Effect of Blank Holding Force on the Gas Tightness of Paperboard Trays Manufactured by the Press Forming Process

Ville Leminen,* Panu Tanninen, Henry Lindell, and Juha Varis

Although several authors have studied 3D forming using the press forming process, the gas tightness of polymer-coated paperboard trays has not been widely researched. In this paper, the effect of blank holding force on the surface quality and tightness of press-formed paperboard trays was researched. The press-formed trays were heat-sealed with a multilayer polymer lid. The tightness of the trays was analyzed by following the oxygen content of the packages over the course of 14 d and by using a penetrant coloring solution to locate possible leaks. The results indicate that the blank holding force had a great effect on the quality and tightness of the trays, especially in the case of a rectangular geometry. The geometry of the formed trays played a significant role in process parameter selection, and more demanding geometries emphasize the importance of parameter optimization. However, with the correctly selected parameters, the use of modified atmospheric packaging (MAP) in polymer coated paperboard trays was shown to be possible. The oxygen content of both analyzed geometries was found to be less than 1% 14 d after sealing. It was also demonstrated that the gas tightness of a seal cannot be confirmed using a penetrant solution test exclusively.

Keywords: Paperboard; Press-forming; MAP; Modified atmosphere packaging; Tightness; Blank holding force

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INTRODUCTION

Both three dimensional (3D) forming and the material behavior of paperboard during press forming have been previously studied by several authors. These articles describe the effect of process parameters, adjustability, and tooling technology (Hauptmann *et al.* 2014; Leminen *et al.* 2013) functionality of materials in forming (Vishtal and Retulainen 2012; Tanninen *et al.* 2014; Zeng *et al.* 2013) and also the gas tightness of trays (Hauptmann and Majschak 2011). However, tray-shaped, paperboard-based, and polymer-coated packages have not yet become a significant competitor to polymer-based packages when the use of modified atmosphere packaging (MAP) is required. The quality of industrially manufactured trays is not often good enough for MAP-usage. One reason for this may be due to insufficiently controlled process and parameters. One reason for polymer-based package dominance is due to the tightness of the packages, as instances where the lid is heat sealed to the package have been problematic. A major cause for this phenomenon is creases in the sealing area. The paperboard blank is creased to control and enable paperboard formation to certain geometric conditions when the blank is press-formed to three dimensional form. Furthermore, the creased wrinkles can act as capillary tubes, which may cause leaks in the package (Leminen *et al.* 2012; Hauptmann *et al.* 2013).

In previous studies, gas tight sealing resulting from pre-creased blanks was not achieved (Hauptmann *et al.* 2013). Poor sealing can critically affect the overall shelf life of food (Yeh and Benatar 1997).

In this study, the press forming of polymer-coated paperboard trays and the heat sealing process of lidding films into these trays with MAP was studied. The study attempted to show that a MAP-tight paperboard based package, manufactured by press forming, can potentially be manufactured. The effect of the blank holding force on the rim area surface quality, and consequently, on the gas tightness of the package with a sealed lid, is presented. The modified atmosphere in the packages was analyzed using an optical fluorescence O_2 analyzer. The purpose of the atmosphere analysis was to investigate the headspace gas and the tightness of the sealed packages. Results of the experiments are presented to support the claims.

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 polyethylene terephthalate (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 materials were stored in a constant humidity chamber at 85% relative humidity (RH) to ensure sufficient humidity. The high humidity was used to maintain the delivery moisture content of the paperboard, and the average humidity of the tested materials was measured using an analysis scale. The measured moisture content of the material was 10.5%.

Elongation values for tested materials, measured in 23 °C and 50% RH conditions, was approximately 5% in cross direction and 2.5% in the machine direction. However, according to Kunnari *et al.* (2007), by varying the moisture and/or temperature of the paper based materials, it is possible to increase the elongation from around 2 to 2.5 percentage points. Vishtal *et al.* (2014) report a conditioning at 75% RH to increase the maximum drawing limit up to 70% at room temperature and up to 30% at 165 °C. Therefore, the elongation values during tray pressing can be increased. 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

The blank holding force (*i.e.*, rim tool force) is the force that controls the folding of the tray corners during the press-forming of paperboard trays. The effect of the blank holding force on the quality of the formed product has been discussed in previous studies (Hauptmann and Majschak 2011; Tanninen *et al.* 2014). In this study, the blank holding force was varied to create trays with different rim surface qualities to observe the effect of blank holding force with respect to the MAP-tight sealability. During the study, the other process parameters were kept constant.

