LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
Faculty of Technology
New Packaging Solutions

MASTER OF SCIENCE THESIS

PAPERBOARD CUP WITH A WINDOW

Examiners: Professor, TkT Juha Varis
Professor, Ph.D Henry Lindell

Supervisors: FM Tapani Sarin
DI Titta Lammi

Imatra 18.2.2009

____
Henna Ahtiainen

Henna Ahtiainen
Suokukonkatu 7
55400 Imatra
Puh. +358 40 773 0332

ABSTRACT

Author: Henna Ahtiainen
Title: Paperboard cup with a window
Faculty: Faculty of technology
Place: Lappeenranta University of Technology
Programme: New Packaging Solutions

Master of Science Thesis. 124 pages, 63 figures, 11 tables and 8 appendices.

Examiners: Professor, TkT Juha Varis
Professor, Ph.D Henry Lindell
Supervisors: FM Tapani Sarin
DI Titta Lammi
Keywords: paperboard cup, plastic window, laser seaming, hot bar sealing

Packaging has to fulfill a lot of demands and the main purpose is to be able to protect the foodstuff packed inside. Typically requirements set on packaging materials reflect the consumer needs. Based on the consumer studies the importance of product visibility is considered as an important property among consumers. However, making the package more transparent the actual shelf life of the product might be reduced. It might have an effect on sensitive foods which contain ingredients vulnerable to light and start to deteriorate more rapidly.

The aim for this Masters of Science Thesis was to develop a paperboard cup with a plastic window where different kind of fatty/dry foodstuffs could be stored. The main target was to be able to create an instruction manual how this kind of cup with a window had to be produced without decreasing air tightness and other barrier properties of cupboard material used as a base board. The focus in this work was on designing a shape of the window and finding critical limits for the size, shape and location of the window in the final paperboard cup.

Windows were made by cutting holes with different sizes and shapes to different places in the cup blank by using a model cutter. For the windows one plastic film type was selected due to its low oxygen and water vapour transmission properties. The window film was attached to the cup blank by using hot bar and laser seaming methods. Cup manufacturing was done at Stora Enso InnoCentre, Imatra.

As a result critical limits for the place, size and shape of the window could be found. The sealing method had a significant effect on the tightness of the cups. Windows didn’t decrease the grip stiffness of the cup. The cup itself gave better light protection than the plastic film used in the windows. The bigger the window, the less the cup could protect the possible foodstuff. Bursting strength was lower in the windows compared to the cup material itself. From environmental point of view DSD licence fees have to be paid due to the amount of used plastic.When using bigger windows the ratio of plastic to fibres increase. This would raise the DSD fee. However, the amount of material is overall reduced which lowers the fee.

TIIVISTELMÄ

Tekijä: Henna Ahtiainen
Aihe: Ikkunallinen kartonkikuppi
Tiedekunta: Teknillinen tiedekunta
Yliopisto: Lappeenrannan teknillinen yliopisto
Koulutusohjelma: New Packaging Solutions

Diplomityö. 124 sivua, 63 kuvaa, 11 taulukkoa ja 8 liitettä.

Tarkastajat: Professori, TkT Juha Varis
Professori, Ph.D Henry Lindell
Ohjaajat: FM Tapani Sarin
DI Titta Lammi
Avainsanat: kartonkikuppi, muovi-ikkuna, lasersaumaus, kuumapalasaumaus

Pakkauksen täytyy täyttää paljon erilaisia vaateita ja päätarkoitus on suojata sisälle pakattua elintarviketta. Kuluttajien tarpeet pitää myös huomioida pakkausten suunnittelussa. Tehtyjen kuluttajatutkimusten mukaan tuotteen näkyvyyttä pakkauksesta pidetään kuluttajien keskuudessa tärkeänä ominaisuutena vaikka läpinäkyvyys lyhentää tuotteen hyllyikää. Erityisesti niiden elintarvikkeiden kohdalla asialla on merkitystä, joissa on valolle herkkiä ainesosia, jotka alkavat pilaantua nopeammin valon vaikutuksesta.

Tämän diplomityön tavoitteena oli kehittää ikkunallinen kartonkikuppi, jossa voidaan säilyttää erilaisia rasvaisia/kuivia elintarvikkeita. Päätavoite oli luoda ohjekirja ikkunallisen kupin tekoon ilman että tiiveys- ja muut suojausominaisuudet heikkenevät. Työssä kokeiltiin erilaisia ikkunamuotoja ja yritettiin niistä löytää kriittiset rajat ikkunan koolle, muodolle ja paikalle kartonkikupissa.

Ikkunat tehtiin leikkaamalla erikokoisia ja – muotoisia reikiä eri puolille kuppivaippaa. Leikkaukset tehtiin mallileikkurilla. Ikkunoihin valittiin muovikalvo, jolla oli halutunlaiset hapen- ja vesihöyrynläpäisyominaisuudet. Ikkunakalvo kiinnitettiin kuumapala- ja lasersaumaamalla. Kuppiajot tehtiin Stora Enso Imatran tehtailla, InnoCentressä.

Työssä löydettiin kriittiset paikat, koot ja muodot ikkunoille. Käytetyllä saumausmenetelmällä oli suuri merkitys kupin tiiveydelle. Ikkunat eivät alentaneet kupin otejäykkyyksiä. Kuppimateriaalilla todettiin olevan paremmat valonsuojaominaisuudet kuin ikkunoissa käytetyllä muovikalvolla. Mitä suurempi ikkuna, sen huonommin kuppi pystyy suojaamaan mahdollista elintarviketta. Puhkaisulujuus on ikkunoiden kohdalla matalampi kuin kuppimateriaalilla itsellään. Ympäristönäkökulmasta katsottuna käytetylle kuppimateriaalille lankeaa DSD maksut johtuen tuotteessa olevasta muovin määrästä. Käytettäessä isompia ikkunoita muovin määrä suhteessa kuidun määrään kasvaa ja tämä nostaa DSD maksua. Tuotteen paino kuitenkin alenee, jolloin DSD maksu pienenee.

PREFACE

This Master of Science Thesis has been made in co-operation with Stora Enso InnoCentre and Research Centre in Imatra, Finland, between December 2007 and December 2008. This Thesis was financed by the Stora Enso Oyj.

I would like to express my gratitude and thanks to my supervisors at Stora Enso, Titta Lammi and Tapani Sarin, but also to other people who helped me during my Thesis: Timo Myllys, Nina Miikki, Teemu Karhu, Johanna Linden, Outi Kylliäinen, Kari Yrjölä, Jukka Nousiainen, Antti Nykänen, Kimmo Väliviita, Marja Ruikkala and Minna Kiviranta. Thank you also to the wonderful staff of InnoCentre and Research Centre for guidance and performing the measurements and tests.

I would also like to thank my examiners at Lappeenranta University of Technology, professors Juha Varis and Henry Lindell for guiding me through this work and all the advises during the work.

Special thanks also to my boss Lea Jaatinen and Stora Enso Oyj as my employer for giving me this opportunity to study a whole new degree beside my work.

Last but certainly not least I would like to express my special gratitude to Ari and my dear friends for understanding and supporting me through this long journey.

Imatra, 18.2.2009

Henna Ahtiainen

TABLE OF CONTENTS

ABBREVIATIONS .... **vii**

1. INTRODUCTION **1**

1.1 Aim of the study 1

1.1.1. Scope of the study 2

1.2. Methodology of the study 2

1.3 Food packaging 3

1.4 Basic functions of packages 4

1.4.1 Demands for the packaging – Logistics 6

1.4.2. Demands for the packaging – Foodstuffs 7

1.5 Why use a package with window? 10

1.5.1 Consumers' point of view 10

1.5.2 Manufacturers' point of view 12

1.6 Light and foodstuffs 12

1.6.1. The concept of light 12

1.6.2. Influence of the light on the packed foodstuff 13

1.6.3. Protection of the foodstuff from harmful light 17

1.6.4 Light protection properties of different packaging materials 19

1.7 Techniques to prevent foodstuff deterioration in packages with plastic windows 20

1.7.1 Utilising nanotechnology in packaging and plastic film manufacturing 21

1.7.2 Usage of UV-blockers 24

1.7.3 Oxygen absorbers 27

1.8. Product safety and food contact regulations 30

1.9 Window cutting 35

1.9.1 Die cutting 35

1.9.2 Laser cutting 37

1.10 Description of joining methods for the paperboard and plastic film 40

1.10.1 Lamination 40

1.10.2 Gluing 40

1.10.3 Hot melt 41

1.10.4 Heat sealing 41
1.10.5. Ultrasonic sealing 42
1.10.6. Laser welding 43
1.11 Recycling and recovery of fibre based packaging material 43
1.11.1 Possible limitations (DSD payments) 45
2. METHODS 47
2.1 Process steps for making a window to AT cup 47
2.1.1 Principle behind AT cups 48
2.1.2 Pre-tests 48
2.1.3 Window cutting 49
2.1.4 Attachment of the window material and plastic film used 50
2.1.5 Cup manufacturing 53
2.2 Testing methods for final cups with windows 55
2.2.1 Grip stiffness 55
2.2.2 Liquid tightness of the window seams 56
2.2.3 Light transmission 57
2.2.4 Bursting strength of the window material 57
2.2.5 Moisture permeability 57
2.2.6 Oxygen permeability 58
3. RESULTS, ANALYSIS AND DISCUSSION 58
3.1 Pre-tests 58
3.2 Window sealing 59
3.3 Cup manufacturing 60
3.4 Results of laboratory tests 69
4. CONCLUSION 76
REFERENCES 80
Appendix 1. Paperboard cup with a window – plan for trials and tests 90
Appendix 2. Laser seaming parameters used. 91
Appendix 3. Detailed information about acceptable cups with windows. 92
Appendix 4. Problematic cups and their blanks. 98
Appendix 5. Unacceptable cups. 102
Appendix 6. Differences in bursting strengths of used materials. 113
Appendix 7. Grip stiffnesses measured from the cups with windows. 114

Appendix 8. Liquid tightness of the seams. 115

ABBREVIATIONS

AT	Air tight
a_w	water activity
BfR	Bundesinstitut für Risikobewertung
DSD	Duales System Deutschland
EVA	Ethylene Vinyl Acetate
EVOH	Ethyl Vinyl Alcohol
FDA	Food and Drug Administration
L-value	L-value is the measure on brightness
MXD6	Nylon (polymer of adipinic acid with 1,3-bis(aminomethyl)benzene
NPS	New Packaging Solutions
PCB	pentachlorobiphenyl
PCP	pentachlorophenol
PE	Polyethylene
PE-LD	Low Density Polyethylene
PEN	Polyethylene naphthalate
PET	Polyethyleneterefthalate
PET-O	Oriented polyethyleneterefthalate
PLA	Polylactic acid
PP-O	Oriented polypropylene
PTR	Pakkausteknologiaryhmä
PVdC	Polyvinylidene chloride
RFID	Radio Frequency Identification
UV	Ultra Violet

1. INTRODUCTION

1.1 Aim of the study

The aim for this Master of Science Thesis was to develop a paperboard cup with a plastic window. The aim was to develop a paperboard cup with a plastic window where different kind of fatty/dry foodstuffs like grated cheese, snacks, candy and chocolate could be stored. The main target was to be able to create an instruction manual how this kind of cup with a window has to be produced without decreasing air tightness and other barrier properties of cupboard material used as a base board. The focuses on this work was on designing a shape of the window and try to find critical limits for the size, shape and location of the window in the final paperboard cup. Also other purposes were to find out whether this kind of packaging solution could be utilized in food packages containing various foods and to collect the main issues which have to be taken into consideration when using these kinds of cups and thinking about food safety.

Before this Master of Science Thesis a pre-study was made to see whether the packages with windows were a commonly used packaging solution on the market and if such packages were used, what kinds of foodstuffs were packed in such packages? In the pre-study one target was also to get more information about used window materials, what kind of plastics were used in the product structures and how they affected on packed foodstuffs.

In the literature part of this Master of Science Thesis the perspective of the pre-study was widened by examining the influences of the light to the different foodstuffs and what kind of light protection properties different packaging materials have. Because the light can harm packed foodstuff through the plastic window, it was also studied in the literature part how the effects can be minimized by using modern nanotechnology. Besides the light, oxygen is also harmful in such packages which are manufactured to be air tight. In the literature part the focus is on how this can be influenced by using different oxygen absorbers.

Window cutting can vary depending on the machinery available and attachment methods for the plastic. Windows can be different due to the products and their properties. Different cutting methods were evaluated more carefully in this work. Recycling and packaging material recovery are nowadays very important and they were handled in this study as well.

1.1.1. Scope of the study

All the tests in experimental part were carried out with Cupforma Classic Barr AT 250 g/m² board of which the paperboard cups were made. Their volumes were 350 ml. All the results are based on certain window forms and therefore the results and conclusions cannot directly be connected with other forms. Also results regarding runnability of the cup machine are based on the results received with cup machine at Stora Enso InnoCentre and cannot be connected directly to other cup machines.

