Controlling the Folding of the Blank in Paperboard Tray Press Forming

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The press forming process of paperboard trays is challenging. The production of trays that fulfill all functional and visual property requirements is demanding. Blank preparation is an essential part of paperboard tray press forming. The aim of this work was to study how a creasing pattern can be utilized in the compaction and folding of the substrate in tray corners. The investigation of creasing pattern designs focused on the positioning of creases, the optimization of the amount of creases, and the width of the creases. The results of the study show that the amount of creases in the tray corner is the most important variable in the pattern design. The substrate folds more evenly and the wall of the tray is smoother when the material has the optimum amount of folds for it to compact during the press forming process. Changes in the creasing pattern primarily affect the amount of unclosed creases in the flange of the tray, which can make tight lidding of the tray impossible. The outcome of the study is a morphological analysis of the introduced creasing pattern alternatives and a selection of formulas that can be utilized in the creasing pattern design process.

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INTRODUCTION

Plastic is the most versatile material for producing 3D packages and providing good barrier properties. From a sustainability and printing point of view, fiber-based materials have properties that are desirable. To utilize the benefits of both materials, composite structures are frequently used to reduce the amount of plastic needed and to provide the needed barrier properties for the packages. However, the conversion of a fiber-based material into a 3D package is a complex process. Thus, there is an urgent need to understand the means by which the forming of 3D packages from fiber-based materials can be improved.

Press forming and folding are the most common methods for producing trays from paperboard in industrial use. Both utilize creases to achieve the desired tray shape. A crease is a groove in the paperboard that facilitates bending or folding along a clearly defined line. The internal shear forces that occur during the formation of a crease cause some internal delamination of the interply adhesion. This results in a bulge on the reverse side of the board, *i.e.* towards the interior of the creasing (Kirwan 2005).

During the folding process, creasing lines with plastic deformation allow the blank to fold accurately and easily without cracking of the board structure (Joukio and Mansikkamäki 1998). Creases are positioned according to the faces of the folded tray, and during the folding phase, the seams of the tray blank are usually glued together.

The use of creases during press forming is much more complex. The geometry of a press-formed tray does not contain clear faces, and the shape of a tray corner is rounded and consists of multiple folds. Creases are used to control the blank forming process. The blank is folded regularly, and the plastic coating of the paperboard blank seals adjacent creases together during the press forming process. Forces that are parallel and perpendicular to the blank plane cause folding in the corner area; thus, creases are used to control how folding occurs. Differences in crease use can be seen in Fig. 1.
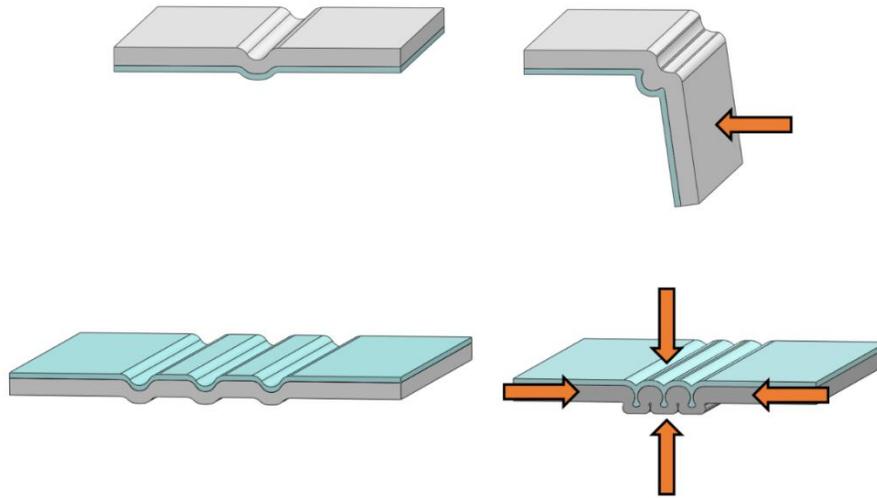
Fig. 1. The behavior of creases in folding (above) and in press forming (below). In these methods, creasing is performed on different sides of the substrate to retain the polymer barrier layer inside the package.

