Gastight Paperboard Package

A new Step in Food Packaging

Packages made from coated paperboard are currently used in food packaging for frosted or microwave food. These cups are usually deep drawn from flat paperboard blanks. The blanks are pre-creased to control the material overflow that appears during drawing. The resulting wrinkles in the sealing area have to be considered as capillary tubes allowing the gas exchange between the package and the environmental atmosphere. A new technological approach in 3D forming enables the prevention of capillary tubes in the sealing area. The result is a gas-tight sealable paperboard cup which is limited by its coating concerning the degree of gas tightness.

Introduction

The use of material originating from renewable resource is a prime aim in packaging development, nowadays. In this context, paperboard in combination with a thin plastic film coating offers a suitable compromise of properties but, until now, it has not been possible to produce a packaging from coated paperboard that offers sufficient gas barrier properties.

Such properties, however, are indispensable for many food packaging solutions and often do not leave any alternative but plastics. Barrier properties against gases are the most demanding requirements for any packaging material, package design and packaging process. Prevention of gas penetration can be requested in either direction, i. e. from the surrounding atmosphere into the interior of the package as well as vice versa.

The latter for example applies to so-called Modified Atmosphere Packages (MAP) which uses inert gases to block out oxygen and prevent microbial growth in order to increase the shelf life of food products. No matter what type of protection is needed, the tightness of a package is always a function of the specifics of the barrier layer's permeability and the tightness of the seal. There are of course a number of materials with excellent barrier properties against gases which can be combined with paper or board. In many case, however, such barrier layers are brittle and can easily be damaged during the forming processes.

Capabilities of paperboard-based packaging processes

In the majority of cases, however, particularly as far as food packages are concerned the gas tightness of a package is a major condition to achieve adequate shelf life. Paper based products in this case exhibit severe disadvantages. Folded boxes for example have many cutting edges which have to be sealed, and their production requires several forming steps which, in the end, lead to complex procedures and a higher risk of failure.

The resulting failure cannot be tracked to its source, easily due to the large number of processing steps. Using the pulp moulding process in barrier applications means that a 3D formed part has to be coated with barrier layers which is difficult and demanding in terms of production time and costs.

Composite cans consisting of a wound paper body and a laminated aluminium foil are able to provide barrier properties, but their production also requires a rather complex process. Furthermore the sealing at top and bottom requires accordingly materials and joining technology.

The most reasonable way to produce packaging components from coated paperboard for barrier application is 3D forming. This process is known for microwave or frosted food cups, but the formed parts cannot be sealed gastight due to the capillary tubes in the sealing area caused by wrinkles.

The wrinkles, however, cannot be avoided in 3D forming because of the poor yielding behaviour of paper and board in comparison to metal or plastic materials which usually compensate the geometrical material overflow.

Wrinkles are an accessory symptom of the forming process, and they are inevitable when an accurate shape and sufficient stability has to be achieved.[1] The process itself is quite simple. A blank holder applies a defined force to the paperboard blank, and a die draws the blank into or through a cavity *(Fig. 1)*.

The material overflow can be described by a comparison of the bottom and the blank circumference or a comparison of the wall total surface before and after forming. This material overflow which eventually results in wrinkles increases quadratically with the increasing height of the walls of the formed parts.[2]

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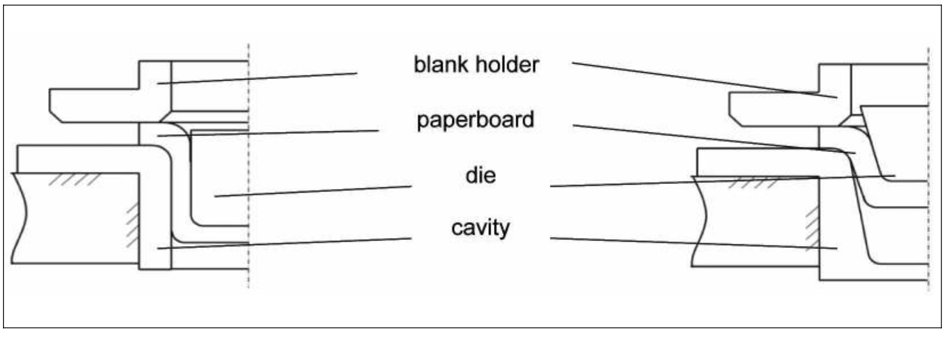