1.2. Methodology of the study

Research method can be divided into quantitative and qualitative methods, or into a combination of these two. The research problem controls the fact, which method is used. (Eskola & Suoranta 2000, p. 14; Hirsjärvi & Hurme, 2000, p. 27) *Qualitative research* aims at comprehensive data collecting in natural, real environment and gives an answer to the questions like what, how, and why. Interpretation and understanding different factors are essential to a qualitative research, whereas *quantitative method* aims at causality, generalized knowledge, and predictability. In quantitative methods numbers and their relations play an essential role and they are used to analyze the phenomena. (Hirsjärvi & Hurme, 2000, p. 20-25) Both methods, quantitative and qualitative methods are going to be used and this can be seen in the study as a literature and experimental part.

Because it is quite difficult to get comprehensive picture by using only one method, in this Masters of Science Thesis work is going to be utilized material triangulation. This means, that several different sources are used like articles, literature and statistics. (Eskola & Suoranta, 2000, p. 68 - 69) To the different areas of this study articles, literature, statistics and NPS lecture materials have been used. When analysing a paperboard cup with a plastic window as a packaging material, also own observations have been made.

1.3 Food packaging

Today food can be packed in many ways using different kind of packaging materials. Packaging materials can be used as pure but also as a combination of different materials. When making a package, also various other materials are needed. (Häikiö et al., 2007)

The state and properties of the foodstuff influences greatly on the choice of packaging material. Different kinds of foods have different demands on packaging size and protection. Fibre based packaging materials can be used when packing solid or dry foodstuffs, but also plastics, metals and combinations of these two can be considered. Powdered substances need to have tight packages because of the dusting and all the possible moisture has to be kept outside of the package to avoid spoilage of the product. Also oxygen and aromas has to be taken into account. Half solid foodstuffs are usually packed in plastic, glass or metal. The closure mechanism has to be paid attention, because very typically these packages end up in dinner table and they are opened and closed all over again. Liquids can be packed in glass bottles, aluminium cans or plastics, but also fibre based packaging materials are widely used. Packaging liquids is challenging, because the liquid can penetrate through even a smallest hole. Gaseous substances are typically only in parts of foodstuffs. They can exist in foams or as a protection gases. (Häikiö et al., 2007)

Changes in the way foodstuffs are manufactured, distributed, stored and retailed are demanding increasingly higher performance of food packaging. Active and intelligent packaging concepts are being developed to extend shelf-life, to improve safety or sensory properties and to improve the performance of the packaging. (Vermeiren et al., 1999, p.1)

Food packaging which interacts chemically or biologically with its contents to extend shelf-life or modify the product during storage is called active packaging. Intelligent packaging senses and informs. (Lindell, 2008, p.5) Active and intelligent packaging concepts employ a wide range of technologies. Active packaging concepts include packaging solutions which absorb oxygen, ethylene or moisture or remove components which cause false taste. Other active packaging systems release ethanol, carbon dioxide, other microbial agents, antioxidants, flavours and/or odours. Intelligent packages can be used for example to reveal gas leaks in modified atmosphere packs, to indicate the presence of microbial deterioration or to provide a history of the temperature to which a product has been exposed to over time. (Vermeiren et al., 1999, p.1)

1.4 Basic functions of packages

However the food packaging business area changes all the time, packaging has to meet the needs of the consumers and retailers. (Vähä-Nissi, 2005, p.2-3) Packaging has several objectives:

Product protection

This is regarded as the primary function of the package. The foodstuffs enclosed inside the package may require protection from different environmental effects like water, water vapour, gases, odours, micro-organisms, dust, shocks, vibrations and compressive forces, but the package must be able to protect the surrounding environment from the product as well. (Järvi-Kääriäinen et al., p. 15-16) For the big part of food products, the protection provided by the package is an important part of the preservation process. If the protection properties of the package suffer, the content will deteriorate more quickly. Packaging also conserves the much of the energy spent during the production and processing of the product. (Robertson, 2006, p.3-4)

Function as a barrier

Typically a barrier from oxygen, water vapour and dust is often required. Package permeability is a critical factor when designing packages. Some packages contain moisture or oxygen absorbers to help extend shelf life. Modified atmospheres or controlled atmospheres are also maintained in some food packages. Keeping the contents clean, fresh, and safe for the intended shelf life is very important. (Järvi-Kääriäinen et al., p. 15-16)

Containment

Small objects are typically grouped together in one package for reasons of efficiency. Liquids, powders, and liquids need a container. (Järvi-Kääriäinen et al., p. 15-16) Without containment, product loss and pollution would be remarkable. (Robertson, 2006, p. 3-4)

Information transmission

Information on how to use, transport, recycle, or dispose the package or product is often included on the product package or its label. With pharmaceutical, food, medical, and chemical products, some types of information are required by governments as well. (Järvi-Kääriäinen et al., p. 15-16)

Marketing

The packaging and labels can be used by marketers to encourage potential buyers to purchase the product. Package design has been an important and constantly growing phenomenon. Marketing communications and graphic design are applied to the surface of the package and in many cases also to the point of sale display. (Järvi-Kääriäinen et al., p. 15-16)

Security

Packages may include authentication seals to help indicate that the package and its contents are not counterfeit. Packages also can include anti-theft devices, such as dye-packs, RFID tags, or electronic article surveillance tags, which can be activated or detected by devices at exit points and require specialized tools to be deactivated. Using packaging in this way is a means of loss prevention. (Järvi-Kääriäinen et al., p. 15-16)

Convenience

Modernization and industrialization have caused big changes in life styles and the packaging industry has had to respond to those changes. There are factors as well like eating snack type meals frequently and on-the-run rather than regular meals, the demand for a wide variety of food and drink at outdoor and increase in leisure time, which have created a demand for greater convenience. This includes the foods which are pre-prepared and can be cooked or reheated in a very short time, preferably without moving them from their primary package. (Robertson, 2006, p.3-4) Packages can have features which add convenience in distribution, handling, display, sale, opening, re-closing, use, and reuse as well. (Järvi-Kääriäinen et al., p. 15-16)

1.4.1 Demands for the packaging – Logistics

Logistic chain sets demands for packages as well in addition to above mentioned properties. According to Mr. Ilpo Lindeman from Inex Partners Oy packages must have properties which enable effective and safe handling in distribution and warehousing all the way to retailers. Products are transported long distances where packages are exposed to dynamical and mechanical stresses. Pallets are usually packed on top of each other and packages should be able to withstand the pressure and possible movements of the pallets. When the pallets containing the products enter retailer’s warehouses, there are differences in technical solutions between warehouses as well. All warehouses are not very automated and in such warehouses product handling is more time consuming and conducted with different kind of machinery. Mr. Lindeman thinks the most important things concerning the future development of logistic chain are: (Lindeman, 2007, p.1-9)

- automation in warehouses will be increased
- following standards will become more important
- modular dimensioning and measuring accuracy will play a big role

These must be kept in mind in package design as well. He states also that packages have to be right size when thinking about product consumption and the package must meet all the relevant standards. (Lindeman, 2007, p.1-9)

1.4.2. Demands for the packaging – Foodstuffs

- Foodstuffs set demands for the packages as well. Packages must fulfil their functions and different regulatory demands. Package cannot be too expensive when compared with foodstuff packed and the main thing for the package is to give extra value to the foodstuff. There are always some interaction between package, foodstuff and environment and it can be seen in Figure 1. (Ahvenainen-Rantala, 2007, p. 1)

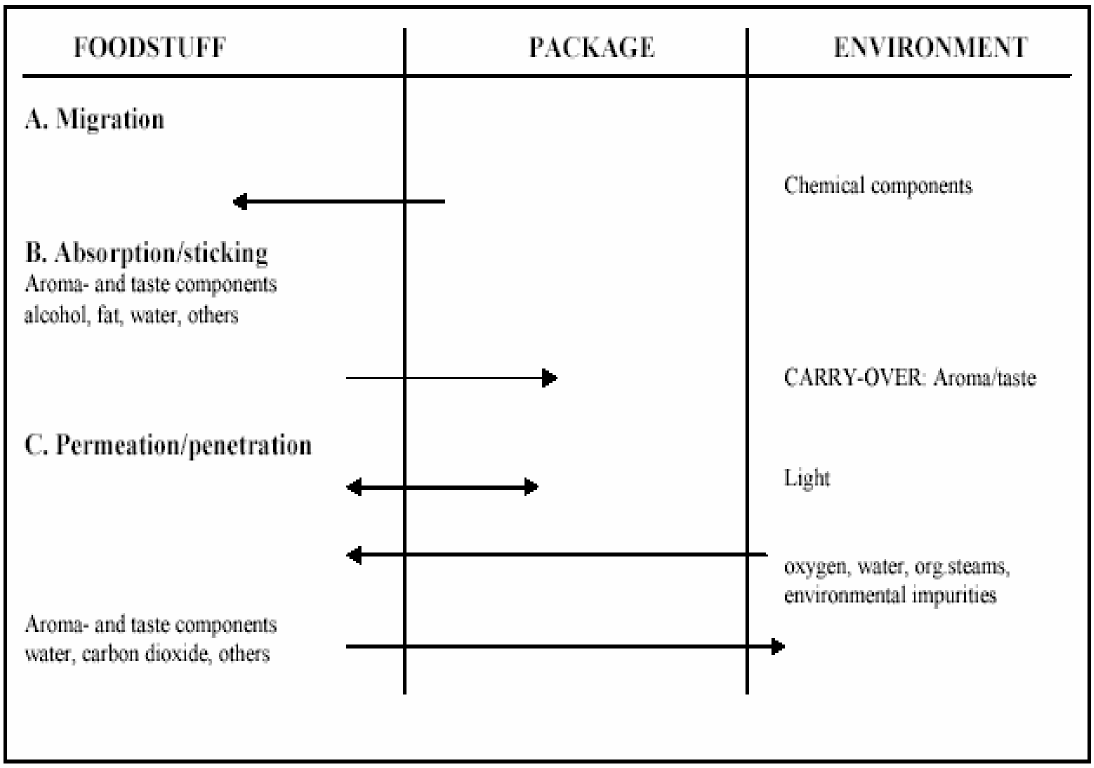

Figure 1. Interaction between package, foodstuff and environment. (Ahvenainen-Rantala, 2007, p. 1)

For example cheese is a very sensitive foodstuff and to be able to preserve it fresh and in good quality, right kind of package has to be chosen. Each cheese type has its own demands for the package. However the flowing demands are similar to all cheese types: (Järvi-Kääriäinen, Ollila, 2007, p. 57)

- Package should be able to preserve the product from the effects of oxygen so the growth of moulds and oxidation of fats can be avoided. The tightness of the packaging seams is known to be more important than the packaging material itself.
- package should be able to protect the cheese from drying
- package should be able to withstand mechanical stresses

packaging material should permeate carbon dioxide properly (Järvi-Kääriäinen, Ollila, 2007, p. 57)

There are several factors affecting permeability such as permeation, polymer characteristics, penetrant, environment, temperature, humidity and pressure. (Mark et al., 1985, pp. 177-192, 317-318)

Permeation

Permeation is known as the rate at which gas or vapour passes through a polymeric material. Permeation speed can be affected by many things including polymer characteristics like the chemical composition of the polymer and its physical state, the penetrating gas or vapour and the surrounding environment. (Mark et al., 1985, pp. 177-192, 317-318)

Polymer characteristics

Polymer characteristics are properties which are influenced by molecular organisation of the polymer. Pendent chains, degree of chain motion, degree of crystallinity and polarity must be taken into account. Formulation, processing properties and the results like the degree of cross-linking, the presence of additives and pinholes also affect the permeability properties. (Mark et al., 1985, pp. 177-192, 317-318)

Penetrant

Penetrant substances are able to move through the material. Permeation depends upon the nature of the penetrant. The type of penetrant is important since the polymer characteristics that result in low permeability to one gas could cause high permeability to another gas. For example highly polar polymer such as EVOH is an excellent gas barrier but poor water vapour barrier. A soluble penetrant will produce swelling of the polymer resulting in an increased permeability coefficient, but a less soluble penetrant will be blocked from the penetration and the permeability will not be affected. (Mark et al., 1985, pp. 177-192, 317-318)

Environment, temperature, humidity and pressure

Environment can also have an effect on permeability. Permeation rates could be affected by temperature, humidity and pressure among other things. According to a common rule of thumb, permeability increases by 30-50% for every 5°C rise in temperature. Increase in temperature results to increase in oxygen and water vapour permeability depending on the moisture content of the barrier material and its nature. Absorbed water is known to have a plasticizing effect on some barrier materials which can lead to increased permeability. Typically polar polymers, like EVOH, lose its barrier properties because of high humidity or when plasticized by water. (Mark et al., 1985, pp. 177-192, 317-318)

