Leakproof Heat Sealing of Paperboard Trays - Effect of Sealing Pressure and Crease Geometry

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The leakproof sealing of paperboard trays depends on factors such as the quality of the sealed tray and the parameters of the sealing process. Leakproof sealing is critical when food products are packed, as poor sealing can result in leakage and cause a reduction in the microbiological quality and sensory shelf life of packed food products. In this paper, factors affecting the leakproof sealing of paperboard trays, such as sealing pressure and the geometry of creases in the trays, were investigated. Trays were sealed with varied sealing pressure and temperature, and the sealed trays were inspected using a coloring solution test, oxygen content measurements, and microscopic analysis. The results show that the sealing pressure is a critical parameter in the sealing process. The minimum sealing pressure that resulted in leakproof within the materials investigated was 1.8 N/mm². The depth of crease that can be sealed in a leakproof manner was found to be up to 150 µm.

Keywords: Paperboard; Tray; MAP; Modified atmosphere packaging; Tightness; Sealing pressure; Heat sealing; Leakproof

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INTRODUCTION

The heat sealing of 3-dimensionally-formed, polymer-coated paperboard trays has been previously researched. Traditionally, the so-called "industrial grade" trays manufactured by the press forming process have not allowed for adequate tightness properties (Leminen *et al.* 2012; Hauptmann *et al.* 2013). However, it has been shown that press formed trays can be also sealed to achieve both liquid tightness and satisfactory modified atmosphere packaging (MAP) tightness (Leminen *et al.* 2015a). The process of sealing paperboard trays is more challenging than sealing polymer trays because of creases and/or wrinkles in the sealing surface caused by the manufacturing process and the material properties of fiber-based materials. The creases and wrinkles can act as capillary channels that may cause leaks in the package (Leminen *et al.* 2012, 2015a; Hauptmann *et al.* 2013). Poor sealing can result in leaks and can reduce the microbiological quality and sensory shelf life of packed food products (Randell *et al.* 1995).

The effect of the resulting sealing pressure on the quality and failure of the heat seals of laminates has been discussed previously. With thin laminates, it has been stated that if too high a pressure (over 0.3 N/mm^2) is used, the sealant of the laminate can form a polyball, which causes the sealant of the laminate film to form along the edge of the heat sealed portion. This can lead to weaker seal strength and a thinner bonding layer (Hishinuma 2009). However, this was observed when two laminates (Al-deposited

CPP/OPP) were used and the heat sealing jaws heated the film from both sides. When a polyethylene terephthalate (PET)-coated paperboard tray was sealed with a multi-layer, PET-sealable film and the heat was applied only from the top of the lidding film, a resulting sealing pressure of about 2.7 N/mm^2 was found to be effective (Leminen *et al.* 2015a). This suggests that the uneven sealing surface and one-sided heating of paperboard trays requires significantly larger surface pressure than thin laminate films. One reason for this might be that the lidding film must fill the wrinkles in the sealing surface, which requires larger surface pressure.

In this study, the effect of the sealing pressure on the seal tightness of press formed paperboard trays was investigated to determine the surface pressure required for adequate seal tightness and properties. The investigation was done in relation to the sealing temperature. Also, the dimensions and shapes of the creases in the trays were measured and analyzed to determine the depth of the creases and wrinkles such that the tray can be sealed with adequate tightness.

The effect of heat sealing variables (temperature and dwell time) has been discussed, for example, with linear low-density polyethylene (LLDPE) (Mueller *et al.* 1998) and paperboard trays (Leminen *et al.* 2012), but the effect of the sealing pressure and crease geometry on paperboard trays has not been investigated. This information is important for the design of new sealing tools for paperboard trays. If the required (optimal) surface pressure is known, then this information can be used to design optimal tooling for the best tightness results. Also, the evaluation of creases can provide insight as to the question of the quality of trays that can be sealed as leakproof.

The modified atmosphere in the packages was analyzed using an optical fluorescence O_2 analyzer and an oxygen transmission rate testing system. The purpose of the atmosphere analysis was to investigate the headspace gas and the tightness of the sealed packages.

EXPERIMENTAL

Materials

The primary material used in the trays was Stora Enso Trayforma Performance 350 + 40 WPET (Stora Enso Imatra Mills, Finland). This material is a PET extrusion-coated paperboard with a base material grammage of 350 g/m^2 and a coating grammage of 40 g/m^2. The base board consists of three solid bleached sulphate (SBS) layers.

