Effect of Elevated Heat Sealing Pressure on the Gas Tightness of Press-formed Paperboard Trays

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The quality of press-formed paperboard trays and its effect on the leakproof heat-sealability of the lidding film is known to depend on the quality of the sealed trays and the parameters of the sealing process. In this study, the elevation of the sealing pressure and its effect on the leak-proof heat-sealing of press-formed trays with reduced surface quality were investigated. Trays with varying quality were manufactured and heat-sealed with a lidding film, using three different sealing pressures. The quality of the sealed trays was evaluated using oxygen content measurements, leak detection by a coloring solution, and microscopic analysis. The results showed that using a higher, elevated pressure resulted in a lower oxygen content in the packages during the analysis. The results also showed that even a high sealing pressure was not enough to achieve a leakproof seal if the quality of the sealed trays was not in a satisfactory level, for example as a result from a low forming force.

Keywords: Paperboard; Press-forming; Modified atmosphere packaging (MAP); Tightness; Blank holding force; Sealing pressure

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INTRODUCTION

Press forming (*i.e.*, tray pressing, press moulding, stamping, sometimes also called deep drawing) is a process that is used to form three-dimensional (3D) shapes from paperboard. The process uses moulding tools that consist of a male mould (punch), female mould (die), and a blank holder (rim tool) (Hauptmann *et al.* 2013; Tanninen *et al.* 2014; Leminen *et al.* 2015a,b). Press-formed paperboard trays and plates are used in the packaging of various food products such as fast food, ready-to-eat meals, and frozen food. Paperboard trays provide an alternative for oil-based plastic packages in various packaging applications.

Heat sealing is widely used for the sealing of food packages, such as thin polymer bags and rigid trays. It can be defined as the joining of two thermoplastic materials by applying pressure and heat to the heat-sealing zone. First, the bonded surface is heated to an appropriate temperature, and then cooled down to complete the bonding. Heat sealing is often used to create airtight closures that can prevent bacterial incursions (Hishinuma 2009). The quality of heat sealing and its parameters for polymer films, such as linear low-density polyethylene (LLDPE), was researched previously (Tetsuya *et al.* 2005; Mihindukulasuriya and Lim 2011; Van Oordt *et al.* 2014).

The heat sealing and manufacturing of press-formed, polymer-coated paperboard trays has been previously reported in several papers. Research emphasis has concentrated on issues such as the manufacturing parameters in press-forming (Leminen *et al.* 2015;

Tanninen *et al.* 2015), forming tools (Leminen *et al.* 2013), sealing pressure and temperature (Leminen *et al.* 2012, 2015b), and the surface roughness and quality of the sealing surface (Hauptmann *et al.* 2013; Leminen *et al.* 2015c,d). Previous studies have made it clear that the most deciding factor regarding leakproof heat sealing of press-formed paperboard trays are the wrinkles in the sealing surface, which usually are defined by pre-creasing of tray blanks, and cannot be completely avoided. The creases in the sealing surface can act as capillary tubes that can cause the package to leak. Another major factor is the sealing pressure, which has to be at a sufficient level to ensure leakproof sealing. Recently there have been advancements in the forming and sealing processes of paperboard trays. Hence, the quality of press-formed trays has been shown to be sufficient for the use of modified atmosphere packaging (MAP), if the whole process chain from tray manufacturing to the heat-sealing process is completed in a sufficient level. In practice, this means that the dimensions of the wrinkles or creases in the sealing surface have to be small enough and the sealing pressure has to be high enough for the lidding film to be sealed with satisfactory results.

This study investigated whether press-formed trays with deeper wrinkles in the sealing surface (*i.e.*, worse surface quality) can be tightly sealed when the sealing pressure has been elevated above the industrial standard (from 6 bar to 10 bar). This could enable a wider range of fiber-based packages to be used with MAP and at the same time replace oil-based plastics with products manufactured from renewable paperboard. The modified atmosphere in the packages was analysed using an optical fluorescence O_2 analyser to investigate the headspace gas and the tightness of the sealed packages.

EXPERIMENTAL

Materials

The primary material used to manufacture the trays was Stora Enso Trayforma Performance 350 + 40 WPET (Stora Enso Mills, Imatra, 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 baseboard consisted of three solid bleached sulphate (SBS) layers. The fiber dimensions of the paperboard were measured using a L&W Fiber Tester (ABB, Stockholm, Sweden). The fiber length, fiber width, and kink index were measured at 1.1 mm, 22.5 µm, and 1.13, respectively.