1.5 Why use a package with window?

Requirements set on packaging materials reflect the consumer needs. Materials must have a wide operating window. They must possess formability, be suitable for an increased number of packaging sizes and designs, as well as provide possibilities for differentiation. The importance of product visibility will continue to increase among consumers. (Vähä-Nissi, 2005, p. 2-3)

1.5.1 Consumers' point of view

There is a study conducted by Mrs. Katja Järvelä, National Consumer Research Centre and Pakkausteknologia, PTR, on consumers' views on grocery packaging. In the study called "As simple and handy as possible", the general discussion emphasised that the fundamental requirement for a good package is its good functionality in daily use. In addition to good functionality, a good package must have many positive properties, such as environmentally friendly method of packaging, the recyclability or disposability of the packaging materials, clear packaging markings, as well as durability. The examples of good packages that consumers offered revealed that they appreciate traditions and continuity, which also means comfort and easiness for the consumers like easy openings and re-closable packaging. (Järvelä, 2004, p. 16-19)

Consumers also considered that a good package keeps the food in good quality and it endures unharmed when it is transported, stored or used. Also transparent packaging or packages with windows were mentioned as a good property. When consumers are able to see what is packed, it creates trust, because they are able to evaluate the content and its quality themselves. Many of the consumers stated that if the product they are buying is such where the outlook is important and they are not able to see it properly or at all, they feel the package is not good and they are deliberately tried to prevent to see the product. Many of them were disappointed because the package size was much bigger than the product content inside and that's why they mentioned this as a one package development theme. (Järvelä, 2004, p. 16-19)

Another research study was made concerning consumers opinions about transparency of food packages. This study was made by Mr. Jussi Huttunen on July 2007. The aim of that study was to find out the importance of the transparency of food package in the consumer buying process. The chosen products consisted of normal foodstuffs such as meat and dairy products, fat and oils, beverages, pre-packed vegetables, cereals, ready-made meals, beer and cider. However the main interest was not in fibre based packaging materials and transparent windows in them, but the main point was also in this study, that consumers kept transparency of food package as a relatively important property. With the packages of meat products, cheeses, pre-packed vegetables, confectionary, bread, ready-made meals and convenience food, the transparency was regarded highly important. Research also revealed that the transparency was valued more by women than by men, exceptions being beverages, spices and dried herbs, bread and beer. (Huttunen, 2007, p. 4-5)

Consumers also thought that protection of the product, easy opening and low cost were important things for them. (Vähä-Nissi, 2005, p. 2-3)

1.5.2 Manufacturers' point of view

Concerning product packaging the brand owners have to consider sales, materials, processes and machinery as well as fancy design and space requirements. This leads to new packaging sizes, product visibility, convenience features and differentiation through shapes, printing and other effects. (Vähä-Nissi, 2005, p. 2-3) However many food manufacturers think that packaging which lets you see the food product may make you feel better as a consumer, but it is not good for the food. (Truelove, 2007) They are afraid that making the package more transparent, will reduce the actual shelf life of the product. They also feel it might have an effect on sensitive foods, which contain ingredients vulnerable to light and start to go bad more rapidly. Also manufacturers have to take into account the air tightness of the package, because many of the foodstuffs might get lumpy due to air and humidity. It is also more common nowadays that food packages are transported longer distances and even from one country to another and manufacturers are worried that packages with windows might weaken the whole packaging structure. (Huhtakangas, 2007, p. 50-51)

Environmental issues and cost savings are also drivers for manufacturers to develop their packaging. Today retailers demand of their packaging material manufacturers to reduce material content without loosing anything of the product quality. That way consumers can decrease on amount of waste and the final package will be more environmental friendly and more sustainable, but still the package has to be suitable for logistics and small store space requirements. (Vähä-Nissi, 2005, p. 2-3)

1.6 Light and foodstuffs

1.6.1. The concept of light

Light is electromagnetic radiation. The wavelength of the light and its frequency has an impact on the radiation energy, i.e. the longer the wavelength, the smaller the frequency and because of that the smaller the radiation energy. (Hautala, 1998) Visible light has wavelength area from about 400-700 nm. Shorter wavelengths which contain more energy are called UV-radiation and longer wavelengths which contain less energy are called infrared radiation. (Bosset et al., 1994) This can also be seen in Figure 2.

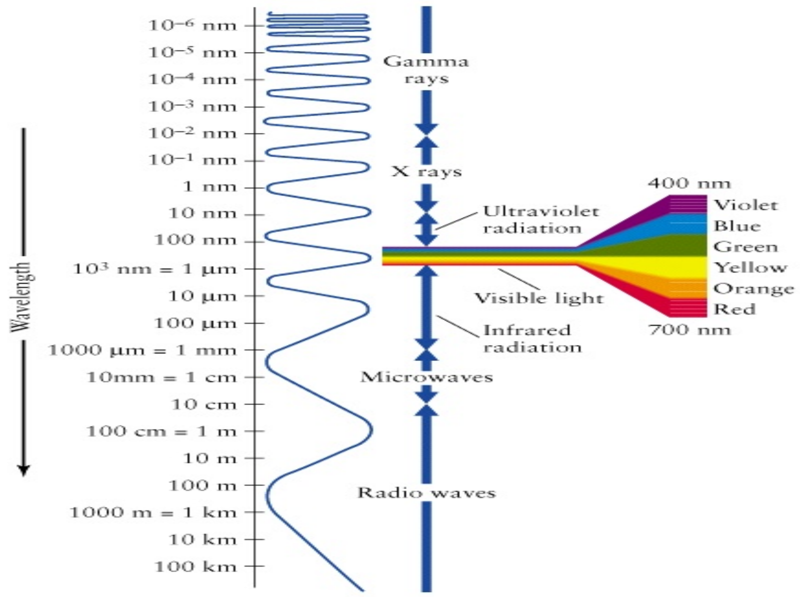

Figure 2. Light wavelengths. (Kusterer, J., 2007)

1.6.2. Influence of the light on the packed foodstuff

The emission spectrum and the light intensity of a light source are found to be capable of causing chemical reactions. For the certain products the wavelength of light and the flow of photons define the extent of quality changes. Temperature is found to have a minor impact on photochemical processes. (Mortensen et al., 2004, p. 85-102) UV-light and light in short wavelengths has been observed to have the strongest effect on foodstuffs. (Bekbölet, 1990, p. 430-440) Sensitivity to light is depending on amount of sensitive components in the product and this varies between foodstuffs. Foods, which contain a lot of unsaturated fat, are oxidized easier when compared to products containing saturated fat. In addition, if exposed area of the food is increased, quality changes due to light can occur more easily because of the flow of photons and oxygen. Differences i.e. in fat-, protein-, pro-oxidant- and antioxidant contents as well as in pH, salt content and micro flora have influences on product's sensitivity to light. (Mortensen, 2004). Also product's oxygen content, moisture level, temperature, pH and content of metal-ions are proved to have an effect on speed and way of decomposition. (Lennersten, 1998) So the time of exposure plays a significant role as well. (Lennersten, 1995)

In Figure 3 can be seen a general picture of the reactions caused by light to the foodstuffs. Mainly light has an impact on the lipids, proteins and vitamin content of the foodstuff through different and complicated reactions. As mentioned already earlier many of the reactions need oxygen to occur and the less the free oxygen is inside the package the better. (Heikkilä, M., 2005, p. 5-22) Photosensitized oxidation can also occur due to different photosensitizers present in foodstuffs. Typical photosensitizers in foods are riboflavin, chlorophylls, flavonoids, hemeproteins and porphyrins. Extremely reactive singlet oxygen is often involved in photosensitized oxidation processes. (Helén, 2008) Light is known to cause for example discoloration, loss of vitamin content and unpleasant odours in the products. (Heikkilä, M., 2005, p. 5-22) Foodstuff will react exposed to light in many ways depending on chemical composition of the food, spectral distribution of the light, intensity of light, distance between the light source and the food package, duration of the light exposure, presence of oxygen and pro-/antioxidants and temperature. (Helén, 2008)

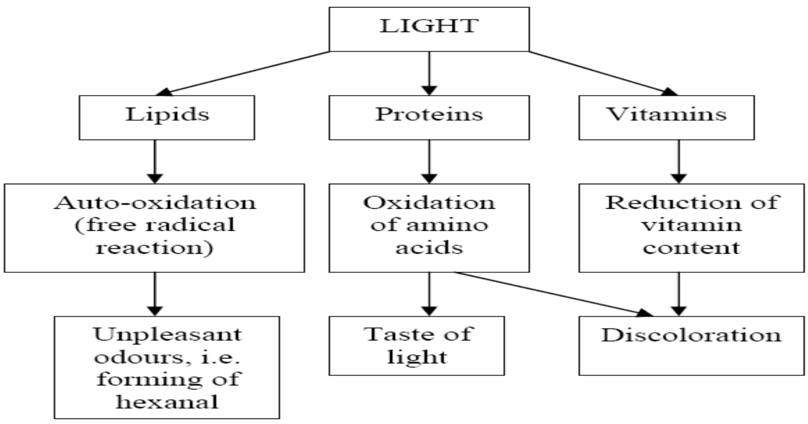

Figure 3. General picture of reactions caused by light to the foodstuff. (Heikkilä, 2005, p. 5-22)

Milk and milk products, fatty foods and meat

Milk and milk products, fatty foods and meat are said to be especially sensitive to effects of light. Exposure to light can cause many kinds of effects on the quality of the foodstuffs, i.e. organoleptic properties suffer, lipids become oxidized, A-, B2- and C-vitamin content decrease and different kind of colour defects occur. (Heikkilä, 2005, p. 1-2) False taste and destruction of nutritive substances happens in milk below 550 nm wavelengths. (Nelson et al., 1983) In some studies it is stated that for dairy products wavelength area 400-450 nm was found to be especially dangerous. (Helén, 2008)

Cheese

According to Mortensen photo-oxidation in cheeses occur mainly on the surface of the cheese and it can happen even at low temperatures. (Mortensen, 2002) Most of the light influences on cheeses can be explained by general oxidation mechanism of lipids combined with absorption properties of β-carotene (vitamin A) and riboflavin. (Mortensen et al., 2004, p. 85-102) Riboflavin, which is also known as B2-vitamin, operates as a sensitivity agent in cheeses. Changes influenced by light in cheeses are studied to be very dependent on the light source, because riboflavin and β-carotene have different absorption spectra and due to the fact they are sensitive to different wavelengths of light. (Mortensen et al., 2003a, p. 57-62) According to Mr. Mortensen et al. when cheeses were exposed to visible light in wavelengths 405 nm or 436 nm, their odour changed very rapidly and this could not be observed when cheeses were exposed to wavelengths near UV-light (366 nm). (Mortensen et al., 2003b, p. 413-421) There was also formation of volatile compounds of secondary oxidizing substances, such as alcohols, aldehydes, ketons and sulphur compounds, and their levels grew in cheeses exposed to light. (Colchin et al., 2001) However formations of these substances are not only depending on light permeability of packaging material but also its oxygen permeability. (Mortensen et al. 2002a, p. 121-127)

Effects of light exposure on the colour of cheeses found in literature have very mixed results. According to several studies as a consequence of light exposure the cheese colour fades and that is influenced by the intensity of light and the time of exposure. (Hong et al., 1995, p. 94-97) However some studies say that L-value decrease because of light exposure and some says there is no effect on the colour. (Mortensen et al, 2002a, p. 121-127) It was also observed that light exposure decreases the amount of riboflavin and β-carotene in cheeses, but in different speeds. (Mortensen et al., 2003a, p. 57-62) The fat content of cheese is also a factor how cheese will behave under light. The most sensitive seems to be the cheese with lowest fat content. (Helén, 2008)

Potato chips

Lennersten and Lingnert noticed that visible light was capable of causing oxidation of lipids in potato chips. During the light exposure there were observed several different volatile compounds of which the amount of one decreased and the other increased. In potato chips which were exposed to fluorescent light, the amount of hexanal and pentanal started to increase rapidly after 10 days of storage. Light also caused changes in colour before lipids started to oxidize. It was found that the colour of potato chips can be influenced most by the shortest wavelengths of the visible light. (Lennersten, 1998) It has been noticed that lipid oxidation is strongest in wavelengths below 455 nm (Lennersten, 1995) Lipid oxidation happens in potato chips even below 380 nm. (Lennersten et al., 1998, p. 162-168)

Peanuts

Also peanuts can be very sensitive to the effects of light and auto oxidation of lipids due to their high content of unsaturated fatty acids. In peanuts light caused formation of free radicals but the amount of oxygen had the biggest influence on formation of hexanal, which is known as a typical volatile organic compound with a quite strong odour. (Jensen et al., 2005, p. 25-38)