Two differently shaped trays, a rectangular tray and an oval tray, were selected for the forming and sealing tests. These two geometries are meant to represent most typical tray shapes used in the food packing industry. The maximum blank holding force for both geometries was investigated. The blank holding force was found using the highest possible force that did not cause cracks in the formed trays. This was the force that was used as the starting point, from which the force was lowered, in order to investigate the effect of blank holding force. The lowest force used was the force that was required to keep the rim tool in the starting position before the pressing process was initiated.

A detailed description of the press forming process is presented in a previous manuscript (Leminen *et al.* 2013). The forming parameters with both geometries were female tool temperature 170 °C, pressing dwell time 1 s, pressing force 135 kN and pressing speed 130 mm /s. The blank holding forces are presented in Table 1. The tray geometries used in the study are presented in Figs. 1a and 1b.

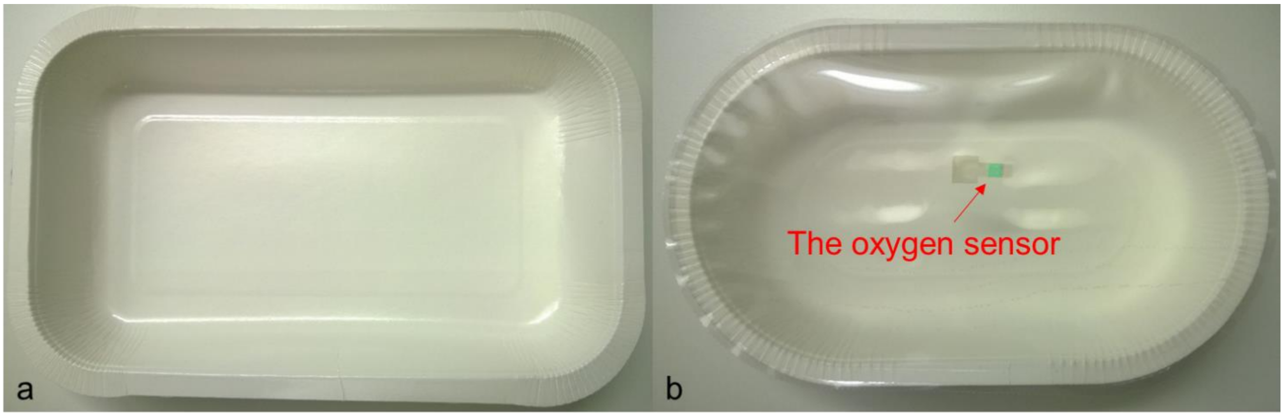

Fig. 1. The tray geometries used in the study: (a) rectangular tray and (b) oval tray with the heat sealed lidding film and O_2 sensor

Table 1. Blank Holding Forces for Oval and Rectangular Geometry

Oval tray	Rectangular tray
1.93 kN	1.16 kN
1.29 kN	0.77 kN
0.94 kN	0.68 kN
0.52 kN	0.58 kN

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 presented in Fig. 2.

After manufacturing of the trays, a lidding film was sealed on top of the trays' rim area. The heat-sealing parameters used in this were sealing temperature 190 °C and sealing dwell time 2.5 s. Lower sealing temperatures and dwell times were also tested, but they resulted in seal leaks with a high frequency. Higher heat input resulted in the melting, and subsequent leaking of the lid material outside the sealing area. Sealing pressure was kept at a constant 6 bar, which is the normal pneumatic pressure used in industrial scale tray sealers. This resulted in a surface pressure of 2.65 N/mm^2. The trays were flushed with a common gas mix for food applications. The used gas composition was 70% N_2 and 30% CO_2.

The used sealing tool 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 silicone surface. The tray rim was placed between the tools and the lid film, and the trays were sealed together by applying pressure and heat.