The materials were stored in a constant humidity chamber at 85% relative humidity (RH) to ensure sufficient humidity. The high humidity was used to obtain the desired moisture content, which was verified with a moisture analyser (Adams Equipment PMB 53, New York, USA). The measured moisture content of the material was approximately 8%. Typically, the moisture content in press forming should be from approximately 7 to 11%. Very low moisture content can result in cracks in forming, while moisture content too high can result in unwanted evaporation of the water and damaging (bubbling) of the lidding film.

The lidding material used in the heat sealing was a PET-sealable multi-layer film, Westpak WestTop 405B PET (WestPak Oy Ab, Säkylä, Finland). The total thickness of the film was approximately 115 µm and consisted of a PET-sealable inner layer and several barrier layers.

Methods

Experimental design

A detailed description of the press forming process has been presented in previous manuscripts (Leminen *et al.* 2015b; Tanninen *et al.* 2015). The forming experiments were done using the LUT Packaging Line, which has a synchronized servo motor controlled mechanical movement. The forming parameters were female tool temperature 170 °C, pressing dwell time 1 s, pressing force 35 kN, and pressing speed 130 mm/s. The pressing force resulted in a surface pressure of 4.7 N/mm^2 on the tray flange in the final flattening phase of the forming. The blank holding force (BHF) was varied using three different settings: 500 N, 750 N, and 1000 N. The used forming parameters (especially the forming force) were different from normal production parameters to achieve a reduction in the surface quality of the trays. The geometry of the manufactured trays and the tray blank are shown in Fig. 1.

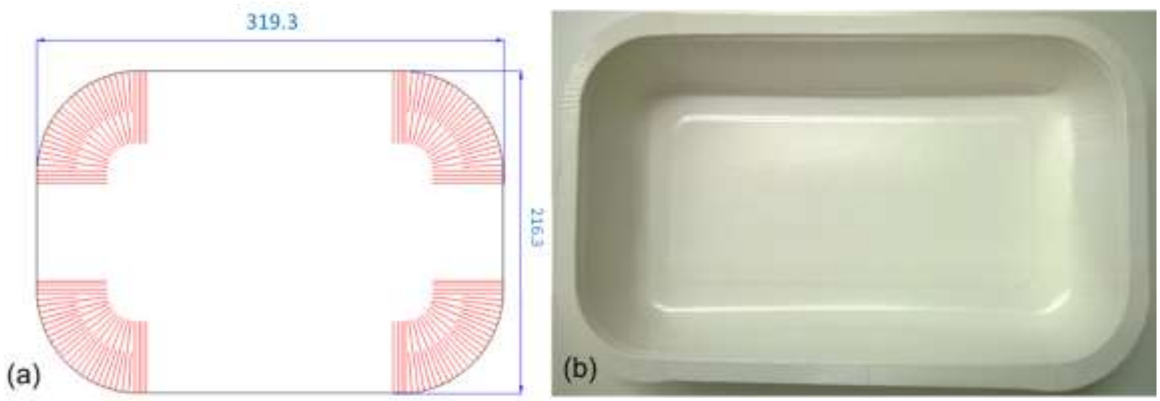

Fig. 1. (a) Tray blank geometry and creasing pattern, the creasing lines are presented in red; (b) Press-formed tray

The manufactured trays were sealed with a lid using an Ilpra Speedy tray sealer (Ilpra S.p.A, Vigevano, Italy (Ilpra 2014)). The sealing equipment was modified by adding a precision pressure regulator (Festo LRP-1/4-10) that could be used to adjust the sealing pressure, and a pressure booster (SMC Booster Regulator VBA 10) that enabled the used sealing pressure to be elevated from 6 bar to 10 bar. A schematic of the heat-sealing of a paperboard tray is shown in Fig. 2a. The paperboard tray is located between the sealing tools in 2b. The lower sealing tool (LST) lifts the tray under the tray flange, and the sealing chamber (SC) is closed. Then, the upper and lower sealing tools (UST and LST) are pressed together with a set force (F), the tray and the lidding film (LF) are sealed together for a set time, and the seal is formed. At the same time, a sharp blade cuts the lidding film according to the tray geometry. (Leminen 2016) The sealing tool consisted of a heated upper tool (T_1) and an unheated lower tool (T_2) with a silicone rubber. The heat sealing temperature and sealing time were kept constant at 190 °C and 2.5 s while sealing was conducted with three different pressures: 4 bar (1.8 N/mm^2), 6 bar (2.7 N/mm^2), and 10 bar (4.5 N/mm^2).