Biscuits and other snacks

Consumer looses easily its trust to foodstuff if the product quality decreases significantly during storage. When thinking of biscuits and other snacks the most important factors which decrease product quality are if they get moist, then dry, lipids get oxidized due to oxygen inside the package or as a resultant of light and microbiological or enzymatic deterioration. (Willhoff, 1990, p. 349-372)

When biscuits or snacks get moist or dry it will mostly cause changes to the composition and the structure. The problem with dry biscuits and snack products is moisture absorption from the environment. With so called cake biscuits which have greater moist content, the problem is water evaporation from the product and due to that biscuit become hard and dry. (Willhoff, 1990, p. 349-372)

As dry products biscuits and snack products don’t suffer from microbiological contamination, but when moist content is increased unwanted, microbiological and enzymatic deterioration become more possible. In addition to that, lipid oxidation causes false taint and odours. Naturally the greater the fat content of the product the greater the risk for lipid oxidation. (Willhoff, 1990, p. 349-372)

1.6.3. Protection of the foodstuff from harmful light

Packed foodstuffs can be protected from the effects of the harmful UV-radiation by using the packaging materials which can block UV-light before penetrating into the foodstuff. Foodstuffs can also be protected by reducing the amount of light or by using the lamps which emit light with less energy. Food processing and structure of food have been observed to have effects on light sensitivity of the foodstuff. (Heikkilä, 2005, p. 1-2) However it is important to know that packaging materials with only UV-absorption is not enough to provide sufficient protection against light effects, because visible light can also damage foodstuffs sensitive to light effects. (Helén, 2008)

Usually foodstuffs sensitive to light are packed in non-transparent packages and packaging materials used for such foodstuffs have been metal-, board- or coloured glass, but also metallized polymer films have been used. Typically a package where a full light protection is needed, aluminium foil is used. Nowadays when aluminium is considered to be a hazardous waste, the amount of aluminium in the packages has been reduced and it has been replaced with other materials. At the same time when the interest towards transparent packaging has increased, new ways of creating light protection for packages have been developed. Among food manufacturers proper and sufficient light protection of foodstuffs are considered problematic, because it is not well known what kind of light causes the changes observed in the product or what mechanism makes these changes to happen. Due to this it is also unknown how it is best to protect foodstuffs from the harmful effects of light and UV-radiation. (Heikkilä, 2005, p. 1-2)

However, foodstuffs packed in transparent retail packages are slowly but surely increasing. Consumers want to see the product in point of sale to be able to judge the quality of the contents. At the same time opening times of shops have become longer providing longer illumination times. There are usually very strong lighting inside the shops and with the help of that, shops try to bring out the products and their packages more. Product selection has also increased in retail shops and due to that, a single product can be exposed to light and its effects longer. (Heikkilä, 2005, p. 1-2) It is measured that clear transparent plastic films transmit usually about 70-90% of the incident light and cannot give any kind of light protection. (Helén, 2008) These are the main reasons why also the effects of light exposure can be detected on the foodstuffs. (Heikkilä, 2005, p. 1-2)

During the delivery chain foodstuffs are mainly exposed to light from fluorescent lamps and a very little from other light sources, i.e. sun and light bulbs. (Heikkilä, 2005, p. 1-2) In light bulbs there is a hot wolfram wire, which emits heat radiation. The spectrum of a light bulb is quite wide and the light contains plenty of red and yellow light, but less blue and green light. The most of the radiation which light bulb emits is outside of the wavelength area of visible light. Fluorescent lamps are gas discharge lamps, where ionisation of gas atoms happens with the help of electricity and electrons are able to move to higher energy levels, when they collide with each other. When this state is deactivated, energy quanta and light in the UV wavelengths can be produced. (Hautala, 1998)

1.6.4 Light protection properties of different packaging materials

Different packaging materials give different light protection for the product packed inside. Light protection of a material is influenced by material type, absorption properties, thickness, material processing, colour, printing, pigmentation, metallization, labelling and usage of UV-blockers, if UV-light is causing the quality changes in the product. (Mortensen et al. 2002a, p. 121-127) Material processing means i.e. orientation of polymers, influencing to crystallinity and adding different additives into the material and by changing these elements the light protection given by a packaging material can be influenced. (Mortensen et al., 2004, p. 85-102)

Differences in light protection properties between packaging materials originated from differences in light reflection, light permeability and oxygen permeability. (Mortensen et al., 2004, p. 85-102) Metals are able to offer the best light protection and then come board and paper, different kinds of polymers and last uncoloured glass, which permeates even 90% of the light. (Lennersten, 1998)

<u>Different polymers</u>

Most of the plastic films used in packing foodstuffs are clear and due to that they don’t give much light protection to the product. (Lennersten, 1998) Polyethylene and polypropylene are known to permeate light in whole UV- and visible light range, 200-800 nm. (Coltro et al., 2003, p. 15-20) By adding small amounts of polyethylene naphthalate, PEN, to polyethylene terephtalate, PET, light protection properties of PET can be improved remarkably. (Conrad et al., 2005, p. E19-E25) According to Lennerstein and Lingnert clear, oriented polypropylene, PP-O, permeated mostly UV-radiation, but clear, oriented polyethylene terephtalate, PET-O, films protected well from light below 310 nm. Both films permeated visible light quite well. (Lennerstein, Lingnert, 1998, p. 162-168)

Polylactic acid is a biomaterial which properties are similar to polystyrene. PLA prohibited colour changes, oxidation of lipids and the loss of β-carotene and riboflavin in unseasoned yoghurt at least as good as polystyrene. (Frederiksen et al., 2003, p. 61-69)

Paper and board

Light protection properties of paper and board materials are considered to be good and light permeation can even be decreased by pigmentation. Grammage of paper and board materials has an effect on light permeability so that the heavier the board the smaller its light permeability is. Unbleached board is proven to give better light protection especially in short wavelengths when compared to bleached board due to its composition. Unbleached board contains light absorbing compounds, such as lignin, and when the board is bleached, the amount of lignin is decreased or changed into other forms. According to Mr. Lennersten unbleached paper grades permeated very little UV-light and bleached grades permeated more light in UV area. It is the same thing as far as visible light was concerned and especially its shortest wavelengths. (Lennersten, 1998)

1.7 Techniques to prevent foodstuff deterioration in packages with plastic windows

Blown film process

Blown film is one of two prime processes used to fabricate film products. The blown film process is used to produce a wide variety of products, ranging from simple mono-layer films for bags to very complex multi-layer structures used in food packaging. (The Dow Chemical Company, 2007)

Cast film process

The cast film process involves the extrusion of polymers melted through a slot or flat dies to form a thin, molten sheet or film. This film is pinned to the surface of a chill roll, typically water-cooled and chrome-plated, by a blast of air from an air knife or vacuum box. The film cools immediately and then has its edges slit prior to winding. Because of the fast cooling capabilities, a cast film generally has much better optics than a blown film and can be produced at higher line speeds. However, it has the disadvantage of higher scrap due to edge-trim, and very little film orientation in the cross-direction. Cast films are used in a variety of markets and applications, including stretch/cling films, personal care films, bakery films, and high clarity films. (The Dow Chemical Company, 2007)

Extrusion laminating also known as sandwich laminating is a process related to extrusion coating, but in this process the extrusion coated layer is used as an adhesive layer between two or more substrates. A second layer is applied to the extrusion coating while it is still hot and then the sandwich is pressed together by pressure rolls. The extrusion layer may also function as a moisture barrier. (Nova Chemicals, 2001)

Multilayer films have a significant role in today's packaging. By combining many layers, usually 3-5, of different polymers, a designer can take an advantage of the mechanical properties of one polymer and barrier properties of another and to create the perfect package for the application in question. In a multilayer film there are structural layers on the outside and barrier layers on the inside. When necessary, tie layers are used as glue between the different layers. (Massey, 2003, p. 40)

1.7.1 Utilising nanotechnology in packaging and plastic film manufacturing

Packaging materials can be modified in ways which prevent harmful effects of light, moisture or oxygen for the foodstuffs. These techniques have a big impact on product shelf life and quality.

Nanotechnology refers to the control of matter at an atomic or molecular scale of below 100 nm. (Halliday, 2007, p. 1-2) Most common are ceramics such as metal oxides (titanium, aluminium or iron) and silicates such as nanoclays. Many of them are available as commercial products in form of powders or dispersions. (Merta, 2006, p. 15) It has found end uses in several industries, including food, nutritional ingredients and packaging. (Halliday, 2007, p. 1-2)

Nanoclays

Super platy kaolin pigments are already on the market. They are big flakes with dimensions of microns, but their thickness is only some nanometers. When the ratio between thickness and other dimensions is increased, as a result smoother surfaces can be obtained. Nanoclays give also stiffness to the coated sheet and it could enable to use sheet of lower fibre weight. Platy kaolin mixed with blocky pigment would provide synergy in optical properties and bulk. It would also give higher light scattering, printing gloss and coverage. (Merta, 2006, p. 15-16)

Nanocomposites

Polymer and clay nanocomposites are formed by layered clays and synthetic polymers. (Hao et al., 2000, p. 7879-7881) With these nanocomposites it is possible to improve film toughness, its thermal stability, barrier properties and flame retardancy. They are more expensive than normal basic fillers but only a little is needed to have a clear effect. (Merta, 2006, p. 16)

Nanocomposites are already used in plastic packaging, but expected innovations are also in new composite materials of cellulose fibres with recyclable polymers. The mechanical, optical and barrier properties of paper and board can be improved. The aim is to manufacture composite materials with:

- extended shelf life and protection of the packaging content
- new paper and board coating techniques based on natural and modified biopolymers and responsive polymers

- cellulose/inorganic hybrids for new packaging materials
- one- and multilayer preparations based on biopolymers
- gas barrier properties – O_2 barrier at different humidity (Merta, 2006, p. 16)

Future of nanotechnology in packaging

Transparent food packaging film is a multi-billion dollar global market, with growth driven by rising demand for convenient foods. Worldwide sales of nanotechnology products to the food and beverage packaging sector jumped to 687.5 million EUR in 2004 from 120 million EUR in 2002, according to study by Mr. Helmut Kaiser released in year 2005. Nanotechnology is forecasted to change 25 % of the food packaging business in the next decade and the surging growth is suspected to come mainly from the rapid increase in the applications employing nanotechnology. (Patton, 2006)

New food packaging technology is regarded by far the most promising benefit of nanotechnology in the food industry. While the nanofood industry struggles with public concerns over safety, the food packaging industry is moving full-speed ahead with nanotechnology products. Leading the way is active or smart packaging which promise to improve food safety and quality and optimize product's shelf-life. Numerous companies and universities are developing packaging that would be able to alert if the packaged food becomes contaminated, respond to a change in environmental conditions, and self-repair holes and tears. (Garber, 2006)

The use of nanotechnology is considered as one of the most promising innovations in smart packaging when developing antimicrobial packaging. Scientists at big name companies including Kraft, Bayer and Kodak, as well as numerous universities and smaller companies, are developing a range of smart packaging materials that will absorb oxygen, block out other harmful gases, detect food pathogens, and alert consumers to spoiled food. These smart packages are claimed to be able to detect public health pathogens such as salmonella and *E.*

coli. Similar technology is being developed for the U.S. Government as a means of detecting possible terrorist attacks on the U.S. food supply. Scientists in the Netherlands are taking smart packaging a step further with nanopackaging that will not only be able to sense when food is beginning to spoil, but will release a preservative to extend the life of that food. (Garber, 2006) Nanotechnology researchers in the United Kingdom reported last year that both zinc oxide and magnesium oxide had been found to be effective in killing micro-organisms. (Patton, 2006)

Clay nanocomposites are being used in plastic bottles to extend the shelf life of beer and make plastic bottles nearly shatter proof. Inner nanocrystals in plastic create a molecular barrier that helps to prevent the escape of oxygen. The technology currently keeps beer fresh for six-months, but developers at several companies are already working on a bottle that will extend shelf life to 18 months. Several large beer makers, including South Korea’s Hite Brewery and Miller Brewing Company, are already using the technology. (Garber, 2006)

A chemical company, Bayer, states that it is developing a transparent plastic film with nanoparticles of clay, which block oxygen, carbon dioxide and moisture from reaching the contents, whether it is meat, vegetables or anything else. This nanoclay is claimed to increase the packs strength and heat resistance while decreasing the weight of the plastic. (Barras, 2006, p. 1)

A company called Nanocor, a developer of nanoclay technologies for plastics, has developed a nanocomposite which has enabled a customer to improve the current barrier level of the coating film for a paperboard juice container. The customer wanted a barrier similar to that provided by EVOH but at a lower cost. An improvement in stiffness of the overall film was also requested to reduce swelling. In this case the use of Bayer’s Durethan nanocomposite nylon was chosen. This offered the required barrier and increased film stiffness by 30%. The use of a nylon-based product improved adhesion to the paper substrate and the polyethylene overcoat. (Moore, 2004, p. 32)