Blank preparation is an essential part of paperboard tray pressing. The basic principle of the manufacturing method is to place a pre-cut and creased, possibly plastic-coated, paperboard blank between molds that are pressed together to form a tray of a desired shape, as shown in Fig. 2.
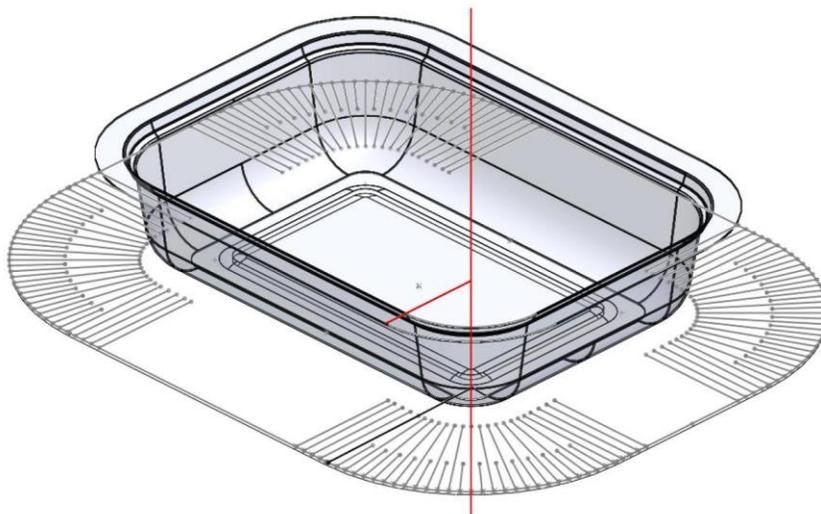
Fig. 2. A paperboard blank and the final product of the tray pressing process. The folding of the paperboard blank is controlled with creases in addition to actual forming parameters. The radius and the rotation axis of the tray corner are marked in red.

The folding of the tray corners is controlled with the blank holding force, applied by a rim tool. The effect of the blank holding force on the quality of the formed product has been previously discussed (Hauptmann and Majschak 2011; Tanninen *et al.* 2014b).

Previous studies have concentrated on the three-dimensional forming and material behavior of paperboard in the press forming process (Hauptmann and Majschak 2011; Vishtal and Retulainen 2012; Leminen *et al.* 2013; Tanninen *et al.* 2014a; Zeng *et al.* 2013; Hauptmann *et al.* 2014). The effects of the creasing rules and grooves in tray pressing have also been analyzed (Tanninen 2015). The behavior of creases in enabling the folding of the tray corner in press forming has not been studied before. Different partners in the packaging value chain provide instructions for crease positioning in folded packages, but guidelines for creasing pattern design in tray pressing are not available. In this study, factors affecting the folding process of a press-formed tray corner were studied, and some basic principles for creasing pattern design are introduced. The design of a creasing pattern includes the positioning of creases, the amount of creases, and the width of the creases.

EXPERIMENTAL

Materials

The substrate used in the die cutting tests and tray pressing was 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 sulfate (SBS) layers, and the total thickness of the substrate is 460 μm. The materials were stored in a humidity-controlled chamber at 80% relative humidity to maintain the delivery moisture content of the paperboard. The moisture content was verified before converting tests were performed with an Adams Equipment (USA) PMB 53 Moisture Analyzer. The measured moisture content of the material was 9.2 to 9.5%.

Methods

Preliminary tests – choosing creasing geometries

A selection of commercial paperboard trays was collected from European region, and the geometry of the trays, including the positioning of creases, was analyzed to form a view on current practices used by packaging industry. Three different methods for creasing pattern design were found on evaluated trays and are presented in Fig. 3. In all methods, the placement of creases correlates to the radii of the tray corners.