Previous manuscripts (Leminen *et al.* 2015a; Leminen 2016) have shown that with paperboard trays the sealing pressure should be above 1.8 N/mm^2 to achieve a leakproof seal when the maximum depth of single creases in the sealing area is up to 150 μm. 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 oxygen composition inside the package was analyzed using a Mocon Optech O_2 Platinum analyzer (Mocon Inc., Minneapolis, MN, USA). The analyzer utilized the standard ASTM F-2714-08 (2013). 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 days (d).

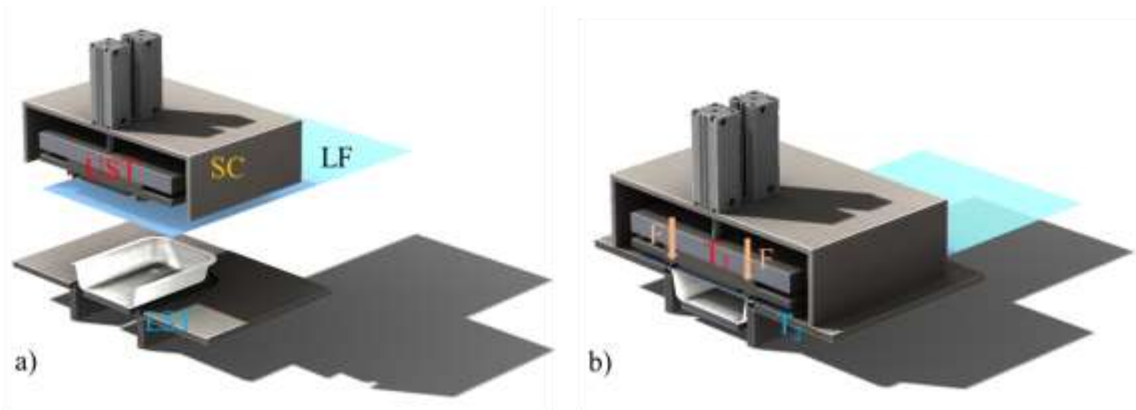

Fig. 2. The heat-sealing process (Modified from Leminen 2016)

The sealed trays were stored in a refrigerator, at a temperature of 6 °C, to simulate realistic storage conditions. The measurements were taken as averages from six samples per test point.

After the 14 d period, the trays were flushed with a coloring solution in accordance with the European standard EN 13676 (2001) to highlight the leaks and points of interest in the microscopic analysis. 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 (Sigma-Aldrich, Steinheim, Germany) and ethanol (96%) (Altia, Rajamäki, Finland). The color solution consisted of 0.5 g of dyestuff dissolved in 100 mL of ethanol. Flushing was used to detect leaks in the package and sealing area. The rim areas (sealing areas) of the trays were studied with a stereomicroscope (Olympus, Tokyo, Japan) to investigate the geometry of the creases and the sealing results, and to observe the effect of different sealing pressures.

RESULTS AND DISCUSSION

Figure 3 shows the average O_2 contents of trays manufactured with a BHF of 500 N. As clearly shown, the trays with 10 bar sealing pressure had the lowest O_2 content and the trays with four bar had the highest O_2 content.

The results show that there was leakage in all of the test series except for 750 N BHF and 10 bar sealing pressure. This was expected, because the trays were manufactured by design with parameters that would cause leaks in the trays. However, a clear trend showed that a higher sealing pressure resulted in better results and a lower oxygen content.

Figure 6 shows the cross-section of a single crease from a tray manufactured with different blank holding forces. The figure shows that the shape of the formed crease was irregular with the smallest holding force due to a noticeable difference in the shape of the formed creases. These irregularities are assumed to be caused by a too low BHF, which prevents a uniform force distribution onto the material. All of the creases still seemed insufficiently folded, and there were large gaps, which were assumed to be caused by the low forming force that caused the flattening of the tray flange to be inadequate.