Driven by the need to substitute plastic materials for aluminium in applications such as packaging, new ultra high barrier nanocomposites are being developed. One of them is said to be nylon MXD6, produced by Mitsubishi Gas & Chemical Co. Inc. According to the producer this semicrystalline resin is said to have good gas barrier properties and it is said to work at high humidity. Converting MXD6 to a nanocomposite further is stated to enhance barrier characteristics and make it better than EVOH. Nanocomposite technology further enhances MXD6 barrier properties while preserving processing characteristics and transparency. The technology consists of dispersing nanometre-sized particles of a clay mineral within the nylon, creating tortuous path for gases, thereby enhancing the product's shelf life. (Moore, 2004, p. 29)

Consumer aspects regarding the use of nanotechnology

The survey, commissioned by BfR, found that consumers were sceptical when asked about utilising nanotechnology in foods but were not so resistant to use nanotechnology in other, non-food areas. In general, 66 % of the respondents said they thought nanotechnology presents more benefits than risks and are in favour of further development subject to further research. Packaging and sunscreen uses also had a relatively high level of support. BfR stated that they felt they received the most reliable information from consumer groups, and the least reliable information from politicians. They were also sceptical of information originating from the business community. (Halliday, 2007, p. 1-2)

1.7.2 Usage of UV-blockers

In polymer materials photo-oxidative decomposing can happen when they are exposed to light. Due to that their properties can change but the change can be prevented by using small amounts of light chemical absorbents, which could be UV-blockers or free radical extinguishers. UV-blockers, typically protect material from decomposition, perform as filters, because they absorb UV-light. (Coltro et al., 2003, p. 15-20)

Titanium oxide is a often used white pigment. By mixing titanium oxide with a polymer, light scattering can be increased from the material and through that light permeability of the material can be decreased especially at wavelengths below 400 nm. (Lennersten, 1998) A decrease of light permeability depends on the amount of added titanium dioxide, but when added too much, the polymer film start to loose its transparency. Also carbon black, talc and chalk can be used to decrease light permeability of packaging material. (Mortensen et al., 2004, p. 85-102)

Kemira Pigments is one of the producers of titanium oxide pigments. The main applications are in paints, printing inks, plastics and paper. (Kemira, 2005, p.1) UV-Titan manufactured by Kemira is a range of different ultrafine rutile structured titanium dioxide which is said to provide dispersibility, stability and performance as an UV-filter. Titanium dioxide is said to be a safe product to use, because it doesn’t migrate and that’s why it can be used as an alternative for organic absorbers. For example benzophenone has a tendency to migrate out of films during long time exposure to UV radiation and benzotriatzoles can not be used in packaging for fatty foodstuffs or ethyl alcohol. (Kemira, 2005, p.2)

According to Kemira, the main difference between ultrafine and pigmentary titanium dioxide is crystal size. The crystal size of pigmentary titanium dioxide is about 200 nm and when looking at ultrafine titanium, it is ten times less. Therefore the optical properties of these two titanium dioxides are different as well. They state that the 200 nm crystals scatter visible light more efficiently, whereas the smaller 20 nm crystals of ultrafine titanium dioxide scatter and reflect UV-light effectively and transmit visible wavelengths through the crystal causing the ultrafine titanium oxide to be transparent. According to Kemira the crystal size and crystal size distribution are critical properties to the effectiveness of UV-Titan in its applications. UV-Titan is composed of both spherical and needle-shaped crystals, of which the latter is said to give better transparency. According to Kemira the smaller the crystal size, the lower the wavelength of the maximum UV-absorption. In Figure 4 are the differences in UV/visible spectrum between ultrafine titanium dioxide and pigmentary titanium oxide presented. (Leinonen, 2004, p.8)

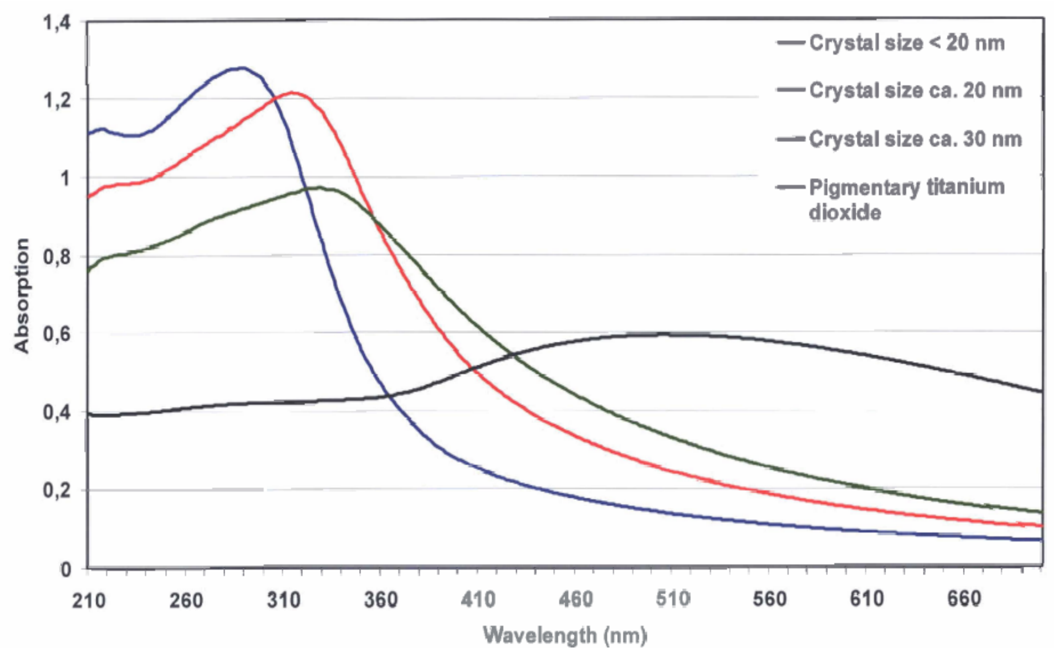

Figure 4. UV/Visible – spectrum. Ultrafine titanium dioxide vs. pigmentary titanium oxide. (Leinonen, 2004, p. 8)

Kemira states that UV-Titan can act as a filter to protect the contents of packaging from UV-light. It is claimed to be a UV-absorber that can be used to increase the UV stability of polymers.

The effects of the environment on a polymer surface can lead to a reduction of gloss, changes in colour or deterioration in other properties such as its strength and flexibility. The most important of these environmental effects is known to be sunlight. UV-light attacks the structure of the polymer, producing highly reactive free radicals which can initiate a series of reactions to break down the polymer molecules. Most organic UV-stabilisers act with these free-radicals or with the products of their reactions. Kemira's UV-Titan are claimed to work by blocking and scattering the UVA and UVB radiation preventing it from penetrating the surface. (Kemira, 2005, p. 6)

Also a chemical company DuPont has announced the release of its Light Stabilizer 210, a plastic additive designed by using very small particles of titanium dioxide, which have been nanoengineered to absorb UV-light. DuPont wants approval for use of Light Stabilizer 210 as a plastic packaging additive in indirect food contact applications. According to DuPont Light Stabilizer 210 is said to work by absorbing UV rays and changing them into small amounts of heat which scatter quickly without damaging the structure of plastic. (ElAmin, 2007)

According to studies UV-blocker added to packaging material cannot totally prevent the loss of riboflavin and A- and C-vitamin content in milk products or the color changes. Milk is also very sensitive to certain wavelengths in visible light, so by preventing the penetration of UV-light does not protect the product from quality changes caused by visible light. (Mestdagh et al., 2005, p. 499-510)

1.7.3 Oxygen absorbers

Active packaging can remove an unwanted component, add desirable ingredient, prevent microbial growth, change permeability to gases as the temperature changes or change the physical conditions inside the package. (Ahvenainen, 1996, p. 179-187)

Atmospheric O_2 is said to have a harmful effect on the nutritive quality of foods and it is therefore desirable to maintain for many types of foods at a low O_2 level or at least prevent a continuous supply of O_2 into the package. Typically changes in the gas atmosphere of packed food depend mainly on the nature of the package. Properly sealed packages effectively prevent the interchange of gases between the food and the surrounding environment. With flexible packaging the diffusion of gases depends not only on the effectiveness of the closure but also on the permeability of the packaging material which depends primarily on the physicochemical structure of the barrier. (Gregory, 1996)

Oxygen absorbers, also known as scavengers, are substances which absorb oxygen in a chemical or enzymatic way. Essentially any substance easily oxidized by oxygen can act as an oxygen scavenger. However commercially suitable scavengers have to satisfy a lot of requirements concerning safety, cost price and performance. (Nakamura et al., 1983, p. 1-45) O_2 absorbers use mainly oxidation of either powdered iron or ascorbic acid, of which the former is more common. (Shimoni et al., 2001, p. 1337-1340) The oxidation mechanism can be expressed as follows when iron is used (Smith et al., 1990, 111-118):

$Fe \rightarrow Fe^{2+} + 2e^-$
$\frac{1}{2} O_2 + H_2O + 2 e^- \rightarrow 2 OH^-$
$Fe^{2+} + 2 OH^- \rightarrow Fe(OH)_2$
$Fe(OH)_2 + \frac{1}{4} O_2 + \frac{1}{2} H_2O \rightarrow Fe(OH)_3$

By using iron powder, it is possible to reduce the O_2 concentration in the headspace of the package to less than 0.01 %, which is much lower than the typical 0.3 to 3.0 % residual O_2 levels achievable by vacuum or gas flushing. Various sizes of O_2 absorbers are available commercially, but there are several factors affecting the choice of the type and size of absorbent required (Shimoni et al., 2001, p. 1337-1340):

- nature of the food (i.e. size, shape, weight)
- water activity, a_w, of the food
- amount of dissolved O_2 in the food
- desired shelf life of the product
- initial O_2 level in the package headspace
- O_2 permeability of the packaging material

The last factor is very important for the overall performance of the absorbent and the product shelf life and if a long shelf life is desired, films containing PVdC or EVOH as a barrier layer are necessary. (Shimoni et al., 2001, p. 1337-1340)

The most well known O_2 scavengers take the form of small sachets containing various iron based powders, together with an assortment of catalysts that absorb O_2 within the food package and irreversibly convert it to a stable oxide. (Tewari et al., 2002, p.209-217) An alternative to sachets is the incorporation of the oxygen scavenger in the package structure itself. Low-molecular-weight ingredients may be dissolved or dispersed in a packaging plastic or the plastic may be made from polymeric scavenger. (Rooney, 1995, p. 74-110) Many commercial alternatives are available, but it should be noted that the speed and capacity of oxygen scavenger plastic films are considerably lower than for iron based oxygen scavenger sachets or labels. (Day, 1998)

The first oxygen absorbing polymer was a blend with PET involved the cobalt-catalyzed oxidation of MXD6 polyamide. When used with 200 ppm of cobalt as the stearate salt, this polyblend allowed blowing of bottles with an O_2 permeability of essentially zero for one year. In one approach being commercialized in both Australia and USA, a polymer-based absorber is coextruded in various packaging structures including bottles, films, coatings, sheet, adhesives, lacquers, can coatings, and closure liners where it acts as both a headspace oxygen absorber and a barrier to oxygen permeation into the package. The O_2 absorbing capability is UV-activated so it must be exposed to UV-light before it can begin absorbing oxygen. (Rooney, 2002)

Some oxygen scavengers use an enzyme reactor surface supposed to react with some substrate to scavenge incoming oxygen. (Brody et al., 1995, p. 174-192) The enzymes can be bound to the film so they can be a part of the package structure. Both polyethylene and polypropylene are good substrates for immobilizing enzymes. Another important unknown factor is the stability over time of the enzyme in the film. (Labuza et al., 1989, p. 1-69) A patent made by Strobel and Gagnon in 1998 describes a porous polyolefin structure containing glucose oxidase. The pores permit the flow of oxygen and water in order to catalyse the reaction which consumes oxygen. (Strobel et al., 1998)

For an O_2 absorber to be effective, the packaging materials used need to have a relatively good barrier to oxygen, otherwise the scavenger will rapidly become saturated and lose its ability to trap oxygen. (Hurme et al., 1998) The use of an oxygen absorber can influence on different food properties. Oxygen scavenging is effective in preventing growth of moulds and aerobic bacteria. (Rooney, 1995)

They can also prevent oxidative damages and discoloration as well as loss of taste and nutritive elements. (Smith et al., 1990, p. 111-118)

Oxygen absorbers have been used for a range of foods including sliced, cooked and cured meat and poultry products, coffee, pizzas, specialty bakery products, dried food ingredients, cakes, breads, biscuits, croissants, fresh pastas, cured fish, tea, powdered milk, dried egg, spices, herbs, confectionary and snack food. (Day, 2003, p. 293)

1.8. Product safety and food contact regulations

Materials used for food packaging must meet variety of legal requirements. Typically a package manufacturer operating within EU area must follow EU Directives, but BfR Recommendations and FDA Regulations are commonly followed as well.