The lidding material used in the heat sealing was a PET-sealable multi-layer film, Westpak WestTop 405B PET (WestPak Oy Ab; Säkylä, Finland).

Methods

Experimental design

A detailed description of the press forming process was presented in previous manuscripts (Leminen *et al.* 2013; Tanninen *et al.* 2014). The trays were formed from pre-cut and creased blanks. The forming parameters included a female tool temperature of 170 °C, pressing dwell time of 1 s, pressing force of 135 kN, blank holding force of 1.2 kN, and pressing speed of 130 mm/s.

The tray size used was approximately 265 x 162 x 38 mm. The blank and tray geometry is shown in Fig 1.

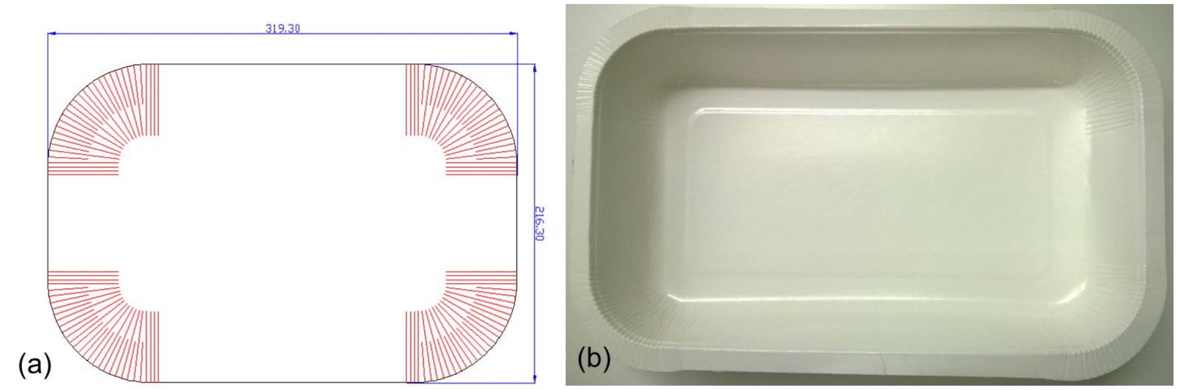

Fig. 1. The (a) blank used and (b) tray geometry. The creasing lines are presented in red.

The manufactured trays were sealed with a lid using an Ilpra Speedy tray sealer (Ilpra S.p.A; Vigevano, Italy (Ilpra 2014)). The tray sealer is shown in Fig. 2. The machine is a standard industrial sealer that was modified by adding a precision pressure regulator Festo LRP-1/4-10 (Festo, Italy) to adjust the sealing pressure.