Several creasing patterns using methods A, B, and C were tested preliminarily, and it was found that patterns using method B facilitated the folding of the paperboard blank in the most favorable manner. Quality of trays were evaluated according to the method presented by Tanninen *et al.* (2014a). Trays with good quality have a smooth sealing area in the tray flange, and creases in the tray corners are folded evenly. Trays that were produced using methods A and B had significantly more partially folded creases, especially in the ends of the creasing sector. Therefore, in all further tests, creases were positioned radially and toward the rotation axis of the tray corner.

A previous study showed that the angle of the creasing groove walls and the width of the creasing groove in relation to the rule width have only a minor effect on the folding behavior of the tray corner (Tanninen 2015). The width of the creasing rule was expected to have a more substantial effect on folding, so a selection of commercial creasing rules with different widths was acquired.

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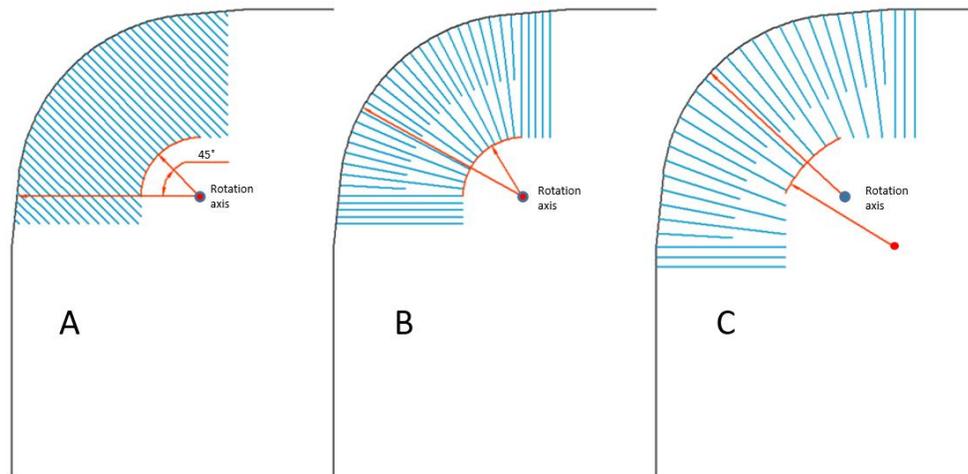
Fig. 3. Creasing pattern designs. A) Creases are positioned in a 45° angle parallel to each other; B) creases are positioned radially toward the rotation axis of the tray corner; C) creases are positioned radially toward a point deviating 10 to 30 mm from the rotation axis of the tray corner.