EU regulations

As stated already earlier, all materials and articles intended to come in contact with food have to comply with EU Regulation No. 1935/2004. It specifies the requirements for a safe food packaging. The principle underlying this regulation is that any material or article intended to come into contact directly or indirectly with food must be sufficiently inert to exclude substances from being transferred to food in quantities large enough to endanger human health or to bring about an unacceptable change in the composition of the food or a deterioration in its organoleptic properties. The demands of this regulation have to be fulfilled before placing the product on the market. (Eur-Lex, 2008)

Relating to plastic materials and articles intended to come into contact with foodstuffs there are also an EU Commission Directive No. 72/2002/EC and its amendments, which set the requirements for the used plastics. It says in the article 2 of this Directive No. 72/2002/EC, that plastic materials and articles shall not transfer their constituents to foodstuffs in quantities exceeding 10 mg/dm². This limit is better known as overall migration limit. This directive also contains a list of authorized monomers and other starting substances which are allowed to use and their possible specific migration limits. (Eur-Lex, 2008)

BfR Recommendations

Federal Institute for Risk Assessment (BfR) was set up in November 2002 to strengthen consumer health protection. It is the scientific agency of the Federal Republic of Germany which is responsible for preparing expert reports and opinions on food and feed safety as well as on the safety of substances and products. Its tasks include the assessment of existing and the identification of new health risks, the drawing up of recommendations on risk reduction, and the communication of this process. In its assessments and recommendations BfR is not influenced by any economic, political or social interests. It presents them in such a way that they can be easily understood by the general public. BfR have also listed recommendations for paper and board products as well as for different kinds of polymers. It is important to remember that these recommendations are not legally binding to food packaging manufacturers except of in national level, but still they have a strong influence on many things. (BfR, 2008)

FDA regulations

In the United States applications for clearance of the safe use of food contact substances are directed to the Food and Drug Administration (FDA). As opposed to the European approach it is also possible to register also complete polymers instead of monomers and/or additives in the USA. Furthermore, the most important difference between European and American food contact regulation is based on the calculation of the possible consumer exposure. FDA regulations also specify under what type of conditions the materials can be used. FDA also pays special attention to impurities and side reaction products of food contact substances. (Tschech, 2005)

Typical procedure for testing paperboard food contact materials

Food contact material manufacturer is always responsible for its final products and their food contact approvals. The procedure to get food contact approval for some material, you have to send representative samples of the product to an independent research laboratory and enclose a full chemical composition including dosages per each chemical with the samples. As a material manufacturer the end use of the product has to be stated and with the help of that information, the regulations which have to be fulfilled can be determined. After receiving the samples and chemical information, the research laboratory can start analytical tests and chemical component evaluation. Every component used and the product itself has to comply with EU Regulation 1935/2004, appropriate FDA legislations (176.170/176.180) and/or BfR recommendations. The test laboratory should not trust directly in chemical supplier's self certificates or other statements received, i.e. opinion letters, because they have no official regulatory background. Instead they should utilise only statements or certificates made by an official test laboratory when they write their certificates. Food contact evaluation for plastic coated board materials can consist of the following tests: (Stora Enso, 2008, p. 1-15)

- Cold water extract (EN 645)
- Determination of the heavy metal content (lead, chromium, cadmium, mercury)
- Fluorescent whitening agents (EN 648)
- Colour leaching (EN 646)
- PCP & PCB content
- Transfer of antimicrobial activity (Hemmhof-Test)
- Overall migration (3 stimulants, each at 2 temperatures or times)
- Specific migration of 2 substances (same conditions as overall migration)
- Sensory Evaluation (three types of food, each at 1 time or temperature)
- EN 45011 Certification of Compliance (Composition and analytical results)
- Extra Certificate of Compliance with Article 11 of Directive 94/62/EC

- Analytical reports

The total price for one material for the complete program as listed above would be about 13 000 EUR. Basic rule of the thumb is that the more complex the material, the more costly the compliance testing will be. (Stora Enso, 2008, p. 1-15)

When different kinds of nanoparticles are used in packaging materials coming into contact with food, the packaging material manufacturer will be responsible for the safety of the package. As far as normal substances are concerned, bio tests evaluate the hazards caused by substances and migration tests evaluate the exposure of the substance. The problem with the nanoparticles is that the current bio tests are not applicable for nanoparticles and that's why the risk evaluation is difficult. According to studies, tiny particles have properties which are hard to predict beforehand. Nanoparticles represent totally different substances regarding some of their properties: (Aurela et al., 2008)

- very small size
- round, tube or platen shape
- composition
- solubility
- charge
- surface properties
- functional groups
- group forming

<u>Product safety of active / intelligent packaging</u>

Safety evaluation of active packaging is more complex than that of ordinary food packaging in general. The substances involved, compounds produced and migration into food are one part of the aspects, while the proper function of the active package is another. Active scavenging and releasing concepts may change the living conditions of micro-organisms. This must be studied to inhibit the formation of any unfavorable microbial flora and the control of the packed foodstuffs will have to be adjusted accordingly. (Fabech et al., 2000, p. 31-32)

Active and some intelligent components are always in direct contact with food. If the active or intelligent ingredient is incorporated in the plastic film, then such material has to comply with the conventional rules laid down in the EU directives. Both positive list and migration behavior should be in compliance because the way of contact as well as the surface to volume ratio is equal to the normal packaging materials. If the system comes in contact with liquid foods, migration has to be tested according to the directives 82/711/EEC and 85/572/EEC. In case of dry foods specific migration of substances should be measured directly in the food as there are no tests prescribed with stimulants. (Rijk, 2001, p. 7)

There are aspects to be considered when thinking about safety of nanotechnology. The main thing is to make sure the product does not endanger the health of the employees and consumers. This is very difficult because the risks are unknown or is known very little and the exposure is unknown as well. The effects on the surrounding environment are unfamiliar. According to experts it is difficult to evaluate the hazards caused by nanoparticles due to the difficulty of characterising the particle mixtures. Current methods and reference materials are not good enough for this purpose. Also interpretation of bio test results is insufficient and because of that it cannot be stated accurately the impacts of nanoparticles to cells and organs. This results to the fact that the final risk cannot be determined if either the hazard or exposure information are insufficient. (Aurela et al., 2008)

Despite the using of different kind of active or intelligent components in food contact materials, the final material must comply with the EU Directive No. 1935/2004. Packaging material is not allowed to change the composition or the organoleptic properties of food or give information about the condition of the food that could mislead consumers. (Eur-Lex, 2008)

Items manufactured for use in contact with food in the USA fall under the jurisdiction of the Federal Food, Drug, and Cosmetic Act (FFDCA, Title 21

United States Code 348). Section 201 (s) of the FFDCA provides a definition for the term “food additive” that includes components of food contact articles like packaging materials whenever they migrate to food as a result of their intended use or if they otherwise affect the characteristics of food. The food additive provisions of the FFDCA provide a framework to ensure the safe use of all chemicals that fall within the scope the food additive definition. These food additive provisions became law in 1958 and may be found mostly in section 409 of the FFDCA. The Food and Drug Administration (FDA) administers the main part of the FFDCA including the section 409. The FDA generally classifies food additives by whether or not they have intended technical effect in food. Federal food additive regulations are listed in Parts 170 through 189 of Title 21 Code of Federal Regulations (CFR). Direct food additives are substances that are added directly to the food and have an intended technical effect in the food. Indirect food additives are those substances that are components of food contact substances, like food packaging, and may migrate to food, but they have no intended technical effect in the food. According to FDA diffusion barriers and scavengers have no direct technical effect on the food and are therefore food contact substances which are subject to the notification approval process. Although the use of diffusion barriers and oxygen scavengers has the potential to create a modified atmosphere within the package that could promote the growth of anaerobic pathogens, the production of safe food is assured by good manufacturing practice regulations found mainly in 21 CFR Parts 110-129. (Song et al., 2005, p. 481)

1.9 Window cutting

A window can be cut to the board by using typical die cutting or by laser cutting methods.

1.9.1 Die cutting

Die cutting is a converting process that cuts and creases blanks from various substrates into the desired shapes. The tool used for this purpose is a cutting and creasing die. (Tanninen, 2007, p.10) There are two different types of machinery used for die cutting: (Tanninen, 2007, p. 12)

- flatbed/platen die cutters, which are available in configurations that either convert sheets or a continuous web.
- rotary die cutters, which are used in configurations that convert packaging material from a continuous web.

The die is made by setting cutting and creasing rules, in a stable wooden forme. Cutting is carried out with rules that have sharp edges and these rules cut vertically through paperboard. (Tanninen, 2007, p.16) Cutting rules should be longer than creasing rules because they have to cut right through the paperboard. The die also contains a compressible material, usually rubber of specific hardness, mounted on the die in close proximity to each side of every rule. The purpose of this material is to press the paperboard against the bed plate of the lower platen and hold it securely during cutting. When the platen closes, the die cuts through the paperboard with the rules making a kiss contact with a backing steel plate. In Figure 5 is described the cutting die more carefully. (Tanninen, 2007, p.17-18)

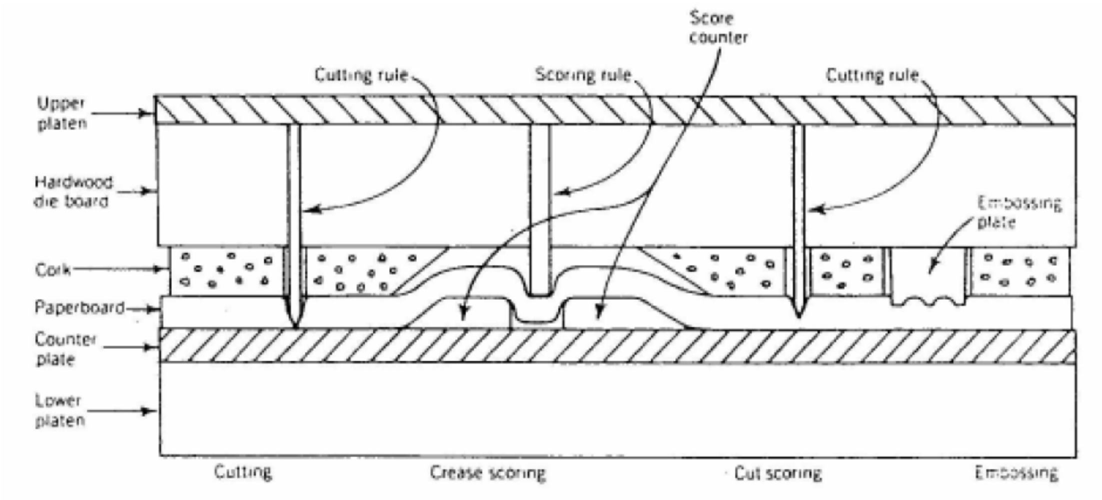

Figure 5. Flat-bed cutting die, schemantic. (Kuusipalo, 2007, p.1)

When webfed rotary die cutter is used, different kind of cutting approaches can be used. In crush-cutting the cylindrical cutting die is used with sharp cutting edges. The sharp cutting edge slices through the board, somewhat like a knife, while the web is moving through the nip of the rotating cutting cylinder and its counter cylinder. In pressure cutting, both die cylinders are provided with land that meets each other at rotating nip point, causing the paperboard to part cleanly without the actual contact between male and female lands. (Tanninen, 2007, p.28-30)

1.9.2 Laser cutting

One of the advantages in laser cutting is that it can be used for tailor-made cuttings. In paper and paperboard cutting CO_2-lasers are used. CO_2-lasers remain the workhorse of the industrial laser systems, because it is simple and reliable and is available as a robust well-engineered industrial machine with output powers of up to 60 kW. The CO_2-lasers emit light with a wavelength of 10.6 μm and have electrical efficiencies of approx. 10-15 %. (Kujanpää, 2007, p. 46)

In CO_2-lasers, a gas mixer prepares the laser gas – a mixture of CO_2, N_2 and He – in ideal mixing ratio (approx. 1:4:10). Electrodes produce the gas discharge in the laser gas while the CO_2 molecules are stimulated to the upper laser lever. The resonator is composed of two mirrors and the laser light is generated between the mirrors in the laser-active material. In Figure 6 the basic principle for laser cutting of paper materials is shown in one type of laser solution. (Kujanpää, 2007, p. 47)

