of the packaging, etc.) directly affect its load-bearing capacity.

So far, only a few studies are available which have addressed the opening behaviour of peelable tray packaging during transport in more detail with the help of experimental tests. For instance, the analysis of existing food product transport chains using peelable tray packaging as well as the research of current test standards for the simulation of transport loads in controlled environments in the past led to some preliminary investigations. The real transport conditions were simulated experimentally by a combination of noise, shock, vertical and horizontal impact tests. The results indicate the unsuitability of load tests in industry by comparing the occurring damages to a sealed seam with ones of the experimental simulation. However, it was also evident that damages occurred solely in the sealed seam area of the packaging, especially during the vertical impact load test of the packaging. This simulates manual handling processes. The further consideration of the deformations caused by critical transport loads, like the vertical input during the manual handling and the resistance correlation of the sealed seam, can potentially help to avoid product losses. For example, in a European case study more than 60% of the companies surveyed stated that measures of packaging development and process innovations are the means of choice to avoid food losses. Based on the aforementioned preliminary tests, the paper describes the systematic procedure of experimental investigations and their results. The aim being to analyse the influences of various packaging design and transport load parameters on the damage which occurs during transport as well as its extent more closely. By revealing the influences and associated design possibilities, these investigations could support the load-optimized design of peelable tray packaging in the future, without losing sight of its easy opening behaviour.

2 | METHODS AND MATERIALS

Since the loads of the vertical impact test, which simulated manual handling as a part of the transport chain, caused the most extensive damages to the area of sealed seams of peelable tray packaging in the preliminary studies, a test rig (Figure 1) was initially developed. The test rig allows the repeated execution of the vertical impact with single peelable tray packaging. An additionally mounted high-speed camera (Mikrotron MotionBLITZ Cube 2 with Television 50 mm 1.8 lens) orthogonally aligned to the front of the respective packaging allows the documentation and the observation of the impact on the plate (solid steel) in slow motion. By aligning the antennae of a light source used, which is essential for high-speed video recording, the reflective influence of the entire packaging is kept to a minimum. With this arrangement it becomes feasible to track white markers (Figure 2) placed 10 cm above the bottom (impact) edge of the package, each on the left and right side of the packaging, to capture and evaluate motion profiles. The resulting footage is evaluated via a software application (tracker as a tool for video analysis, version 4.11.0). With the described test rig, the manual handling of individual tray packaging was experimentally simulated and afterwards an analysis of the occurring seam damage and deformations was carried out.

Considering these experiments, both the design parameters of the packaging and the load parameters of the vertical impact were specifically varied. Subsequently, characteristic output parameters were detected and evaluated to assess the influence of different factors on transport safety. In general, 10 repetitions of the tests were performed for each input parameter set. Table 1 provides an overview of both input and output parameters. In the following, all parameters are briefly explained.

2.1 | Varied input parameters

To produce and fill the test packaging (Figure 3) for the experiments, an industry typical thermoform filling and sealing machine (GEA Power Pak ST 420) was used. The process parameters of the machinery were adjusted to be at a constant level (e.g., 150°C sealing temperature, 110°C thermoforming temperature). The thermoformed trays themselves consisted of commercial PET-PE (polyethylene terephthalate - polyethylene) films. For the sealed cover, the machine was fed commercial PET-PE peel films. Two versions with varying polybutene content were used to enable the specific adjustment of two different seam strengths during the packaging production, without the need to adjust the sealing parameters.
2.1.1 | Tray geometry

Two different tray geometries (Figure 4) were used in the experiments. These differ mainly regarding the respective position of the front side surfaces in relation to the horizontal cover film. Regarding the “straight” geometry, this surface stands in a 90° angle to the top. In contrast to this, an acute angle was formed at this point considering the “oblique” geometry. Both represent simplifications of typical tray geometries that can be found in retail for packaging food products like sausages and cheese. Focusing on the main differences considering the tray geometry, this simplification has reduced the amount of testing required. The production of different types of trays was realized by changing the cavities used by the machine mentioned at the beginning. For the “straight” geometry, a standard cavity from the machine

| Input parameters          | Output parameters |
|---------------------------|-------------------|
| Design parameters         | Tray geometry     | Damage depth   |
| Contour of sealed seam    |                   |                |
| Bottom film thickness     |                   |                |
| Strength of sealed seam   |                   |                |
| Load parameters           | Drop height        | Compression path|
| Filling mass              |                   |                |

![Figure 1](image1.png) Scheme of the test rig arrangement for the behaviour investigation of a single packaging during the vertical impact.