Paperboard manufacturers recommend the use of creasing rules with widths of 0.71 mm (2 pt.) for testing a substrate's thickness. Also, rules with widths of 0.40 mm (1.1 pt.), 1.05 mm (3 pt.), and 1.42 mm (4 pt.) were tested. The purpose of these tests was to study how material compaction and folding occurred in the tray corner area when the width of the creases was altered to determine if a single, wider crease could compact more material. The main dimensions of the creasing rule and groove are presented in Fig. 4.
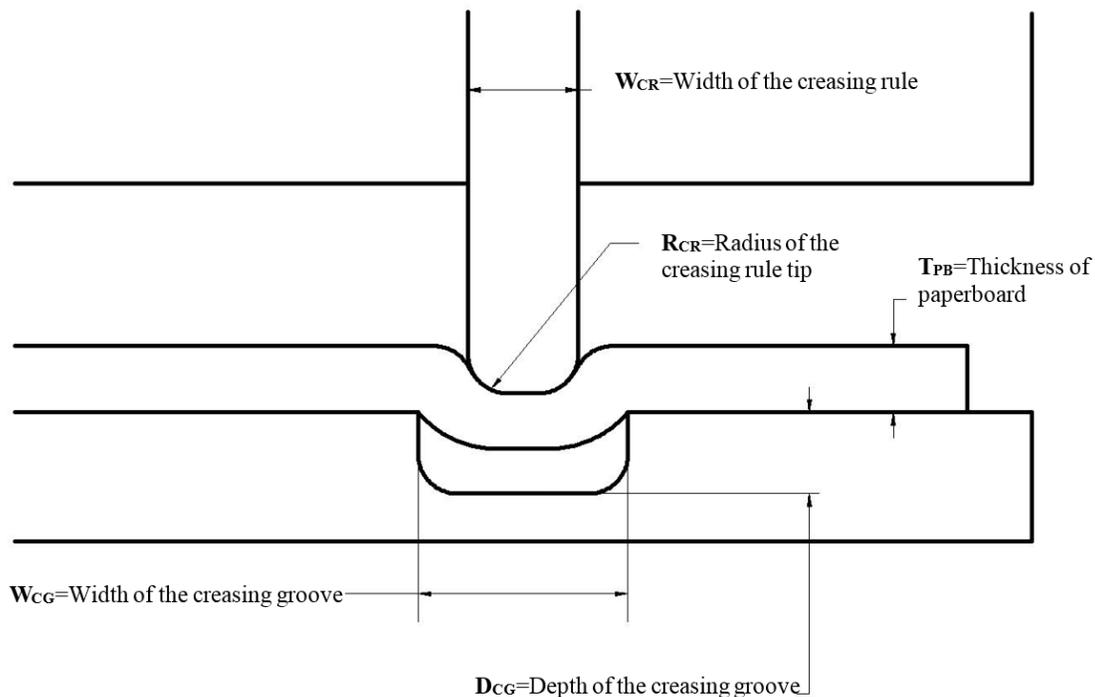
Fig. 4. The main dimensions of the creasing rule and groove

Groove widths were calculated to fit corresponding creasing rules using the following formula,

$$W_{CG} = \mu\ T_{PB\ +}\ W_{CR} \tag{1}$$

where W_{CG} is the creasing groove width, μ is the creasing coefficient, T_{PB} is the thickness of paperboard, and W_{CR} is the creasing rule width.

The creasing coefficient, which defines the creasing groove width in relation to the substrate thickness, is normally between 1.2 and 1.7, depending on the application. The behavior of the creases in tray pressing was found in a previous study to be most desirable with the value of 1.4 (Tanninen 2015). Smaller values result in creasing grooves that are too narrow and the die cutting process becomes too fierce for the paperboard to withstand. The surface of the paperboard fractures at the tops of the creases. Larger values make the grooves too wide and the shape of the crease too round.

Rectangular trays (265 x 162 x 38 mm) were press-formed using a similar creasing pattern with all crease widths. Process parameters were kept constant in press forming phase of the die-cut blanks (blank holding force 1.20 kN, female mould temperature 170°C, male mould temperature 50 °C, pressing force 135 kN and pressing speed 130 mm/s). The tray wall area was visually estimated to be smoother, with narrower creases, but a more noticeable difference was found in the tray flange, an area on which lidding film sealing is performed. The folding in some of the creases was uneven and one-sided, which makes successful lid-sealing impossible.

The amount of creases on one tray with unacceptable quality, resulting from different crease widths, is presented in Fig. 5.
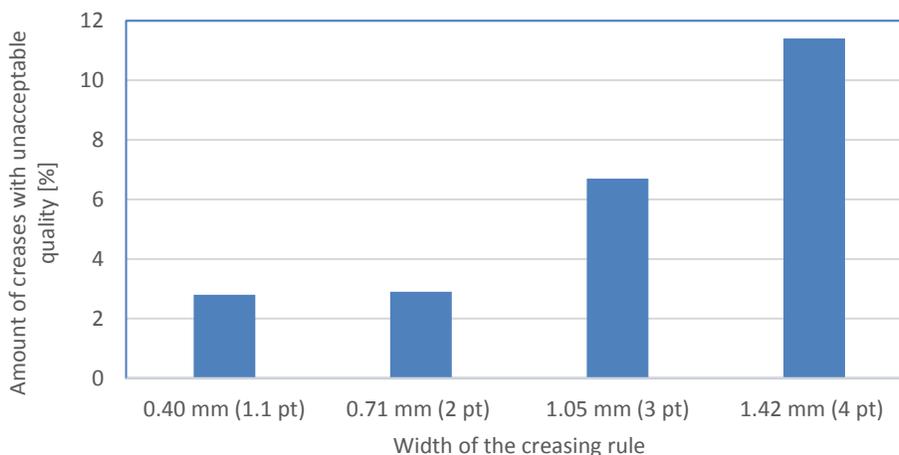
Fig. 5. The amount of creases with unacceptable quality resulting from different creasing rule widths. Values are the average of ten trays.