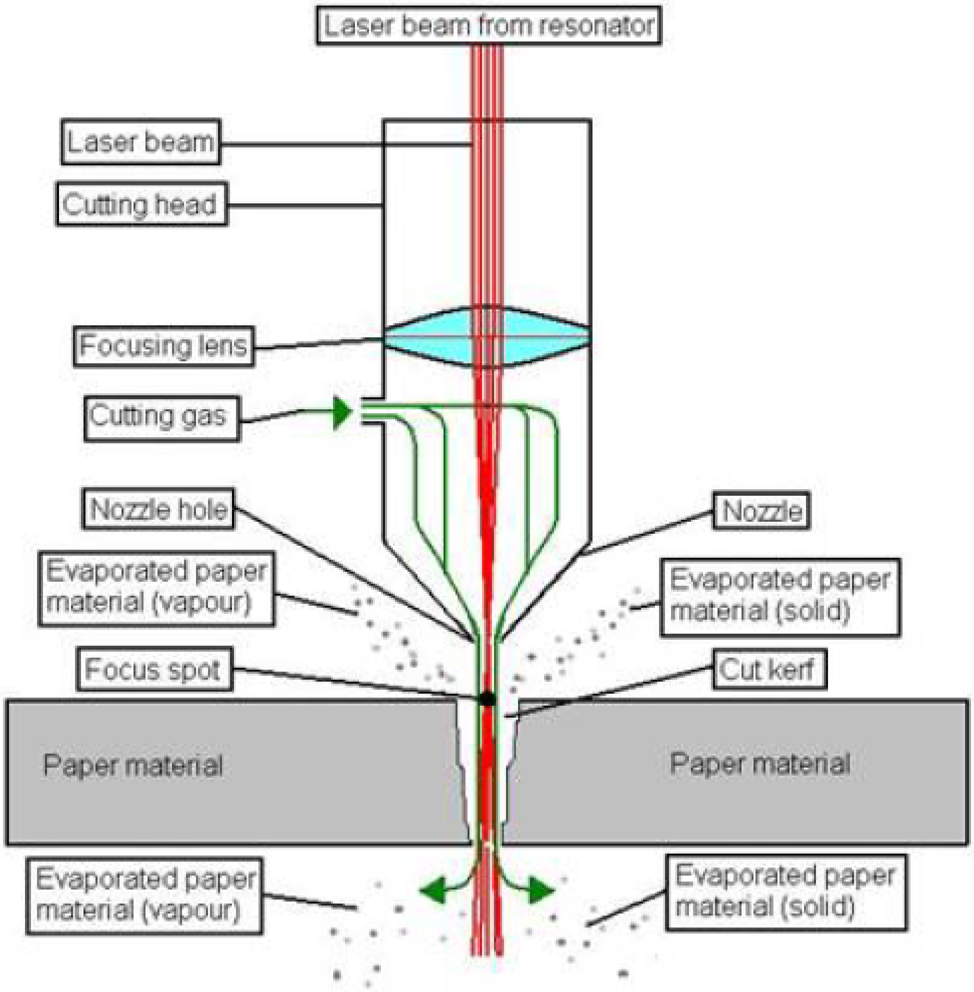

Figure 6. Basic principle of laser cutting of paper materials (Piili, 2007, p.31)

The cutting mechanism in laser cutting of paper materials is vaporisation cutting. This mechanism means a cutting method where the laser beam heats up the material top surface to evaporation point or to a point where chemical degradation happens. The physical phase change in vaporisation cutting is from solid to vapour. It is possible to use an inert cutting gas, like nitrogen or argon, to prevent combustion of vaporised material and to protect the focusing lens from dirt. Physical change from solid to vapour occurs through chemical degradation with paper materials. Most of the laser power is used to break chemical bonds of material and when paper materials are cut with laser beam, chemical degradation means breaking of long-chained cellulose molecules to carbon and water vapour.

(Piili, 2007, p.32) Because the cutting process is fast and oxidation is incomplete all intermediate oxidation forms can be found. (Miikki, 2008)

While there are several cutting needs in the papermaking process, also laser cutting of fibre material consists of several application possibilities. Laser cutting of uncoated and coated paper materials can be done successfully and laser cutting is claimed not to have any effect to printability properties of them. Also printed paper and board can be cut with a laser beam and cutting quality is stated to be very good. Laser cutting technology can be also combined with digital printers. It could provide also as on-line cutter flexibility to the whole printing process. A change in cutting pattern is only question of programming and no new cutting tool is needed. In Figure 7 laser cut paper edge is compared with mechanically cut edge. (Piili, 2007, p.33)

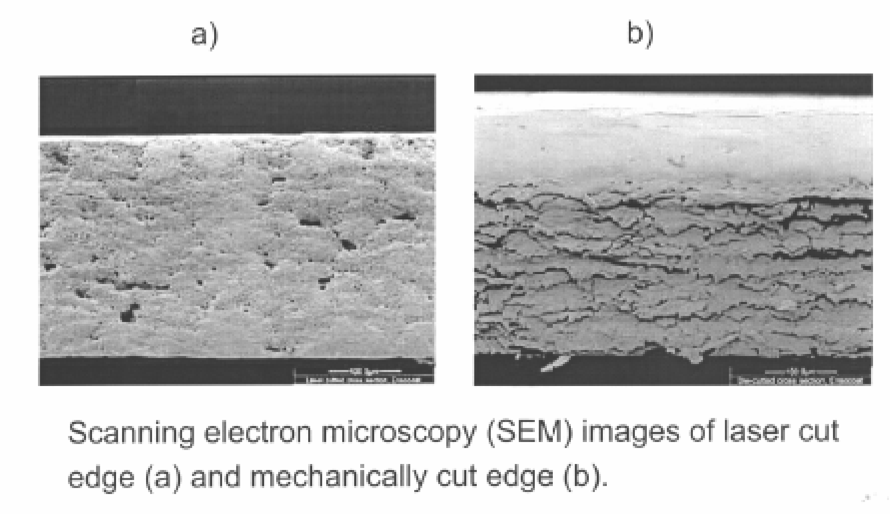

Figure 7. Appearance of laser cut edge and mechanically cut edge (Piili, 2007, p.36)

When comparing laser cutting and conventional mechanical cutting methods there are several differences: (Piili, 2007, p. 35)

- laser cutting is a flexible cutting method. When geometry of cutting pattern is changed there is no need to change the tool; it is only question about programming
- Laser cutting is a contact-free method; there is no tool to be worn

- Mechanical cutting causes lots of dust. With laser cutting this dusting can be in much more minor scale depending on the material properties.
- With laser cutting material loss can be reduced, when cut blanks can be positioned so that material loss is slight
- With laser cutting also very complex geometries can be cut fast

1.10 Description of joining methods for the paperboard and plastic film

There are requirements for seals in packages. Generally, seals must be strong enough to hold the load so it can't be the weakest link in package. Seams can be either fin seals or lap seals. Strength of the package seals is important in providing durability to the packaged product during distribution. The role of package sealing in product protection is extremely important, for example a high barrier material is of a little value without a continuous seal. (Kuusipalo, 2007, p.1)

1.10.1 Lamination

In lamination resin is melted and formed into thin hot film, which is coated onto a moving, flat substrate such as paper, paperboard, metal foil, or plastic film. The coated substrate then passes between a set of counter-rotating rolls, which press the coating onto the substrate to ensure complete contact and adhesion. (Kuusipalo, 2007, p. 23)

1.10.2 Gluing

When choosing the right kind of glue for package, there are several things to take into account, for example, product, packaging material, temperature, humidity, cleanliness, equipment and line speeds. Generally starch based, dextrin, casein or synthetic polymers are used, because they are water-soluble, harmless and approved for food contact. They are so called cold/dispersion glues and can be used at room temperatures. Often optimal results need a few days drying of the glues. (Kuusipalo, 2007, p.17)

1.10.3 Hot melt

Hot melt adhesives are solids at room temperature and are activated upon heating above their softening point. (Lahtinen et al., p.5) Hot melts, applied in molten form, contain thermoplastics, waxes and modifiers. (Kuusipalo, 2007, p.17) Generally it can be said that polymers give cohesion, modifiers adhesion and waxes appropriate rheology. Hot melts can contain different kinds of polymers, but the most common one is EVA polymer. Because it is a polar substance, it has good specific adhesion. (Uggla et al., 1981, p.4)

Hot melt adhesive creates a strong, rigid bond. The strength of a hot melt seal depends on mechanical stresses, temperature, relative humidity, cohesion and adhesion. Most typically seals fail when the adhesion between two surfaces fails. It could be the case especially if the two glued surfaces are made of different materials. (Uggla et al., 1981, p.4) Hot melt adhesive systems are also easy to apply, low in cost and possess short setting time in the bonding process. (Lahtinen et al., p.5)

They are suitable for fast gluing processes and for dense (surface) packaging materials, e.g. frozen food. (Kuusipalo, 2007, p.17)

1.10.4 Heat sealing

Heat sealing combines two thermoplastic surfaces using heat and pressure for a specific time. In Figure 8 the principle of heat sealing is demonstrated. When heat is applied to the plastic surfaces, crystallines start to melt and when the temperatures of both plastics are at same level, materials become amorphous. After that, with the help of pressure and time, gradual interdiffusion occurs so molecules are able to entangle with each other. By cooling the material a firm bond can be formed. (Kuusipalo, 2007, p.1)

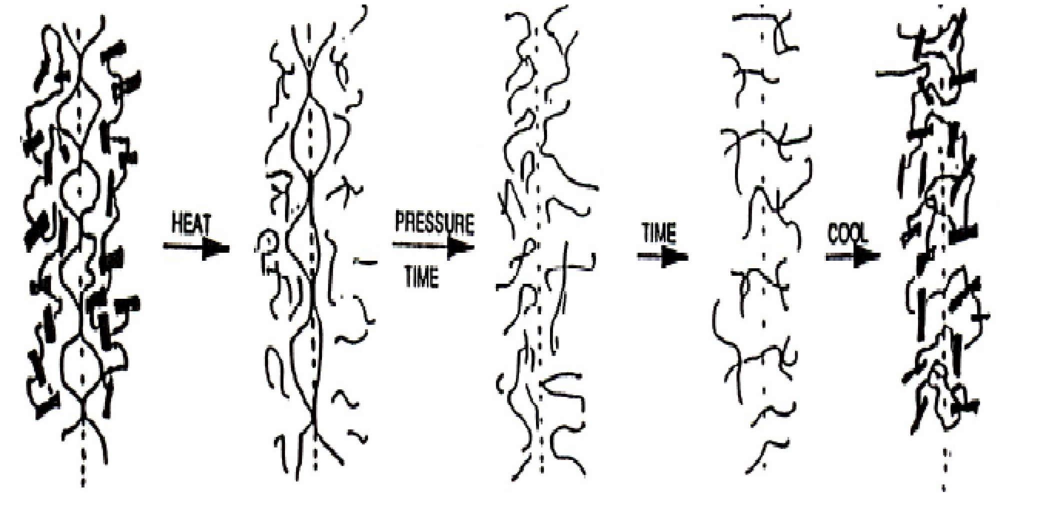

Figure 8. Principle of heat sealing. (Kuusipalo, 2007, p.3)

The most important properties of heat sealing are heat seal strength, hot tack strength, heat sealing range and seal initiation temperature. Heat seal strength is the force required to separate the seal perpendicular to its long axis and it can be measured by tensile strength test. Hot tack is the resistance to separation of a seal immediately after removal of the pressure and temperature of sealing. Usually it is lower than heat seal strength. Heat sealing range is a range of temperatures/pressures/dwell times in which effective seals can be obtained. The seal initiation temperature is at the bottom of the range; the top is the highest temperature at which a satisfactory seal can be obtained without deterioration of the seal or the structure. (Kuusipalo, 2007, p.5-10)

1.10.5. Ultrasonic sealing

In ultrasonic sealing acoustic vibration causes mechanical wave motion and this oscillation results in friction between the particles which generates heat. (Määttä, 2003, p. 2) It is transferred to the seal surfaces with desired frequency, amplitude and power. This method affects only the surfaces and it is very suitable for example for oriented plastics. It is also applicable for thick materials, when it is difficult or even impossible to conduct heat through the whole material to the sealed surfaces and for contaminated surfaces, because the ultrasonic breaks the particles to smaller pieces, thus the sealing is easier. (Kuusipalo, 2007, p.36)

1.10.6. Laser welding

With the help of a laser beam, two plastic surfaces can be joined together tightly. This process is called laser welding. There laser beam provides the concentrated heat source, allowing narrow, deep welds and high welding rates. Laser beam welding has high power density resulting in small heat-affected zones and high heating and cooling rates. Laser welding is usually more expensive compared to normal welding, but its accuracy, speed, low heat imput and uniform quality of the final welds make the laser welding competitive solution in welding two pieces together. (Huttunen, 2008)