![Figure 2](image2.png) Position of the white markers for tracking purposes.
The “oblique” geometry was produced by means of a special 3D-printed cavity made of heat-resistant ABS (acrylonitrile butadiene styrene copolymer).

2.1.2 | Contour of the sealed seam

The contours of the sealed seams were also varied. Based on typical seam contours for the opening flap of peelable packaging, six different contours were compiled for the tests which are presented in Figure 5. To produce these, different tools were used in the sealing module of the machine. For the later comparison evaluating the influence of these contours on the opening behaviour during transport, each required opening force was determined on the basis of the entire finished packaging, following DIN 55409-1.

2.1.3 | Bottom film thickness

While the cover films used had a constant thickness of 57 μm, the thickness of the bottom films used for the trays varied. Thus, bottom films of 250 and 300 μm thickness were used. The characteristic structure of PE and PET layers was retained. Only the various thicknesses of the PET carrier layers caused differences considering the overall thickness.

2.1.4 | Strength of sealed seam

As mentioned above, the sealed seam strengths were specifically modified to assess their influence on transport safety by using two almost similar cover films with different compositions of polybutene in the corresponding PE-sealing layer. Finally, the seam strengths were set on an average of 8 and 12 N/15 mm. Both strength values are within the range that can be considered as “easy to open” according to previous study. The strengths of the sealed seams of the various film combinations, as well as the other pretended seam strengths specified in this paper, were investigated in accordance with the DIN 55529. Thus, 15 mm wide test strips were taken from the sealed packages, to determine the strength via a T-peel test with a tensile testing machine (Zwick Roell Z005) at a testing speed of 100 mm/min.

2.1.5 | Drop height

The test rig allows for the adjustment of different drop heights between 100 to 600 mm for simulating vertical impact on the packaging. During the experiments presented in this paper, heights between 200 and 600 mm were applied as specific input parameters; 200 mm was selected as the lowest value, since with first preliminary tests with the same setup, damages to the sealed seam became apparent when dropping from this height. Below that, at 100 mm, no damage was visible. The upper limit was set at 600 mm, based on the tests explained in previous work and the standard noted in DIN EN 22248, which describes a procedure for carrying out drop tests of packaging for business-to-consumer shipment.

2.1.6 | Filling material and mass

Preliminary tests were carried out to select a suitable filling material for the test packaging. The goal was to identify material that behaves similarly during the impact compared with real packaged products, such as cheese slices. The aforementioned machine was used to produce test packaging for the preliminary tests with three different filling materials:

- real cheese slices
- silicone plates (manufacturer: Resogoo, hardness 60 shore, density 1.2 g/cm³, 130 mm × 95 mm × 2 mm)
- rigid plastic plates (polyethylene, hardness 65 shore, density 0.947 g/cm³, molar mass 300 000 g/mol)
Subsequently, 10 drop tests each per filling material were carried out from a height of 600 mm with the described test rig. Figures 6 and 7 sum up the qualitative and quantitative results of these executions. The qualitative comparison (Figure 6) of the occurring damages after the impact from 600 mm shows a similar behaviour and extent for the packaging filled with silicone plates and cheese. The damages to the packaging with rigid plastic plates differs greatly from the rest due to their higher stiffness. A quantitative determination of the average depth of damage (damage depth as an output parameter is described below), further demonstrates this fact (Figure 7). While the tested packages with rigid plastic plates show a higher depth of damage, the ones with silicone plates show less damage, which comes closer to the damage pattern of the packages with real cheese.