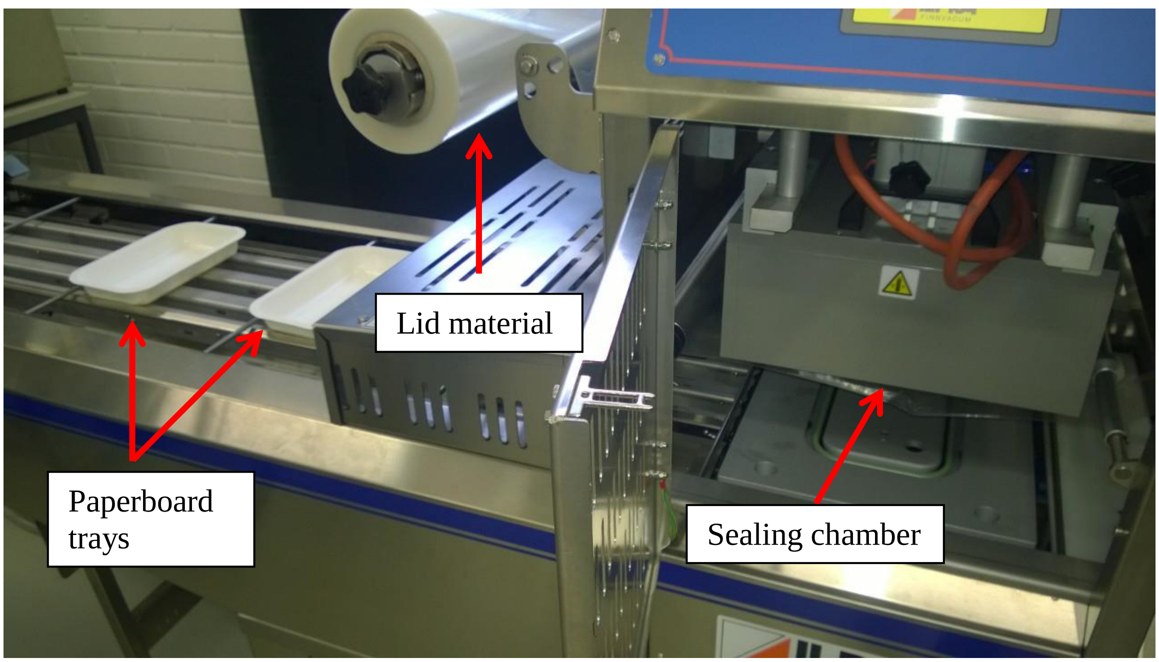

Fig. 2. Sealing equipment used in the study

The sealing process is described in Fig. 3. The sealing time was constant at 2.5 s, and the other heat sealing parameters used are presented in Table 1. The trays were flushed with a common gas mix for food applications. The gas composition was 70% N_2 and 30% CO_2. The accuracy of set temperature in the used equipment was ±4 K.

The sealing tool used was designed specifically for use with paperboard trays. The tool-set consisted of a heated upper tool with a flat metal surface and a bottom tool with a metal surface with silicone rubber. The tray rim and lidding film were placed between the tools and the trays were sealed together by applying pressure and heat. The width of the heated upper tool was 3 mm.

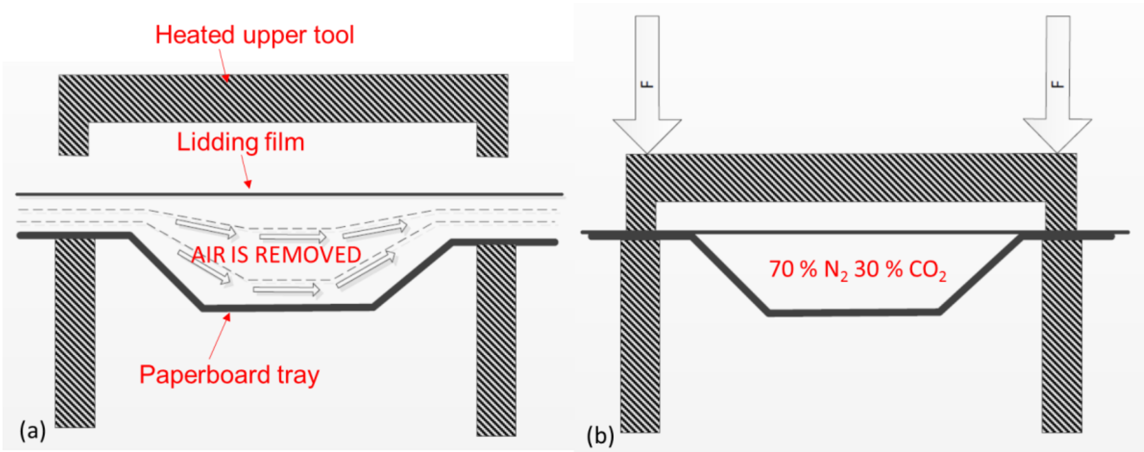

Fig. 3. The heat sealing and MAP process. (a) The tray is flushed with a protective gas and air is removed from the package, and (b) the tray and lidding film are sealed together for a set time and a seal is formed.

Table 1. Heat Sealing Parameters

Sealing Temperature (°C)	Sealing Pressure (bar)	Resulting Surface Pressure (N/mm^2)
170	6	2.7
170	5	2.2
170	4	1.8
190	6	2.7
190	5	2.2
190	4	1.8
190	3	1.3
210	6	2.7
210	5	2.2
210	4	1.8
210	3	1.3

After the sealing of the lid, the trays were flushed with a coloring solution in accordance with the European standard (EN 13676 2001). The coloring solution was applied to the tray and the sealed area for 5 min, and the seal was inspected for leaks. The reagents in the coloring solution were dyestuff E131 Blue and ethanol (C_2H_5OH, 96%). The color solution consisted of 0.5 g of dyestuff dissolved in 100 mL of ethanol. Flushing was done to detect leaks in the package and sealing area. The packages that had no leaks of the color solution were then selected to be sealed with the same parameters to investigate the oxygen composition inside these packages.