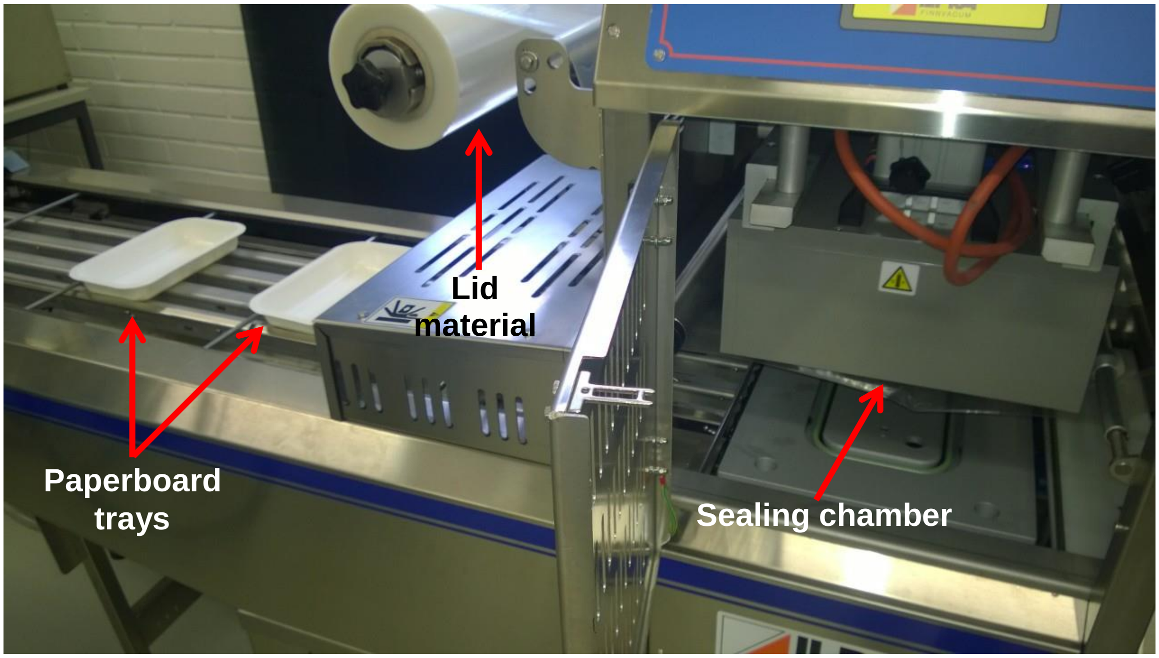

Fig. 2. Sealing equipment used in the study

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 hand held light beam device. The analysis occurred over the course of 14 d. The sealed trays were stored in a refrigerator, at a temperature of 6 °C, to simulate realistic storage conditions. Figure 1b depicts a tray with a heat sealed lid and an O_2 sensor inside the package.

After the O_2 measurements, the trays were flushed with a coloring solution in accordance with the European standard (EN 13676 2001). The gas sensor was removed, and a hole was cut into the lid. The coloring solution was applied to the tray and the sealed area for five minutes 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. This was done to investigate if this commonly used leak detection method can be used to confirm the gas tightness of a package.

RESULTS AND DISCUSSION

The effect of the blank holding force on the flatness of the tray flange was quite apparent. The magnitude of parallel and perpendicular forces enabling the folding process is known to depend on the blank holding force. When blank holding force is too low the paperboard blank folds insufficiently and the desired quality of the rim area (flange) is not achieved. However, it is not possible to visually evaluate the exact quality in which a tight seal can be achieved.

Figures 3 and 8 show tray corners with different rim holding force settings. Figure 3 shows that, if the blank holding force is low enough, the change in rim area quality is clear in trays with rectangular geometry. Both the lower surface quality and the subsequent leakage caused by the heat-sealing can be detected with the coloring solution. Rectangular trays manufactured with a blank holding force of 1.16 kN, 0.77 kN, and 0.68 kN did not have leakage in the coloring solution tests, while the trays manufactured with a blank holding force of 0.58 kN showed leakage in the tray rim area.