Finally, the silicone plates were selected for the current investigations because they showed good overall agreement and can be reused as often as desired. However, it should be noted that even here greater levels of damage occur, which implies that real packaged goods could be used in future tests. The filling mass of the test packaging was varied by changing the number of these silicone plates contained as a replacement weight. The mass was chosen to match the real filling weights of packaging in retail. Using three silicone plates resulted in a filling weight of 100 g and six plates achieved 200 g in total.
2.2 | Determined output parameters

The quantitative evaluation of damages, mainly in the seam area, was done by taking photographs of the respective areas. For comparable documentation of the damage, an arrangement with a transmitted light unit (Kaiser LED-panel slimlite plano) and a camera (EOS 550D with EF 18-55 mm lens) mounted on a tripod (Kaiser RS 2 XA) was arranged orthogonally according to the top of the packaging. Subsequently, the damages to the area of the sealed seams shown on the photos were analysed with a software tool (Image J as an image editing and processing program, version 1.52a). These evaluations allow for the comparison of input parameters effects.

2.2.1 | Damage depth

Thus, the propagation of any damage in relation to the respective seam width is determined as a relative quantity, which is defined as the damage depth and was normalized to 1 (Figure 8).

2.2.2 | Damage area

In contrast to this, the damage area (Figure 8) as an absolute value defines the surface area of a damage in square millimetres (mm²).

2.2.3 | Compression path

To quantify the deformation in the moment of the impact, the compression path of each packaging (Figure 9) was detected and evaluated by analysing the captured high-speed recordings with the previously mentioned software application Tracker.

The path is determined by trace the white marks, which are located 10 cm above the lower edge of the tray, from the first contact with the impact plate before stopping at the maximum deformation. Finally, the vertical distance between the start and the recorded end point provides the compression path. This parameter makes it possible to quantitatively document different degrees of deformations to the tested packaging.
3 | RESULTS

The experimental tests were carried out by using the rig along with the parameters explained above to assess the impact of defined load and design parameters on the prespecified output parameters. This should enable estimates regarding the transport-optimized design of peelable tray packaging. The determined effect of individual input parameters is explained section by section in the following part.

3.1 | Influence of tray geometry

To determine the influence of tray geometry on occurring damages, and thus on transport safety, two test tray geometries were manufactured. These strongly deviating geometrical properties have a significant effect on the damages that occurs, given the vertical impact test results.

As the diagram in Figure 10 shows, a low drop height of 200 mm only caused minor depth of damage, in the two lower corners of the seam area with “oblique” tray geometry. In general, damage to the seam, was only detectable in the two corners located directly at the impact edge of the packaging. As such, they require special attention for further evaluation. Considering packaging with the “straight” tray geometry, no damage was visible after impact from 200 mm. The depth of damage here was 0 for both corners.

At a drop height of 600 mm, the damage depth increased on the “oblique” geometry packaging (Figure 11). Regarding the one with the “straight” geometry, the damage depth now spiked. Considering this second drop height, the determined damage depth for the “straight” geometry with identical test parameters can be estimated as higher. In other words, the damage has propagated much further through the width of the seam on average than compared with the “oblique” geometry (Figure 12). This is further underlined by the fact, that here four out of 10 packages were opened by the impact test. In case of the “oblique” geometry damages have occurred but remained completely closed in the specific test.

This can be explained by different damage mechanisms. While the “oblique” geometry is more susceptible to deformation during impact, the deformation possibility of the “straight” geometry is limited by a higher stiffness due to its vertical wall. This varying deformation behaviours can also be attributed to the recorded compression paths, which quantify the deformation during every impact (Figure 13).
Due to the high stiffness, more cracks appeared in the “straight” geometry tray to reduce the impact energy. This often led to a completely opened seam, as resulting damage spread through the whole tray and sealed seam area. Caused by the greater deformation the “oblique” geometry absorbed a large part of the impact energy. Therefore, cracks did not occur. A peeling of the seam itself was observed instead due to the higher deformation. Thus, the damaged areas which occurred here are larger (Figure 14), as opposed to the trays with “straight” geometry. This suffered often completely opened seams, but only a slight peeling of the seam because of the cracks spread.