The oxygen composition inside the package was analyzed using a Mocon Optech O_2 Platinum analyzer (Mocon Inc., Minneapolis, USA). The analyzer utilizes the standard ASTM F-2714-08 (Standard Test Method for Oxygen Headspace Analysis of Packages Using Fluorescent Decay). The measurement method consisted of inserting an oxygen sensor inside the lidding film before heat sealing the film to the tray. The response of the phosphorescent sensor was analyzed using a handheld light beam device. The analysis occurred over the course of 14 d. The sealed trays were stored in a refrigerator, at 6 °C, to simulate realistic storage conditions.

The oxygen transmission rate of trays sealed at 190 °C and 6 bar was also analyzed with an Oxygen Transmission Rate (OTR) testing system (Mocon Ox-Tran, Mocon Inc., Minneapolis, USA) according to the standard ASTM D3985-05 ("Standard Test Method for Oxygen Gas Transmission Rate Through Plastic Film and Sheeting Using a Coulometric Sensor," 2010) to verify the results of the platinum analyzer. OTR measurements were conducted at 50% Relative Humidity (RH) and 23 °C.

The rim areas of the trays were studied with a stereomicroscope (Olympus Tokyo) to investigate the geometry and dimensions of the creases and the sealing results. The quality of the commercial, industrial grade, press-formed trays was also analyzed. Three different commercial trays were analyzed, the dimensions of the creases were measured, and the shape of the creases in the sealing surface was analyzed. The measured surface roughness parameters of manufactured trays were reported by Leminen *et al.* (2015b). The roughness parameter peak height (R_p) was found to be a useful indicator of the surface quality of paperboard trays. The average R_p value of the creased area of the trays sealed in this study was R_p (max) = 36.

RESULTS AND DISCUSSION

Table 2 shows the results of the color solution flushing. Five trays for each test point were used. The sealing pressure influenced the sealing result significantly, as expected. The temperature also had an effect on the required sealing pressure. However, when the temperature was at a proper level (190 to 210 °C) and sealing pressures of 4 bar or more were used, the seals appeared leakproof. When the temperature was too low (170 °C), the seals exhibited significant leakage with all pressures used. When the pressure was too low, regardless of the temperature used, the lidding film did not melt deep enough to the bottom of the creases, resulting in leaks.

Table 2. Heat Sealing Parameters

Sealing Temperature (°C)	Sealing Pressure (bar)	Leaks Shown by the Coloring Solution
170	6	Yes
170	5	Yes
170	4	Yes
190	6	No
190	5	No
190	4	No
190	3	Yes
210	6	No
210	5	No
210	4	No
210	3	Yes

Table 3 shows the average oxygen content in the packages after 14 d of storage. The values are averages of 5 trays. The trays that leaked when flushed with the coloring solution were discarded from the gas tightness test runs. The results show that the oxygen content averages in the packages were well under 1%. The measured Oxygen

Transmission Rate (O_2TR) average of the trays sealed at 190 °C and 6 bar was 4.1 cm^3/package·d. The area of the tray is approximately 0.053 m^2 and the area of the lidding film is approximately 0.034 m^2. The O_2TR value for the paperboard used is listed at 80 $cm^3/m^2 \cdot d$ (Ipack 2011). The permeation through the material used matches the measured values for the sealed packages. This means that the only permeation was caused by permeation through the tray, and that the lidding film materials and the seals were not leaking.

Table 3. Average Oxygen Contents in the Packages after 14 d of Storage

Sealing Temperature (°C)	Sealing Pressure (bar)	Average Oxygen Content after 14 days (%)
190	4	0.68
190	5	0.39
190	6	0.67
210	4	0.68
210	5	0.57
210	6	0.51

In the work of Leminen *et al.* (2015a), it was stated that even if the coloring solution exhibited no leaks, there could be significant gas leakage into some of the packages. With the trays used in this study, it was shown that if the coloring solution did not leak, the trays were also gas-tight. This was assumed to be caused by the better surface quality of the trays. When the surface quality deteriorates, there is more variance between these analysis methods.

It was noted that a seal that appears intact and properly sealed when inspected visually from the surface can be leaking under the surface on the bottom of the crease. This kind of effect is shown in Fig. 4.