Creases die-cut with rule widths of 0.40 and 0.71 mm folded most desirably, and the use of wider rules produced a substantially larger amount of unacceptable creases. However, the die cutting tool with the thinnest rules (0.40 mm wide) caused some problems during die cutting, and the pressing force had to be very carefully adjusted to prevent cracking the polymer coating layer. Even slightly too large force caused the creasing rule

to cut through the polymer coating layer. Tools with wider creasing rules did not cause the same issues.

Based on the results of the preliminary tests, 0.71-mm-wide creasing rules were chosen for use in the subsequent tests.

The compilation of creasing patterns

An array of industrial-scale press-forming tool sets was selected with the basic shape of the tray corner in mind. Tool sets enabled the production of trays representing four different rectangular designs and one oval-shaped design. Even though the main dimensions of the trays varied, the main focus was on the dimensions related to the tray corner area: the depth of the tray and the corner radii.

Creases were positioned uniformly to the corner area of the tray blank and radially toward the rotation axis of the tray corner. The composition and essential dimensions of the creasing pattern design are shown in Fig. 6.
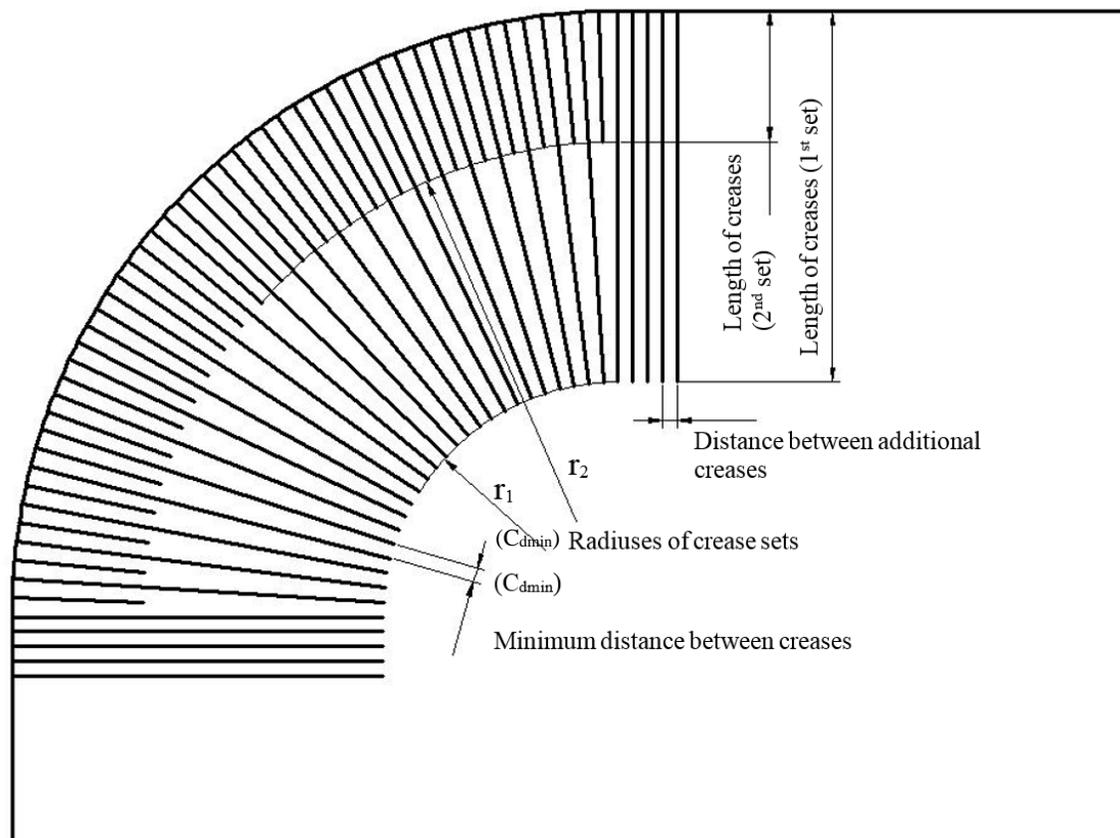
Fig. 6. The composition and essential dimensions of creasing