Fig. 1: Tool arrangement in deep drawing of paperboard

Improved forming process

In the past it was the rather poor optical appearance resulting from rough wrinkles and partially discoloured or stained surfaces which largely limited the application of deep-drawn packages.

In order to expand their application range and to tap into new markets these drawbacks have to be overcome. The clue for corresponding efforts lies in a very thorough analysis of the many impacts of the main process parameters (e.g. the force applied by the blank holder or the temperatures of the tool) on quality criteria such as the distance of the wrinkles, their deflection, or the back spring angle of the wall.[1]

Measures based on the results of such investigations help to drastically improve the quality *(Fig. 2b)*.

In a second step, the draw ratio which characterizes the drawing height divided by the base diameter and which until now strongly limited the application of deep-drawn container had to be improved. The challenge in this case is to prevent a fracture at the bottom of the formed part. The tensile load on the material around the base diameter is in close relation to the compression in plane resulting from wrinkling. That means with higher wall the material experiences higher tensile load. With the help of the experiences made when optimizing the optical quality, the draw ratio was successfully increased to a value of 0.63, which apparently was not yet the best what could be achieved *(Fig. 2c)*.

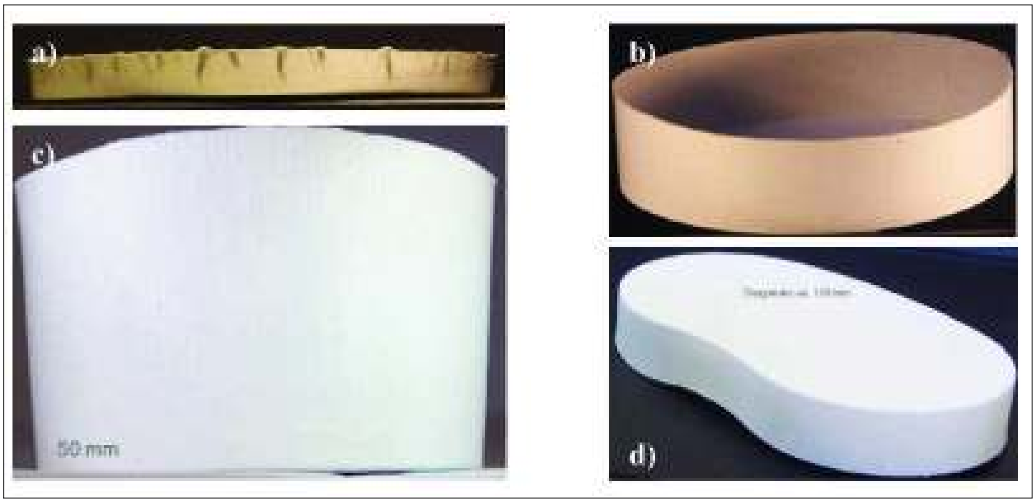


Fig. 2: 3D formed packaging components a) common industrial quality, b) optimised quality, c) improved draw ratio 0.63, d) sample of non-cylindrical base geometry[3]