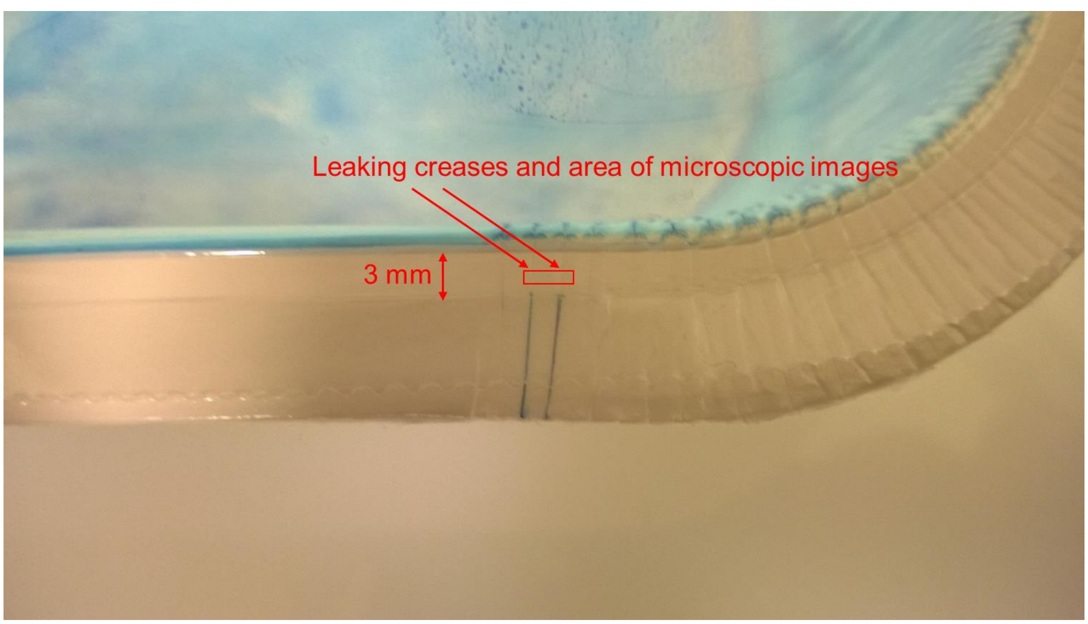

Fig. 4. Two leaking creases as revealed by the coloring solution. The leaks on the bottom of the crease are not visually apparent in the sealed area (the area with a width of 3 mm). The approximate area where samples were cut from the samples is indicated by the red box.

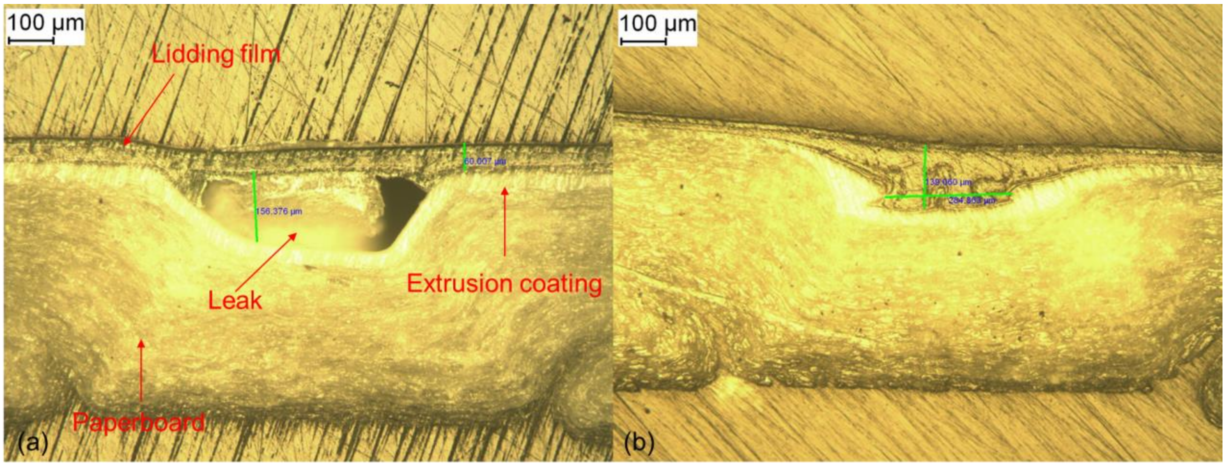

Fig. 5. Samples heat sealed with a pressure of (a) 3 bar, resulting in inadequate depth in the melting of the lidding film and leaks; and (b) 6 bar, resulting in a successful, non-leaking seal