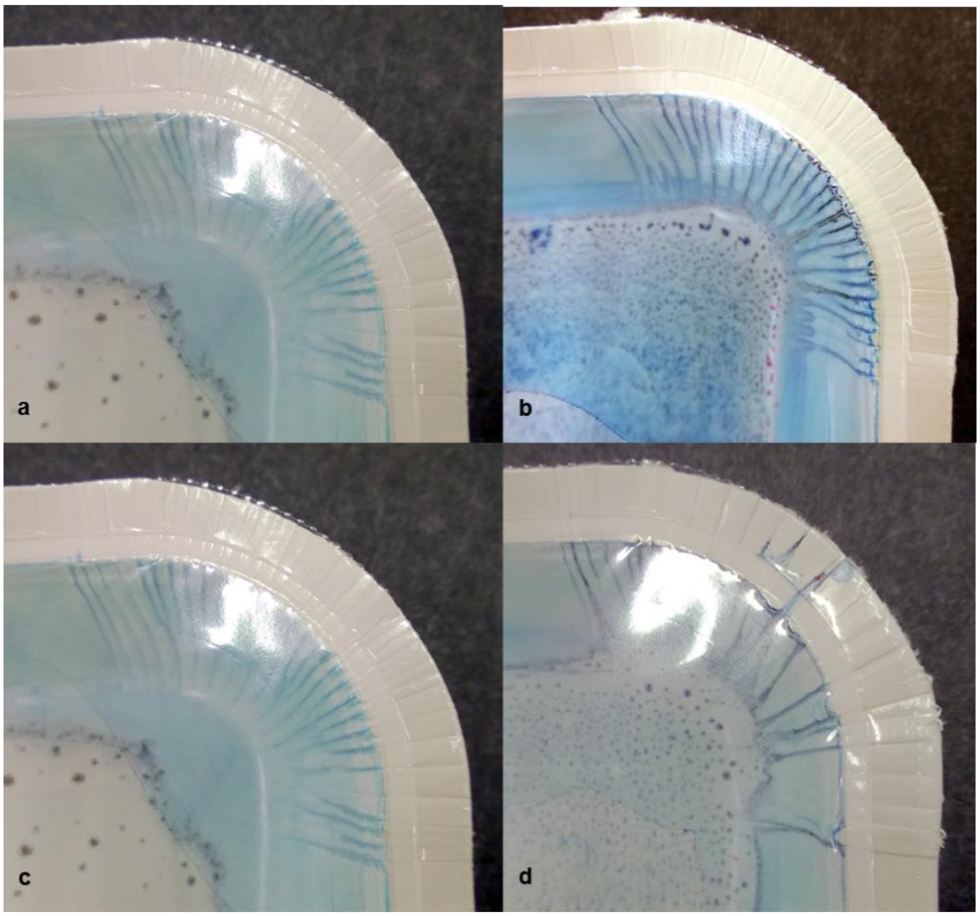

Fig. 3. Rectangular tray corners with different blank holding forces: (a) 1.16 kN, (b) 0.77 kN, (c) 0.68 kN, and (d) 0.58 kN

Figure 4 clearly shows gas leakage in the packages manufactured with a blank holding force of 0.58 kN and 0.68 kN. While the tray shown in Fig. 3b appears to have an intact seal, the MAP composition in the package changed drastically (Fig. 4, 0.68 kN). This shows that the gas tightness of a package cannot be confirmed using the coloring solution, even though the results would indicate a gas-tight package.

The oxygen content in the packages manufactured with a blank holding force of 0.77 kN and 1.16 kN still registered at less than 1% two weeks after the initial sealing. The results of the coloring solution test and O_2 measurements indicate that the blank holding force has a clear effect on the tightness of the sealed package. There is a threshold between blank holding forces of 0.68 kN and 0.77 kN which enables the tray rim area to form more evenly and make possible the gas-tight sealing.

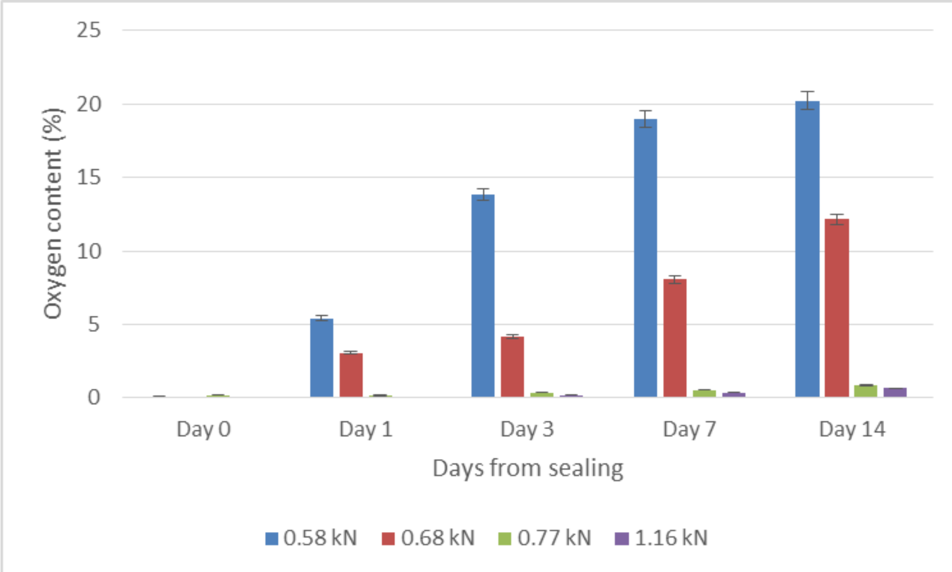

Fig. 4. Oxygen measurement averages of the rectangular trays manufactured with a varied blank holding force. Data provided with ± 3% accuracy of measuring.