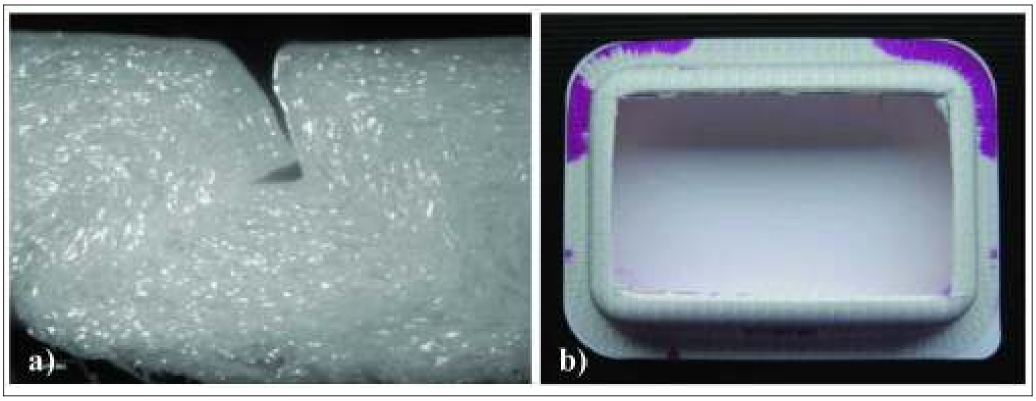


Fig. 3: a) Wrinkle in cross section microtome cut of the wall of a deep drawn part, b) Rhodamine test of a food cup showing leakage

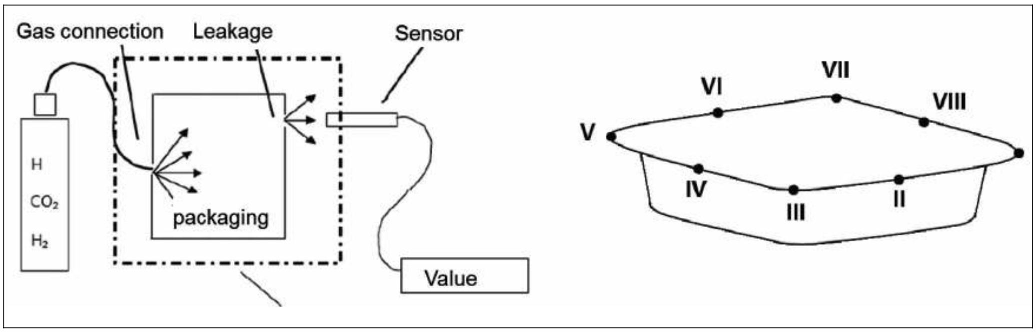


Fig. 4: Gas transition measurement a) test setup, b) points for measurement around the packaging

This value, however, is far better than the state-of-the-art ratio which is in the range of 0.2. It also turned out[2] that the geometry of deep-drawn containers is not necessarily limited the cylindrical shapes. We also succeeded in producing rectangular shapes with rounded edges or shapes with partially concave walls *(Fig. 2d)*.

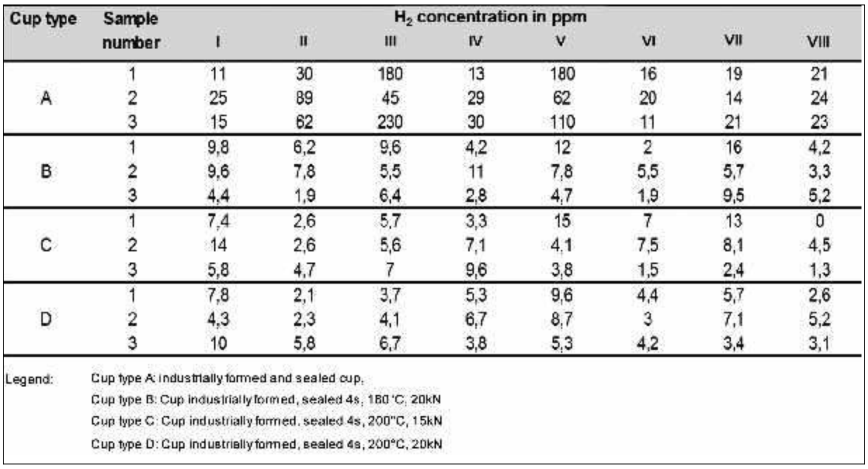
Application of 3D forming for gastight packaging components

In industrial applications, especially for the production of food cups, the blanks are creased prior to forming in order to predetermine the place where wrinkles should appear and, thereby, to make sure that they are distributed uniformly over a convex radius which is important if an acceptable visual quality of the formed parts is desired. If the creasing is done properly discoloration does not appear and the wall looks uniformly. But at the cutting edges of a gas-tight sealing these pre-creased wrinkles are weak points.