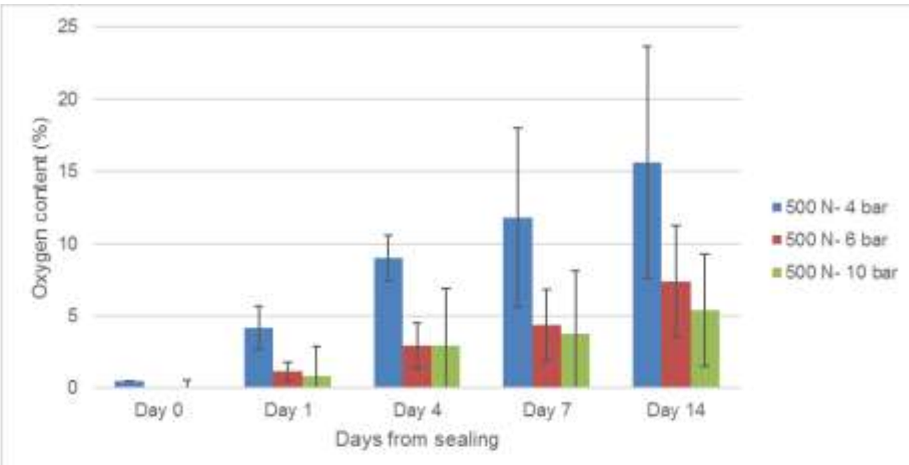

Fig. 3. Average O_2 contents of the trays manufactured with a blank holding force of 500 N sealed with varied sealing pressures. The data are presented with the standard deviation.

A similar trend is shown in Figs. 4 and 5, which show the O_2 contents of trays manufactured with a BHF of 750 N and 1000 N.

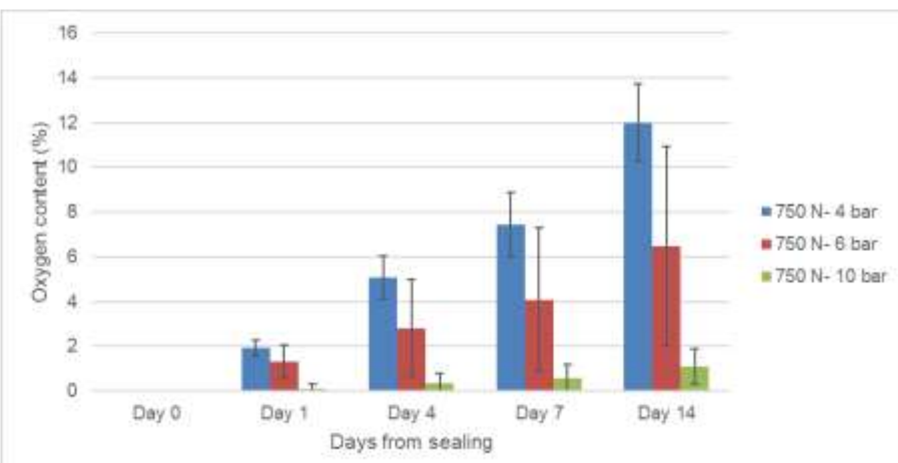

Fig. 4. Average O_2 contents of the trays manufactured with a blank holding force of 750 N sealed with varied sealing pressures. The data are presented with the standard deviation.

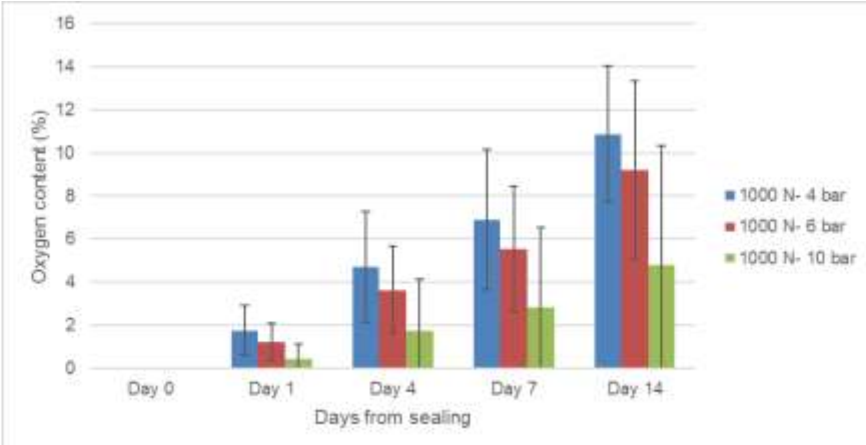

Fig. 5. Average O_2 contents of the trays manufactured with a blank holding force of 1000 N sealed with varied sealing pressures. The data are presented with the standard deviation.

This indicated that the pressing force of 35 kN, which was used in this study, was not enough to flatten the tray flange for leakproof sealing, which was expected, as a lower sealing surface was desired to subsequently experiment the effect of the sealing pressure. In a previous study (Leminen *et al.* 2015a), trays manufactured with a BHF of 770 N and above were sealed without leaks when a pressing force of 135 kN was used. It must be noted that a high pressing force itself was not enough to ensure a flat sealing surface, but the whole converting process must be controlled optimally to enable a flat sealing surface.