Differences are also noticeable when comparing the damage depth and area to the different corners of the packaging’s lower edge. With the “oblique” geometry, the damage in the opening flap area was greater than in the area of the opposite corner, as greater deformation had occurred here due to the larger inner wall radius. The area
without a flap was generally less deformed, due to the higher stiffness of the smaller radius, which, in case with the “straight” geometry, led to an increase of crack formations from energy dissipation, and thus higher damage.

The sealed seam as a part of trays with “oblique” geometry becomes apparent as a factor to optimize transport safety, as damages were most prevalent in this area. As for the “straight” geometry, the sealed seam itself appears as less relevant due to the crack formations in the tray itself. The investigation was preferably focused on the behaviour and design of the sealed seam itself, which is why in the following the other input parameters and their influences are discussed only for packaging with the “oblique” tray geometry.

### 3.2 Influence of the sealed seams contour at the corner of the opening flap

The evaluation as part of the experimental tests was enhanced by accounting for the usage of different seam contours at the corner of the opening flap. For this, six different marking contours, standardized in retail, were examined. Differences concerning the damage that occurred after the drop test and the contours themselves can be observed in Figure 15 qualitatively.

![Figure 15](image1)

Dependent on the respective contour, clear differences are apparent in the extent of damage to the sealed seam. This is also confirmed by observing the corresponding evaluated data of the damage depth following 5 test runs for each contour. Regarding this Figure 16 shows that seams with the contours 1, 2 or 4 are more susceptible to open completely due to the peel off. The remaining contours 3, 5 or 6 suffered only minor damage and remained completely closed during all experiments. Despite this, it should be kept in mind that using contours, which bear less risk of damages during transport, are subsequently harder to open, and therefore counterproductive to customer experience. For example, packaging with contour 1 (11.3 N), contour 2 (14.9 N) and 4 (12.4 N) can be opened by applying less force as opposed to contour 3 (19.9 N), 5 (16.1 N) and 6 (18.9 N). If, based on these results, one was to select a contour that is both safe for transport due to low damage and easy to open, then contour 5 appears most suitable. Only minor damage was found, and the required opening force is lower compared with contours 3 and 6.

### 3.3 Influence of the bottom film thickness

When investigating the influence of the bottom film thickness from which the packaging tray is made, increasing its thickness led to...
decrease in damage to the sealed seam area. This becomes most prevalent at lower drop heights, that is, at a low impact load. Figure 17 shows this fact in accordance to recorded damage depth. Packaging with a bottom film thickness of 250 μm showed little damages at a drop height of 200 mm. In contrast, no visible damage occurred to the packaging with a thickness of 300 μm. Evidently, reductions in thickness, which are often made to save resources, can have an impact on transport safety. Therefore, corresponding effects have to be assessed.

3.4 Influence of the sealed seam strength

Additionally, the experimental data provides insight on the impact of the strength of the sealed seam itself. In accordance with previous findings, increasing strength decreased damage to the area. In Figure 18 this influence is shown. During the tests the drop height was set at 600 mm. It can be concluded that packaging, which is easy to open due to the lower seam strength, seems particularly susceptible to the loads that can occur during manual transport handling. For such packaging, the proper balance between sturdiness against transport loads and ease of usage poses a noteworthy criterion for optimization.

3.5 Influence of the drop height and filling mass

As for the effects of drop height on damage depth, it became apparent that the extent increases concomitantly with height (Figure 19). This results from a higher degree of deformation due to the greater drop height. An increase in potential energy and correspondingly higher kinetic energy during the impact, caused more deforming force. This is confirmed by observing the detected compression paths (Figure 20). The evaluated average was greater for a vertical impact from a height of 600 mm compared with the one with 200 mm. However, an even greater degree of deformation was prevented by the geometric properties of the “oblique” tray geometry. Thus, the packaging deformed relatively smoothly up to the end of the oblique wall and increased with the height of the fall. From here on, the resistance to further deformation increased. If the load was even higher, e.g. due to a greater drop heights above 600 mm, cracks would probably also occur due to the decreased deformable area, as it could be observed for the “straight” geometry at lower loads.