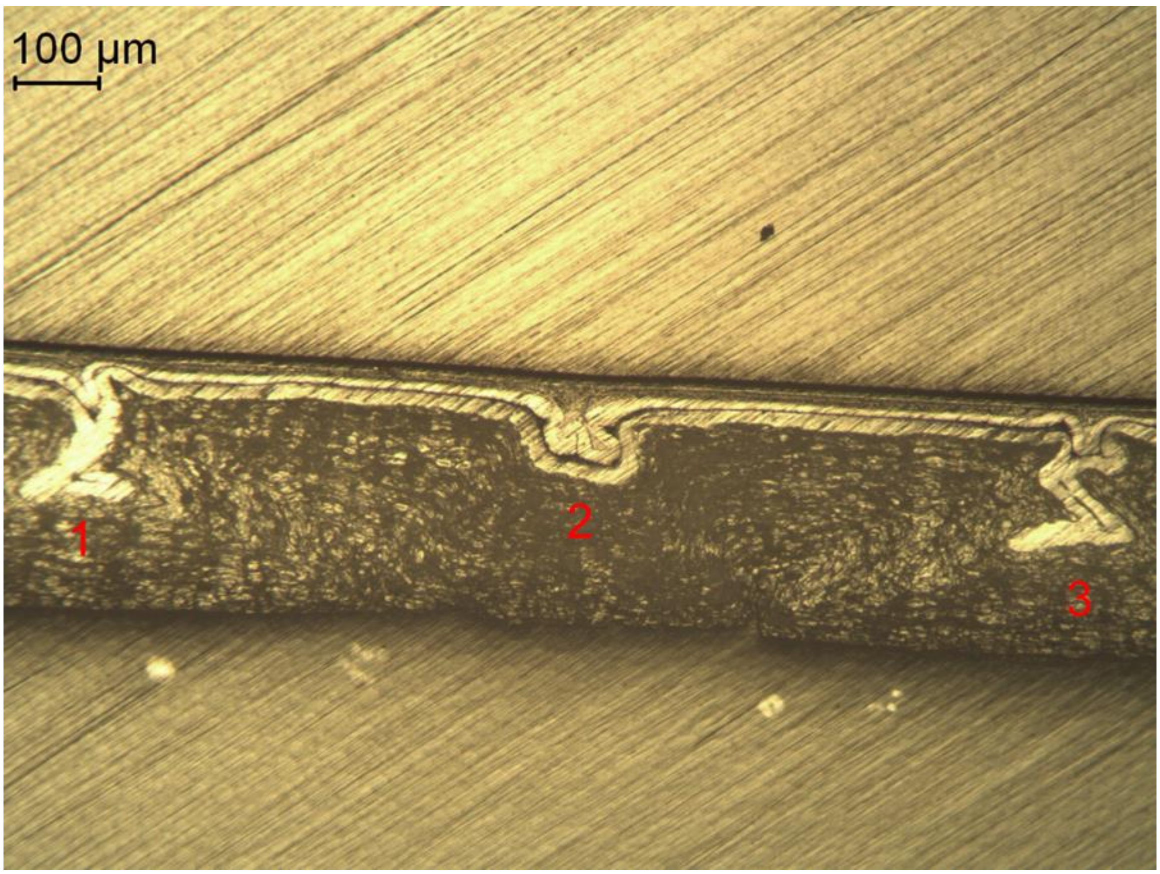

Fig. 6. Heat sealed creases with a sealing pressure of 6 bar, resulting in the lidding film melting to the bottom of the creases. Creases numbers 1 and 3 are so called "closed" creases and crease number 2 is an "open" crease.