Fig. 6. Cross-section of single formed creases before sealing in trays manufactured with different blank holding forces: a) 1000 N, b) 750 N, and c) 500 N

Figure 7 shows the cross-sections of the creases in the trays manufactured with a BHF of 1000 N after heat sealing with a 10 bar pressure. The heat-sealing process flattened the sealing area to some extent. However, because the creases were insufficiently folded in the tray-pressing phase, this caused capillary tubes under the sealing surface, which subsequently cause leaks and compromise the integrity of the sealed packages. This effect has been previously discussed (Leminen *et al.* 2012; Hauptmann *et al.* 2013). An example of such a capillary tube leak is highlighted with the red arrow and the blue coloring solution in Fig. 7. The depth of insufficiently folded creases was from 250 to 400 µm. The formation of creases was more irregular than in earlier studies (Leminen 2016), which is expected to be caused by the lower forming force. The frequency of insufficiently folded creases with a BHF of 500 N was over 80% while with 1000 N the number was approximately 20%.

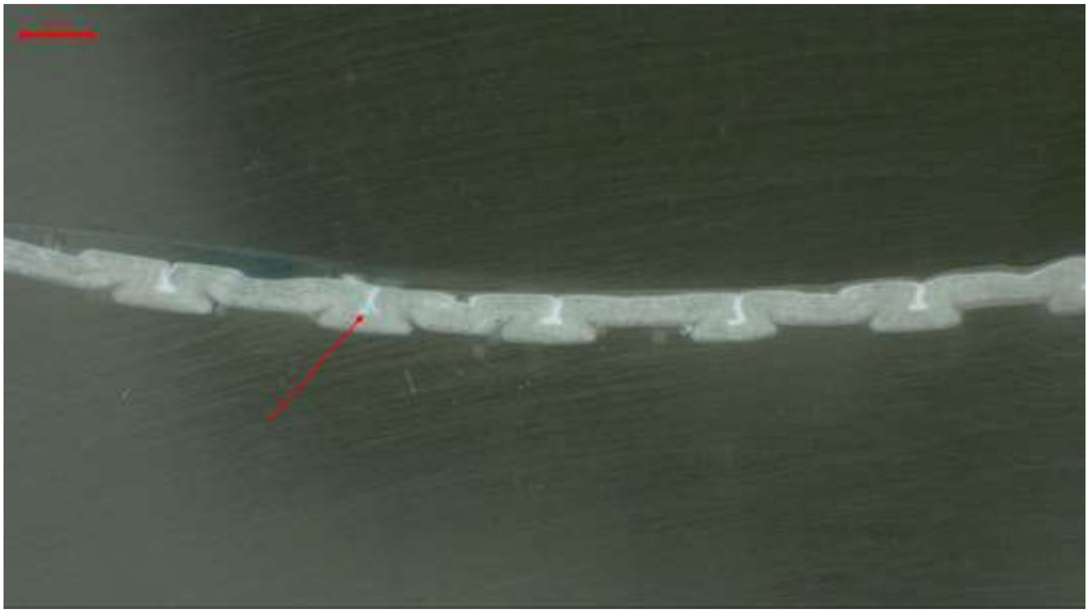

Fig. 7. Cross-section of sealed creases with BHF 1000 N and sealing pressure 10 bar; the red arrow highlights a leak

The results were in good agreement with earlier observations (Hauptmann *et al.* 2013; Leminen 2016) that state that if the quality of the formed trays is low enough the sealing phase cannot mend the result. However, the results also clearly indicated that the elevation of sealing pressure over the industrial standard (6 bar) improved the sealing result with all press-formed trays to some extent. With the increase of sealing pressure, small variations in the surface quality of formed trays were mended and a leakproof sealing result was achieved with trays that had worse surface roughness in the sealing area. The cost of a pressure boosting system is also fairly low, approximately 500 €, which makes the system easily available to existing filling machinery. The forming force (pressing force) clearly had a great effect on the surface quality of the trays. The forming machinery used typically defines this force. A more thorough analysis of the required forming force with different geometries to enable a leakproof sealing result would provide an interesting topic for further research and better help understand the requirements for machinery and process development.