The distance between adjacent creasing grooves was changed within the range of 0.5 to 3.0 mm. The respective amounts of creases, calculated on basis of distance values, are listed in Table 1 along with the dimensions of the trays produced. The depths of the trays enabled the use of two sets of creases with different lengths in the corner area.

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Table 1. Test Tray Specifications

	Tray 1 Rect-angular	Tray 2 Rect-angular	Tray 3 Rect-angular	Tray 4 Rect-angular	Tray 5 Oval
Height of the Tray (mm)	50	35	38	56	45
Length of the Tray (mm)	209	209	265	326	219
Width of the Tray (mm)	139	139	162	261	130
Radius of Tray Corner (mm)	37	40	40	75,5	65
Length of the Blank (mm)	288	260	319	400	286
Width of the Blank (mm)	219	190	216	334	199.5
Radius of the Blank Corner (mm)	77	62	70	110	99,25
r_1 (mm)	20	20	19	37	48
Distance between adjacent Creasing Grooves/C_{dmin} (mm)	Total Number of Creases	Total Number of Creases	Total Number of Creases	Total Number of Creases	Total Number of Creases
0.5	164	164	157	279	177
1	135	135	129	226	142
1.5	116	116	112	191	120
2	103	103	99	167	104
2.5	93	93	90	149	92
3	86	86	83	135	83

The press forming process parameters were optimized for each mold set and paperboard combination to achieve trays with good quality. Differences in the size of the trays were compensated for by adjusting the blank holding force (Trays 1 and 2 0.81 kN, Tray 3 1.20 kN, Tray 4 2.38 kN and Tray 5 0.79 kN). Other parameters were kept constant during the trial runs: female mould temperature 170 °C, male mould temperature 50 °C, pressing force 135 kN and pressing speed 130 mm/s.

The changes made to the creasing pattern primarily affected the amount of unclosed creases in the flange of the tray. Trays were also press-formed using a higher blank holding force, which caused fractures in the tray corners. Altering the creasing pattern had no noticeable effect on the amount or length of the fractures.

RESULTS AND DISCUSSION

The effect of the creasing pattern and the quality of crease formation were evaluated with the same methods as in previous research (Leminen 2013): by observing the quality of folding and the flatness of the tray flange. Discarded creases were not formed properly, and the corresponding folds had large gaps in the tray flange area, which make tight lidding of the tray impossible. A pair of discarded creases is marked in Fig. 7.

The amount of creases with unacceptable quality resulting from different creasing patterns is shown in Fig. 8.