Figure 5 shows two samples with sealing pressures 3 and 6 bar. In Fig. 5a, a clear leak is visible on the bottom of the crease in the sealing surface. It is clear that the sealing pressure had an effect on the melting depth of the lidding film. If the sealing pressure is too small, the film could be melted to the bottom of the crease, and leakage occurred. This shows that trays with deeper wrinkles and creases could potentially be tightly sealed if the surface pressure were higher. However, because the sealing tool width (3 mm in this case) cannot be reduced infinitely, the only way to increase the surface pressure would be to increase the pressure in the cylinders that produce the sealing force. Raising this pressure to above around 6 bar would require a pressure booster regulator, which could lift the system pressure to 10 bar. This is an interesting topic for further study. With polymer based trays, which have flatter sealing surfaces, the process window is much larger and there has not yet been a need for a higher surface pressure. This is also apparent in Fig. 5, where the flat surfaces around the wrinkles were successfully sealed even with the smaller surface pressure.

Figure 6 shows three creases which were sealed with the lidding film. The shape of these creases was typical for a creasing pattern, like those presented in Fig. 1a. The longer creases are usually formed "closed", like creases 1 and 3, while the shorter creases are formed "open", like crease 2. However, this kind of shape variance did not have a noticeable effect on the sealing result, as both geometries could be sealed with satisfactory leakproofness when the depth of the creases formed is not too large and the tray is otherwise intact. The results indicate that creases and wrinkles with depths of about 150 µm can be sealed in a leakproof manner.

Three industrial-grade trays were also analyzed to investigate the dimensions and shapes of the creases in the sealing surfaces of trays manufactured by commercial equipment. One of these trays was used with MAP for cold-cut ham and the other two samples were not sealed. In the tray used with MAP, the depth of the tray was approximately 16 mm, and the geometry of the tray was designed such that that the radius of the creased area was very large (about 110 mm). This generally makes the quality of the rim area flatter and prevents leakage (Leminen *et al.* 2015a). It was found that the coating film of the tray could not be clearly distinguished from the lidding film. This indicates that the different layers became melted together because of the high heat input and pressure in the sealing process. An example of this tray is presented in Fig. 7a.

The depth of the unsealed, industrial-grade trays ranged from 28 to 32 mm and the corner radius was about 50 mm. Figure 7b shows an image of a crease from an industrial-grade tray with an open crease that was approximately 400 µm deep. This kind of shape and dimension prevents the tray from being sealed without leaks.

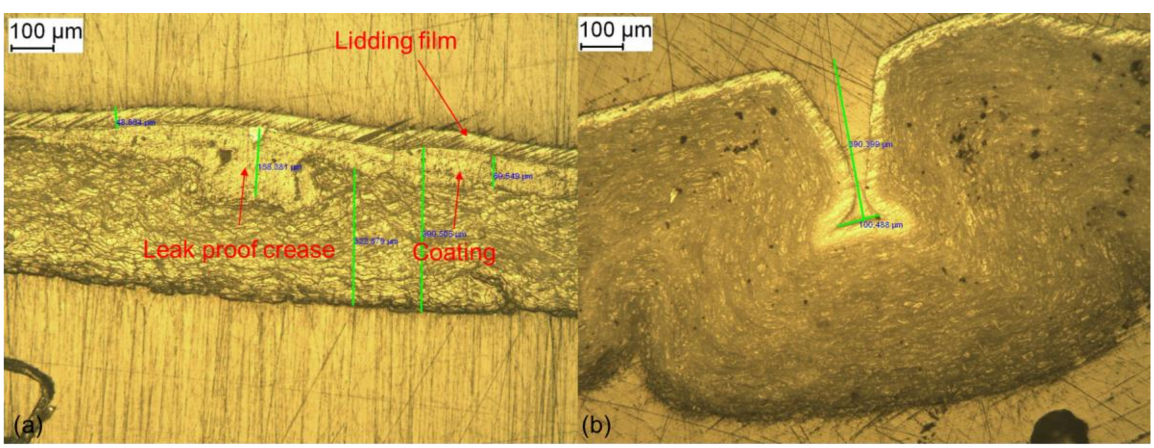

Fig. 7. (a) A heat sealed, leakproof, industrial-grade sample with a crease depth of approximately 160 µm; (b) An industrial-grade tray with an open, roughly 400-µm-deep crease.

The depth and width of the creases and the sealing process parameters are not the only factors important when considering if the tray can be sealed without leaks. When the manufacturing process of the tray is not satisfactory, the tray can have capillary channels that compromise its integrity. An example of an industrial-grade tray with a capillary channel is shown in Fig. 8. The heat sealing of the lidding film cannot mend this kind of defect in the trays. This kind of effect was also discussed in the work of Hauptmann *et al.* (2013).