CONCLUSIONS

1. Increased sealing pressure had a positive effect on the heat-sealing result of press-formed paperboard trays, and reduced the total oxygen content inside the sealed packages with all of the tested trays.
2. A high sealing pressure was not enough to achieve a leakproof seal if the quality of the sealed trays was not of a satisfactory level. The main reason for this was the non-optimal and irregular geometry of folded creases in the tray flange, which resulted in leaks.

3. A high forming force (pressing force) should be used to achieve a flat sealing surface in the tray flange. A pressing force of 35 kN was not high enough to achieve a leakproof sealing result.

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REFERENCES CITED

ASTM F2714-08 (2013). "Standard test method for oxygen headspace analysis of packages using fluorescent decay," ASTM International, West Conshohocken, PA.

EN 13676 (2001). "Polymer coated paper and board intended for food contact - Detection of pinholes," European Committee for Standardization, Brussels, Belgium.

Hauptmann, M., Schult, A., and Zelm, R., Gailat, T., Lenske, A., Majschak, J. P., and Großmann, H. (2013). "Gastight paperboard package," *Professional Papermaking* 2013(1), 48-51.

Hishinuma, K. (2009). *Heat Sealing Technology and Engineering for Packaging*, DEStech Publications, Lancaster, PA.

Leminen, V., Kainusalmi, M., Tanninen, P., Lohtander, M., and Varis, J. (2012). "Effect of sealing temperature to required sealing time in heat sealing process of a paperboard tray," *Journal of Applied Packaging Research* 6(2), 67-78.

Leminen, V., Tanninen, P., Mäkelä, P., and Varis, J. (2013). "Combined effect of paperboard thickness and mould clearance in the press forming process," *BioResources* 8(4), 5701-5714. DOI: 10.15376/biores.8.4.5701-5714

Leminen, V., Tanninen, P., Lindell, H., and Varis, J. (2015a). "Effect of blank holding force on the gas tightness of paperboard trays manufactured by the press forming process," *BioResources* 10(2), 2235-2243. DOI: 10.15376/biores.10.2.2235-2243

Leminen, V., Mäkelä, P., Tanninen, P., and Varis J. (2015b). "Leakproof heat sealing of paperboard trays - Effect of sealing pressure and crease geometry," *BioResources* 10(4), 6906-6916. DOI: 10.15376/biores.10.4.6906-6916

Leminen, V., Mäkelä, P., Tanninen, P., and Varis, J. (2015c). "Methods for analyzing the structure of creases in heat sealed paperboard packages," *Journal of Applied Packaging Research* 7(1), 49-60. DOI: 10.14448/japr.03.0005

Leminen, V., Mäkelä, P., Tanninen, P., and Varis, J. (2015d). "The use of chromatic white light 3D-profilometry in the surface quality analysis of press-formed paperboard trays," in: *Proceedings of the 25th International Conference on Flexible Automation and Intelligent Manufacturing*, Wolverhampton, UK, Volume II, pp. 74-81.

Leminen, V. (2016) *Leak-proof Heat Sealing of Press-formed Paperboard Trays*, Ph.D. Dissertation, Lappeenranta University of Technology, Lappeenranta, Finland.

Mihindukulasuriya, S., and Lim, L.-T. (2011). "Effects of liquid contaminants on heat seal strength of low-density polyethylene film," *Packaging Technology and Science* 25(5), 271-284. DOI: 10.1002/pts.978

Tanninen, P., Lindell, H., Saukkonen, E., and Backfolk, K. (2014). "Thermal and mechanical durability of starch-based dual polymer coatings in the press forming of paperboard," *Packaging Technology and Science* 27(5), 353-363. DOI: 10.1002/pts.2036

Tanninen, P., Leminen, V., Kainusalmi, M., and Varis, J. (2015). "Effect of process parameter variation on the dimensions of paperboard trays," *BioResources* 11(1), 140-158. DOI: 10.15376/biores.11.1.140-158

Tetsuya, T., Ishiaku, U. S., Mizoguchi, M., and Hamada, H. (2005). "The effect of heat sealing temperature on the properties of OPP/CPP heat seal. I. Mechanical properties," *Journal of Applied Polymer Science* 97(3), 753-760. DOI: 10.1002/app.21320

Van Oordt, T., Barb, Y., Zengerle, R., and Von Stetten, F. (2014). "Lamination of polyethylene composite films by ultrasonic welding: Investigation of peel behavior and identification of optimum welding parameters," *Journal of Applied Polymer Science* 131(10), 40291 (1 of 7 - 7 of 7). DOI: 10.1002/app.40291

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