They represent capillary tubes in the seal that are not closed neither by heat nor by ultrasonic sealing *(Fig. 3)*. The depth of the capillary tubes is considerable and cannot be compensated by the melting of the plastic coating.

To investigate the H_2 gas transition the cups were injected with a gas consisting of 5 % H_2 and 95 % N_2 and checked for H_2 leakage at different positions around the sealed cup *(Fig. 4)*.

Industrially formed and sealed cups made of a PET coated paperboard (Enso Tamfold 350+40 g/m^2) taken from a production line (cup type A) proved to be very leaky *(Tab. 1)*. As expected, most of the leakage occurred at the radii of the cup where the material overflow is pressed into the pre-creased wrinkles.



Cup type	Sample number	H₂ concentration in ppm I	II	III	IV	V	VI	VII	VIII
A	1	11	30	180	13	180	16	19	21
	2	25	89	45	29	62	20	14	24
	3	15	62	230	30	110	11	21	23
B	1	9,8	6,2	9,6	4,2	12	2	16	4,2
	2	9,6	7,8	5,5	11	7,8	5,5	5,7	3,3
	3	4,4	1,9	6,4	2,8	4,7	1,9	9,5	5,2
C	1	7,4	2,6	5,7	3,3	15	7	13	0
	2	14	2,6	5,6	7,1	4,1	7,5	8,1	4,5
	3	5,8	4,7	7	9,6	3,8	1,5	2,4	1,3
D	1	7,8	2,1	3,7	5,3	9,6	4,4	5,7	2,6
	2	4,3	2,3	4,1	6,7	8,7	3	7,1	5,2
	3	10	5,8	6,7	3,8	5,3	4,2	3,4	3,1

Legend: Cup type A: industrially formed and sealed cup,
Cup type B: Cup industrially formed, sealed 4s, 180 °C, 20kN
Cup type C: Cup industrially formed, sealed 4s, 200°C, 15kN
Cup type D: Cup industrially formed, sealed 4s, 200°C, 20kN

Tab. 1: H_2 concentration of different cup types using standard industrial forming and sealing equipment

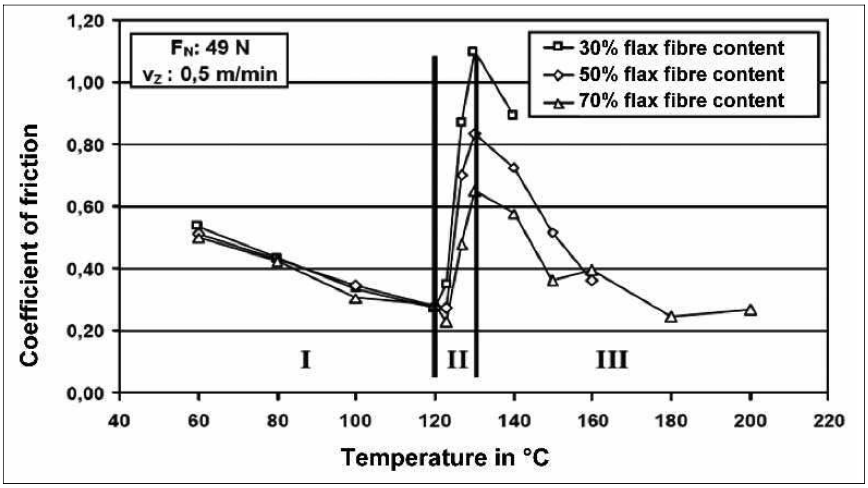


Fig. 5: Coefficient of friction in dependence of contact temperature of metal to a non-woven material consisting of Polypropylene and flax fibre

This means that the material overflow is far more uniformly distributed with lowest possible distances between wrinkles. It turned out that the wrinkles changed their shape eventually exhibiting a wavy line at maximum blank holder forces.[3] Accordingly a single wrinkle does no longer act as a capillary tube as it is the case with parts made from creased blanks.