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Fig. 7. Discarded creases in the tray flange. Creases have not been formed adequately leaving a gap between flat areas surrounding the crease.
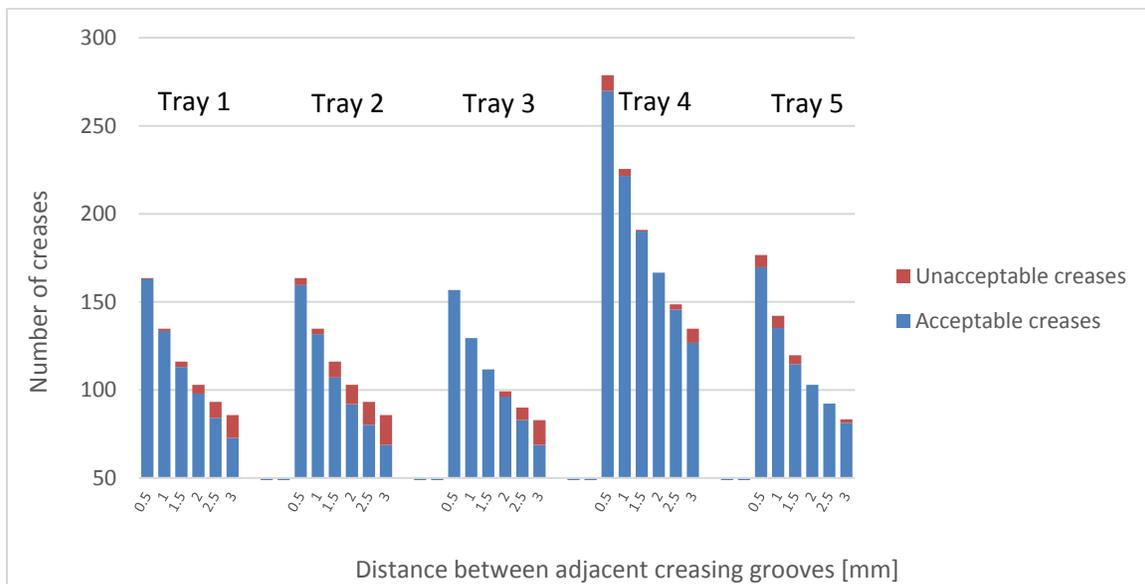
Fig. 8. Functionality of creases in test trays

In trays with the smallest blank corner radius (trays 1, 2, and 3), a greater distance between adjacent creases was correlated with an increased amount of discarded creases. The substrate folded more evenly and the wall of the tray was smoother when the material had more possibilities (folds) to compact during the press forming phase. However, when the distance between the adjacent creases was 0.5 mm, the durability of the thin land between the creasing grooves was a cause for concern, especially when a plastic matrix was used. Therefore, the minimum distance between creases should be limited to 1.0 mm. In trays 1, 2, and 3, the amount of creases was as high as possible in the tray corner within the limitations of the creasing rule and groove dimensions discussed earlier. Tray 2 could not be produced without unacceptable creases, which indicates that the clearance between

the male and female mould was not correct everywhere and that the mold set needed modification. Trays 4 and 5, which had larger blank corner radii, were more successful when a larger distance between adjacent creases was used. Smoothness of the tray walls was considered best when the greatest amount of creases was used for all the trays. The following formulas were established on the basis of the trial runs.

The minimum distance between adjacent creases (from the center line of one rule to another) was defined as,

$$C_{dmin} = W_{CG} + W_{ML} \tag{2}$$

where W_{ML} is width of the land between adjacent creasing grooves. W_{ML} is 1 mm when the radius of the blank corner is below 80 mm. W_{ML} is 2 mm when the radius of the blank corner is 80 to 110 mm. Further testing with different mold sets should be performed to make the recommended values more accurate. Also testing of other types of paperboard in further studies is advisable.

The quantity of creases in first set (90° tray corner) is defined as

$$Q_{c1} = \frac{(2\pi \cdot r_1)/4}{C_{d\min}} = \frac{\pi \cdot r_1}{2C_{d\min}} \tag{3}$$

Sets of shorter creases should be placed regularly between longer creases.

The angle between adjacent creases in the first set is defined as

$$A_{c1} = \frac{90°}{Q_{c1}} \tag{4}$$

Finally, the radius of the second crease set is

$$r_2 = 2r_1 \tag{5}$$

Additional creases should be placed on each side of the corner creases to avoid wrinkles (folds that are not assisted by creases) in the walls of the tray. These creases are placed perpendicular to the sides of the blank and are full-length. The distance between creases can be calculated with Eq. 2. The amount of additional creases was optimized to 3 to 4 for tested tray designs, depending on the tray shape.