A similar relation and behaviour applies to the influence by the filling mass. Due to the greater mass, the greater potential and consequently kinetic energy causes greater deformation and damage to the sealed seam area.
**FIGURE 19** Average damage depth depending on the drop height for the “oblique” tray geometry (scheme on the right shows different positions of occurred damages)

**FIGURE 20** Average compression path depending on the drop height for the “oblique” tray geometry (scheme on the right shows different positions of occurred damages)

The high deviation of experimental results is mainly the consequence of high variance between the individual test runs. The current test setup proved insufficient at simulating impact processes because the repeat accuracy is limited. One reason being the distance between tested packaging and the linear guiding profiles of the test rig. It initially served to reduce the risk of friction, but in turn provided a greater range of motion for the packaging and therefore, disparities between test runs. For this reason, the guiding-system used in the test rig requires optimization for future tests. Another cause for the deviations resulted from the initial positioning of the filling plates, causing different points of impact. Only in a few instances the packaging did drop evenly along the whole bottom edge. The consistent accuracy of the filling plates deposition largely depended on the test personal. The contents had to be centred manually before testing to account for gaps between the filling plates and outer walls. It should be noted that this variance also occurs in industrial packaging, as the exact position of the products contained is neither standardized nor maintained even after the packaging process itself. Same is the case with other
following distribution processes. Further fluctuations are the direct result of the manufacturing process of packaging. For instance, the sealing temperature set on the typical industrial system is constantly readjusted, so that it never remains constant throughout the production of a sample packaging causing variations of the sealed seam strength.

Finally, another limitation of the results is worth mentioning: So far, only tests of the vertical impact has been carried out, since these were assumed to be of particularly critical interest based on the various preliminary tests. Further loads along the entire transport chain and their possible cumulative interactions, as well as possible mishandling of the packaging, have not yet been taken into account. Only one-time occurrence of load impact with packaging in pristine condition was simulated in the experiment. Therefore, it cannot be assumed with absolute certainty that no additional critical loading scenarios occur afterwards, which should be considered for further investigation of influences and packaging design.

5 | CONCLUSION

Based on the defined experimental investigations regarding the impact behaviour of peelable tray packaging by means of a vertical drop test, it became possible to demonstrate fundamental influences of given design and load parameters on the damage behaviour and thus on transport safety. The observed tendencies stand unprecedented in literature. However, the variations that occurred between the tests are reason to strive for further and more in-depth investigations and developments. For instance, it becomes necessary to analyse how several successive loading scenarios interact with the packaging and thus influence transport safety, instead of considering only one, as it has been the case for this first study. In addition, the influence of previous damage to the packaging (impairment in the seam area, deformation of the tray) on transport safety should be further investigated. Further effort should be put in increasing the statistical reliability of results, for example by optimizing the repeatability of the test arrangement and increasing the number of test runs. These precautions would contribute to increasing the statistical certainty of results and significance of detected differences, thus establishing approaches for regression methods for transport related packaging design. To keep the future experimental effort low and to be able to represent a multitude of further influences at the same time, it is also recommended to set up a simulation model that allows for the application and investigation of multiple parameter manipulations. The development of a model basis for this purpose based on the finite element method has been started yet. In the future, this approach will initially be validated by means of the available experimental results from this first study.

ACKNOWLEDGEMENTS

The presented results are a product of the IGF research project "TransPEEL" (19857 BR) of the "Industrievereinigung für Lebensmitteltechnologie und Verpackung IVLV e.V.," which was funded by the “German Federal Ministry of Economics and Energy” (BMWi) within the framework of the program for the promotion of “joint industrial research” (IGF) based on a resolution of the German Bundestag. Open access funding enabled and organized by Projekt DEAL.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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