What is equally crucial is an appropriate compromise of the temperature during deep drawing for both, paperboard and plastic material since the investigations[3] also showed that the thermal energy the board blank receives during the forming process leads to a further quality improvement comparable to the effect of the blank holder.

The exploitation of this effect, though, is limited due to the rheological behaviour of plastic material which changes drastically with increased temperature, at least close to their glass transition or even more their melting temperature.

The investigations of non-woven to metal friction 5 indicated that already at temperatures below the glass transition temperature the coefficient of the friction increases considerably *(Fig. 5)*.

This increase in the friction especially between the blank holder and the plastic film leads to a fracture of the material. Considering that a temperature of 150–180 °C from either side, i. e. the die and the cavity, is suitable for forming, it is evident that the optimum forming conditions for paperboard cannot be reached with coated paperboard. The use of a tool coated with e.g. PTFE or a comparable material allows higher temperatures because of a lower coefficient of friction.

The investigation of the sealing parameters with the same industrially formed (but not sealed) cups on a laboratory sealing test device indicates that the density can be improved considerably by adapting the sealing parameters temperature, pressure, and contact time.

However, it is still not possible to reach a sufficient density since the variation of sealing temperature and pressure (see cup types B, C, and D) does not show any remarkable differences in the H_2 transition, and the H_2 concentration values show that there are weak points left in the seal (Tab. 1).

This experience gives rise to the assumption that in order to achieve a gas-tight sealing it is much better to start from a flat un-creased blank because in this case the material overflow is not supposed to be arranged in a certain pattern described by the creasing line pattern since creasing lines represent a weak point in material.

In the reference[3] the blank holder force was proved to be a decisive tool to control the distribution of the wrinkles and thus to improve the quality of the formed parts. The higher the force applied by the blank holder is, the smaller are the distances between the wrinkles and their standard deviation.

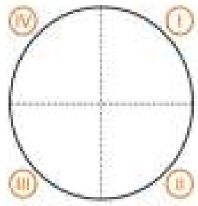
Gas-tight paperboard package

The improved technology approach with defined blank holder forces and optimized temperatures allow for a remarkable reduction of the size of the capillary tubes, i.e. the wrinkles. This in turn directly translates into a much better impermeability, an effect which was convincingly confirmed by a cup that was formed and sealed on a special forming test equipment at TU Dresden *(Fig. 6)*.

Fig. 6: Test equipment for deep drawing of paperboard at TU Dresden

Cup type	Sample number	H_2 concentration in ppm I	II	III	IV	forming radius	wall surface
E	1	0	0	0	0	0	0
	2	0	2,1	0	0	0	0
	3	1,2	0	0	0	0	0
	4	0	0	0	0	0	0
	5	0	0	0	0	0	0
	6	0	0	0	1,5	0	0

Legend: Cup Type E: Laboratory formed and sealed with 4 s, 200 °C, 28 kN, 11 MPa



Tab. 2: H_2 concentration of different a cup types drawn and sealed on test equipment at TU Dresden

The cup (type E) consisting of the same material (Enso Tamfold) as the samples A-D *(Tab. 1)* was tested according to the same procedure. The H_2 gas transition was tested at 4 equally spaced points around the circumference. The result shows that only marginal H_2 penetration occurred (Tab 1). The seal is gas-tight and the permeability values in the vicinity of the forming radius between the bottom and the wall and at the wall surface itself show that there is no perceivable damage of the material as might have been expected because the wrinkles were seemingly damaged. But the plastic layer was obviously not damaged.