Fig. 5. Oval tray corners with different blank holding forces: (a) 1.93 kN, (b) 1.29 kN, (c) 0.94 kN, and (d) 0.52 kN

Figure 5 shows no visible leakage in any of the tested oval trays. It seems that when the trays were subjected to a pressing force of 135 kN and the press-forming process was otherwise controlled correctly, the rim area quality remained tight, withstanding all blank holding forces. Oval trays with all blank holding forces did not have leakage in the coloring solution tests. The coloring solution test also did not reveal any cracks or pinholes in either tray geometry.

Figure 6 shows that the gas composition of the oval trays was less than 1% oxygen after 14 d with all used blank holding forces. The formation of oval shape trays during tray pressing occurred more homogeneously in comparison to the rectangular trays with different blank holding force values. This could be due to the less demanding geometry of the tray, as the radius in the tray corners and the density of creases are larger. The rectangular tray is more sensitive to process parameter alterations; therefore, its processing window is smaller.

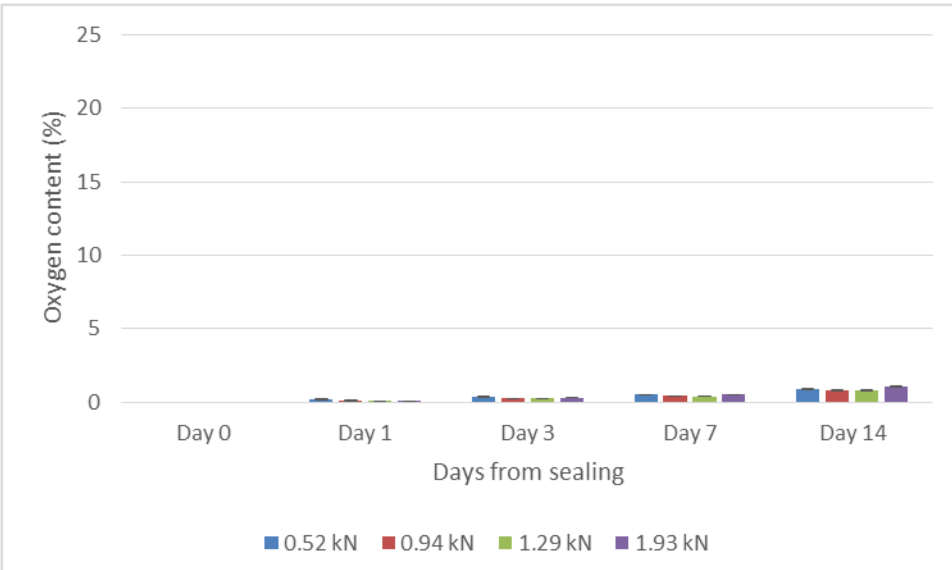

Fig. 6. Oxygen measurement averages of the oval trays manufactured with a varied blank holding force. Data provided with ± 3% accuracy of measuring.

The geometry of the trays affects the manufacturing process of the MAP-trays as a whole, as incorrectly selected process parameters for the press-forming stage can cause deterioration in the tray quality. Typically, deterioration of tray quality cannot be mended during the heat sealing of the lid.

Due to paperboard properties a crimpled appearance cannot be avoided completely if certain geometries are formed. However, when every process step is done correctly, gas-tight seals can be reliably achieved when polymer-coated paperboard trays are formed from pre-creased blanks.

CONCLUSIONS

1. The blank holding force affects the surface quality of the rim area of press-formed polymer coated paperboard trays. The surface quality directly affects the gas tightness of the package after a lid has been sealed to the tray.

2. The change in surface quality is more apparent in trays with a rectangular geometry than those with an oval geometry.
3. The gas tightness of press-formed polymer coated paperboard trays sealed with a multi-layer polymer lidding film is considered satisfactory for the use of modified atmosphere packaging (MAP) in food solutions. This requires that suitable tools, materials, and process parameters are selected and used during the tray manufacturing process and lid sealing process.

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