Results from trial runs were analyzed and supplemented with observations made from commercial tray samples to facilitate the creasing pattern design process. Relationships between the presented formulas and features of the tray were also evaluated. Morphological charts were developed as a tool for designers to determine the relationships between the functional and structural aspects of in multi-dimensional, non-quantifiable design problem tasks. Morphology provides a structure for an overview of the considered functions and aspects and their alternative solutions. The functions and aspects are derived from the demands and wishes of the designer and define the functional requirements of the product. The tool itself is a simple table or matrix in which the possible solution principles for each function or aspect are listed. Different overall solutions are created by combining

various solution principles to form a complete combination to find a solution for the design task (Zeiler and Savanovic 2010).

Table 2. Morphological Analysis of the Creasing Pattern Alternatives

		1st Crease Set	2nd (and 3rd, *etc.*) Crease Set	Additional and Assisting Creases	Formability in Tray Forming Process
Outer Dimensions of the Tray	**Length**			Larger length provides room for additional creases	Small influence
	Width			Larger width provides room for additional creases	Small influence
	Height	Affects length of creases	Affects length of creases. If height is small, 2nd set aren't required		Very large influence. Deeper the tray, harder to form.
Features of the Tray	**Steepness of the Tray Wall** (Eq 5)	Affects length and number of creases	Affects length and number of creases	Affects length of creases	Very large influence. Steeper the tray wall, harder to form.
	Main Radius of the Tray Corner (Eq 3-5)	Affects number of creases	Affects number of creases		Very large influence. Larger the corner radius, easier to form.
	Radii of the Bottom Corner of the Tray (Eq 3-5)	Affects number of creases	Affects length and number of creases		Average influence. Small radiuses demand more from material properties.
Thickness of the Paperboard (Eq 1-5)		Affects number of creases and distance between creases	Affects number of creases and distance between creases	Affects distance between creases	Average influence. Thicker paperboard has usually better strength properties in forming.
Shape of the Tray (Eq 3-5)		Affects positioning of creases	Affects positioning of creases	Affects positioning of creases	Very large influence. Round and oval shaped trays easiest to form. Complex shapes can be impossible to form.

Morphological chart analysis can be regarded as a formal design tool enabling collaborative product development. It is widely accepted in textbooks and by practitioners as an effective technique for the conceptual design of products, processes, and systems. This type of analysis has been developed during the past decades, and Huang and Mak (1999) discuss the use of Web technology in the implementation of morphological chart analysis. The results of Huan and Mak's study showed that the incorporation of various decision-making activities of concept design into one integrated Web-based system allows

the designer to choose the most appropriate idea from numerous potential alternatives in an objective, systematic way. Weber and Condoor (1998) stated that the morphological matrix is a key methodology that can improve the effectiveness of the concept generation phase of the design process. However, as discussed in Weber and Condoor's paper, identifying independent design functions and determining the synergistic compatibility of combining alternative solutions is difficult. In this study, morphological chart analysis was utilized to determine the most reasonable combination of creases to design the optimal creasing pattern.

CONCLUSIONS

1. It is possible to produce press-formed paperboard trays that fulfill all of the required functional and visual properties when the creasing pattern is designed according to recommendations presented in this study.

2. The amount of creases in the tray corner is the most important variable in the pattern design when the trays are produced by press forming.

3. The substrate folds more evenly and the wall of the tray is smoother when the material has a greater amount of folds to compact during the press forming process.

4. The correct amount of creases can be determined on the basis of the radius of the blank corner using formulas presented in this study.

5. The outcome of this study is a morphological analysis of the creasing pattern alternatives and a selection of equations that can be used during the creasing pattern design process.

6. Wider creases cannot be utilized to compact material in tray corners. Creases die cut with narrower rule widths folded the most desirably, and the use of wider rules produced a substantially greater amount of discarded creases.

7. This study also indicates that creases positioned radially toward the rotation axis of the tray corner assist the folding of the paperboard blank most suitably.

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