The high pressure of 11 MPa is necessary to allow for a true quality seal at the wrinkles. To close the capillary tubes before sealing it is also possible to execute an additional thermal pressing at the sealing area after forming with the help of the blank holder. This might be a suitable solution since industrial sealing equipment usually is not dimensioned for such high pressure levels.

In the end, the package is gas-tight, and the capillary tubes are closed *(Fig. 7a)*, but the visual quality of the cup from material coated with sealing layer is not the same as that of the standard deep drawing product from basic paperboard *(Fig. 2b, 7b)*.

The reason is that the angle between the wall and the bottom of food cups is larger than 90 °. The compression of the wrinkles takes place after they were generated but still able to form freely. This seems to be a remarkable difference in the process.

Furthermore, the compression force needed to reach a comparable compression level is some orders of magnitude larger because the direction of the compression force differs from the standard. The compression force is not orthogonal to die motion as is known from deep drawing with 90 ° wall angle.

Fig. 7: Gastight seal without capillary tubes a); Plastic coated cup with sufficient sealing area for gastight seal made by deep drawing without compression at the wall b)

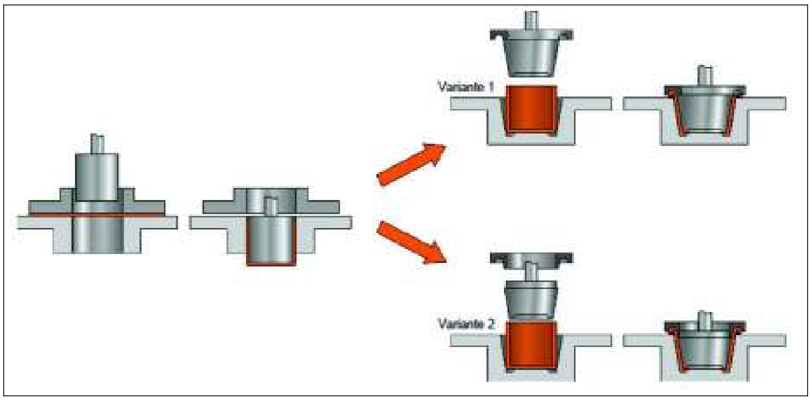


Fig. 8: Two step forming process for the production of gastight sealable cups

Modified forming procedure for quality improvement

In order to meet high quality demands with the same functions of the package the drawing process should be divided into two steps *(Fig. 8)*. The first step is a deep drawing process as is known from the reference[1]. The paperboard blank is drawn to a shape with an angle of 90 ° between the bottom and the wall with a wall height corresponding to the later height of the cup adding the sealing area. This step assures an accurate quality of the wall with fine and uniformly distributed wrinkles. In a second step, the drawn part is embossed to its final shape including an embossing of the bottom, for example.

The wall, especially the material overflow at the wrinkles in this case is formed in the opposite direction to the forming direction of the first step and pressed again. The final angle of the wall is reached, and the sealing area is crimped and pressed with a heated tool mounted at the die. The result is a cup that can be sealed gas-tight with industrial equipment.

Summary

It has been demonstrated that the deep-drawing process is not necessarily restricted to non-food packaging or a limited number of special secondary packaging solutions for food packaging but could also be used for primary containers in direct food contact and for comparably sensitive goods.

For these applications, however, leak-proof and in particular gas-tight packages are indispensable. According to results presented in this paper a process comprising of a combination of the standard deep-drawing process with a subsequent embossing step and the improved control of the excess material in order to provide an as uniform and as close as possible distribution of the wrinkles allows the production of perfectly gas-tight food containers with a flexible complex geometry.

It was successfully proved that the forming process does not damage the PET coating, and the capillary tubes coming from a creasing treatment of blanks before forming are reduced sufficiently to prevent leakage.

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