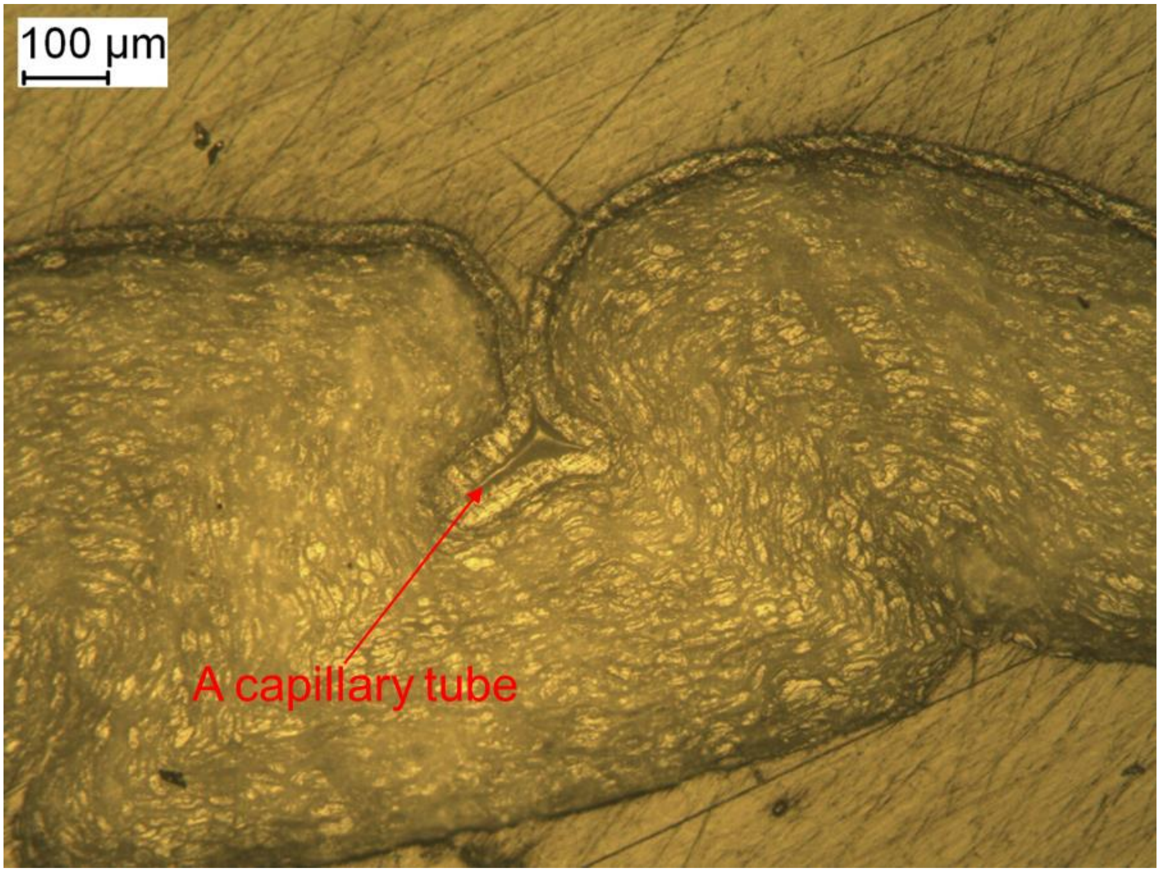

Fig. 8. A capillary channel on the sealing surface of an industrial grade tray

CONCLUSIONS

1. Sealing pressure has a great effect on the tightness of heat seals when press formed, polymer-coated paperboard trays are heat sealed with a lidding film. Too low a pressure results in leaks, which first occur at the bottom of the creases in the sealing surface.
2. The resulting surface pressure which resulted in successful seal tightness with these products ranged from 1.8 to 2.7 N/mm^2. This should be taken into account when sealing tools for press-formed trays are designed.
3. The O_2TR values and oxygen contents of the trays show that press-formed paperboard trays can be sealed without leaks such that the only O_2 permeation is through the sealed materials, not from the seal.

4. Creases in the sealing surface of depths of up to 150 μm can be sealed without leaks.
5. The depth of the creases is not the only factor determining if the seals are leakproof; defects such as capillary channels can appear if the tray manufacturing process is not controlled properly.

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