1.11 Recycling and recovery of fibre based packaging material

Legislation has set demands for different packaging materials concerning recycling and reuse. Recycling and reuse possibilities vary between countries. In Finland firms are required to take responsibility for the packaging they have placed on the domestic market in accordance with legislation and Finland's targets confirmed with the EU. The aim of the legislation is to reduce the quantity of packaging waste and at the same time increase the reuse of packaging and recover the waste that has been generated. The Waste Act imposes the obligation to attend the recovery of packaging on every producer or firm with a turnover of 1 million EUR or more that places packaging on the Finnish market together with its products. In addition, the companies have obligations to provide information and report on matters concerning recovery. The obligations of the directive 94/62/EC on packaging and packaging waste have been implemented as a part of national legislation by the Council of State decision no.962/1997 on packaging and packaging waste. (PYR Ltd, 2007)

In many applications food packaging boards are polymer-coated. The trim and scrap from the manufacture of polymer-coated such as paper cups, milk cartons and other containers are routinely recycled. After use articles and containers can be collected and recycled separately or together with other paper and board products. Collected fibrous material is a good fibre source for non-food products. (Harju-Eloranta, 2007) According to Table 1 the recycling of fibre based packaging in Finland is increased over 20% in less than ten years. (PYR Ltd., 2007)

Table 1. Recycling of packaging waste in Finland (PYR Ltd., 2007)

YEAR	TOTAL	FIBRE	GLASS	METAL	PLASTICS	WOOD
1998	45 %	57 %	62 %	16 %	10 %	
1999	50 %	61 %	78 %	19 %	13 %	
2000	50 %	62 %	64 %	25 %	14 %	
2001	47 %	58 %	50 %	39 %	15 %	
2002	49 %	61 %	50 %	46 %	15 %	
2003	41 %	63 %	61 %	50 %	14 %	7 %
2004	40 %	70 %	55 %	55 %	15 %	7 %
2005	43 %	79 %	63 %	54 %	14 %	5 %

In Finland more packaging is used when compared with Europe, but over 2/3 of the packaging is reusable and it is reused in existing systems. Here more than 2 200 000 million tonnes of packaging is used annually, but only 648 000 tonnes packaging waste is produced including the wood materials. According to Table 2 packaging recovery percentages are very high in Finland. (PYR Ltd., 2007)

Table 2. Recovery of packaging material (recycling + use as energy) in Finland (PYR Ltd., 2007)

YEAR	TOTAL	FIBRE	GLASS	METAL	PLASTICS	WOOD
1998	56 %	72 %	62 %	16 %	20 %	
1999	60 %	72 %	78 %	19 %	30 %	
2000	60 %	72 %	64 %	25 %	36 %	
2001	62 %	74 %	50 %	39 %	44 %	
2002	61 %	75 %	50 %	46 %	38 %	
2003	67 %	72 %	61 %	50 %	37 %	84 %
2004	68 %	77 %	58 %	55 %	34 %	78 %
2005	68 %	88 %	65 %	54 %	15 %	76 %

1.11.1 Possible limitations (DSD payments)

If fibre based package has a plastic window, there are limitations in some European countries for plastics concerning the recovery which should be taken into consideration. Since the German Packaging Ordinance came into force in 1991, the principle of producer responsibility has applied in Germany: once packages have served their purpose, manufacturers and vendors have to take them back, arrange for eco-friendly recovery, and finally document the entire procedures involved. These duties are assumed by Duales System Deutschland GmbH for all responsible parties in the sales chain – from the packaging material manufacturer and the filler to the actual retailer: (Duales System Deuchland, 2008)

- For industrially filled packages, the fillers, as the producers of the consumer goods ultimately available in the retail outlets, will usually be responsible.

- For service packages like carrier bags, paper bags, wrapping films and disposable cups/plates, etc., which are only filled in the shop itself, responsibility will usually be vested in the retailers involved.
- For imported goods, the responsibility can be vested in both the German importer and the exporter, if the latter is domiciled inside the European Economic Area.

By paying what is called a licence fee, a company responsible for the product, acquire the right to use the Green Dot on their packages, and in return are exempted from their statutory obligations to take them back and recycle them, and document the procedures involved. (Duales System Deuchland, 2008)

If more that 95% by weight of the primary packaging, the secondary packaging or a further packaging level consist of one main material, the total weight of the respective packaging level may be calculated at the price for the main material. According to Table 3 board material coated with polyethylene on one side containing less that 5% plastic, is considered as monomaterial and licence fee is 17.5 cent/kg (G.2, Paper/board/cardboard). But if the board is coated with polyethylene on both sides containing more than 5% plastic, it is considered as composite with licence fee 101.4 cent/kg (G.7, Other composites). (Niininen, 2007, p.2-3)

Table 3. DSD fees valid from 1.1.2007, weight based prices (Niininen, 2007, p.2)

Material	Cent/kg	Category
Glass	7.4	G.1
Paper/ board/ cardboard	17.5	G.2
Tinplate	27.2	G.3
Aluminium, other metals	73.3	G.4
Plastic	129.6	G.5
Composite cartons (LPB) with special acceptance and recycling guarantee	75.2	G.6
Other composites	101.4	G.7
Natural materials	10.2	G.8

There is a possibility to get reductions to licence fees. There are mentioned two categories for reductions: package size and product group based reductions. If the cardboard/rigid board packaging size is more than 25 litres, the licence fee reduction is 30%. Also if the package is used among others, for medical products, washing powders, consumer electronics, the licence fee reduction is 12%-35%. However the licence fee reduction is not applied to food packaging. (Niininen, 2007, p. 4)

2. METHODS

2.1 Process steps for making a window to AT cup

The aim in the experimental part was to develop a paperboard cup with a plastic window where different kind of fatty/dry foodstuffs like grated cheese, snacks, candy and chocolate could be stored. The main target was to create an instruction manual how this kind of cup with a window has to be produced without decreasing air tightness and other barrier properties of cup material used as a base board. The focus in this work is on designing a shape of the window and finding critical limits for the size, shape and location of the window in the final paperboard cup.

2.1.1 Principle behind AT cups

Air tight AT cups are made of polymer coated paperboard Cupforma Classic Barr AT (PE30+250+42EB58) and their primary function is to protect the product packed inside from different kind of hazards. Cups have a barrier to prevent the product from contamination of moisture, oxygen, light and mechanical damage. To be able to guarantee these barrier properties the side seam of the cup is also protected. (Stora Enso, 2008, p. 3) Main foodstuffs which could be packed inside an AT cup are confectionary, chocolate, biscuits, snacks, breakfast products, dried fruits, pasta, cereals, flour and flakes, but also it could be used as PET coated for ready meals, soups and other ovenable or microwaveable applications. (Stora Enso, 2008, p.4-15)

2.1.2 Pre-tests

Pre-tests were conducted with cup blanks by cutting different kind of shapes into cup blanks. The size and the shape of the cutted area were changed and different locations were used. The target was to find out how the shape, the size and the place effected on the cup forming. Windows were cut to the blanks by using a sharp carpet knife. After cutting a certain size and shape window to a carton blank, the blank was bent to the shape of a cup and evaluated whether the cup will be round after cup machine. After those first pre-tests six window shapes were selected to further studies.

The window types for further studies were the following: circle, ellipse, square, rectangle, a star and customer shape which can be found in appendix 3, in Figure 32. These shapes were selected due to the fact that they are basic shapes. The aim for these second pre-tests was to limit the amount of different shapes and determine the critical sizes of each type of window. In addition critical places, where the windows coud be located, were evaluated. Also in these tests, after cutting a certain size window to a carton blank, the blank was bent to the shape of a cup and the window size was evaluated roughly by looking at the blank whether the cup would still be round after cup machine. After the second pre-test there was a rough idea where it would be best to place a window and how large it could be.

2.1.3 Window cutting

Out of six types of windows several different sizes were cut into the cup blanks and placed differently among each other. This was done because only in this way the final places could be located in the cup. Finally 41 test points were cut which each one of the test points contained 20 pieces of similar blanks. There were altogether 820 blanks and with this amount the runnability of the blanks could be tested at a cup machine.

Selected window forms and cup blanks were cut from the board sheets by using model cutter Zünd M-800 located at InnoCentre, Imatra. Before cutting all models had to be transformed into electrical format and for that Free Hand- software was used. That software showed the printable area and excluded the parts, which were needed for cup making process. Areas can be seen in Table 4. With the help of this information the places for windows in the cup blanks are easier to design.

Table 4. Areas needed for cupmaking process.

Areas needed for cup making process	
Seam area, right side (mm)	7.8
Bottom seam (mm)	8.4
Upper seam for rim roll (mm)	10.3

All 41 test points had to be reworked with the software into digital form. At the model cutter all window forms had to be saved into .dxf file format. Before cutting the model cutter had to be programmed for the tests. The model cutter needed certain parameters to be able to operate well. In Table 5 the parameters which were used in the model cutter are presented.

Table 5. Parameters used in model cutter.

Parameters for model cutter	
Used mode	1
number of steps per row x	1; 0 mm
number of steps per column y	4; 165 mm
Offset x	7 mm
Offset y	97 mm

Mode 1 was used for diecutting. Before actual cutting, the picture had to be formatted on the computer screen and right parameters had to be entered. First a few model cuttings were made just to see that the cutting blade was set into a right cutting depth. The blade had its own settings:

- Pen up position = Z-zero point – up position

In pen up mode the knife moved over the material at preset height.

- Up position = material thickness + 2 mm

Die cut

- Pen down position = Z-zero point

The knife was considered to be in a down position when it is as thick as the material or down to the upper edge of the cutting surface. In order to get a good cutting quality the knife must cut into the cutting surface. This cutting depth depends on the material and is adjusted with the Z-offset.

- Cutting depth = Z-zero point + offset

If the blade was not deep enough, the window cut was difficult to release from the cup blank and it caused material tears.

2.1.4 Attachment of the window material and plastic film used

The film which was used as a window material had a composition of LDPE-EVOH-LDPE and it had the following structure: LDPE 33µm/tie/EVOH 5µm/tie/LDPE 33 µm. Because LDPE is considered to be poor oxygen barrier, but fairly good moisture barrier, it could not be used alone in windows when manufacturing an air tight package. However it could be used in multilayer structures to give good heat sealability between the base board and window barrier material. It also cannot withstand grease very well. On the other hand EVOH is known to be an excellent barrier against grease and oxygen. Typically on both sides of the EVOH layer, there were PE-layers to prevent the humidity effects. The chosen film was ~ 71 µm thick and its basis weight was 63.5 gm^2. Its appearance was slightly opaque due to the presence of polyethylene.

Hot bar sealing

Hot bar sealing was used as one sealing method. The used equipment was a RDM Test Equipment HSE Heat Sealer. The settings of the hot bar sealing machine is given in Table 6.

Table 6. Parameters for hot bar sealing machine.

Parameters for hot bar sealing	
temperature of upper jaw	75-85°C
temperature of lower jaw	115°C
pressure	2.00 kN
dwell time	1 sec.

Laser seaming

Laser seaming was tested as one attachment possibility for window films. Seaming was made by using Linx 500 SL sealed carbon dioxide laser which can be seen in Figure 9. It has been developed mainly for coding purposes, but cutting and seaming can be made as well. It has an average power of 50 W and it can operate with power peaks of 100 W. It can be adjusted to tight places due to its mobile cabinet and articulated arm. (Linx Printing Technologies Ltd., 2006)

Figure 9. Linx 500 SL carbon dioxide laser.

Laser seaming was made by using the carbon dioxide laser at Stora Enso Reasearch Centre Imatra. The laser was air-cooled and operated under normal luminous flux. Compressed air was used to protect the lens. The operating area was 75 mm x 75 mm and the used spot size was 0.25 mm in focus.

First the suitable parameters for seaming had to be found. Parameters are unique and they vary depending on the materials which need to be seamed. There were three main parameters: focus point, energy and mark speed which had to be found on each seamed sample separately. Also before seaming for each geometry an own program had to be made. In the beginnig laser was set to make 10 lines per 5.5 mm, but depending on the seamed sample that could be changed with scaling. Scaling had to be used also because the differentiation in window sizes. In some cases sealable area had to be rotated to be able to get seams in correct places. Laser seaming was used to seal 15 test points out of 41 and the parameters used at each test point are given in appendix 2.

Ultrasonic sealing

Ultrasonic sealing was considered as one sealing option for plastic film and cupboard blanks. This was tested with a couple of samples but it was rejected right away due to the fact that the used sealing bars were unfit to the purpose of window sealing. The size of the sealing bars was either too big or too small and their shape was not suitable for this purpose. Another reason for rejection was that ultrasonic sealing left very clear marks on the printing side of the blank like a kind of embossing.

2.1.5 Cup manufacturing

Basically actual cup making process begins with printing which is possible to do as a sheet fed or as a roll fed. The principle of web fed cup making process can be seen below in Figure 10. (Kuikka, 2004, p. 56-57)

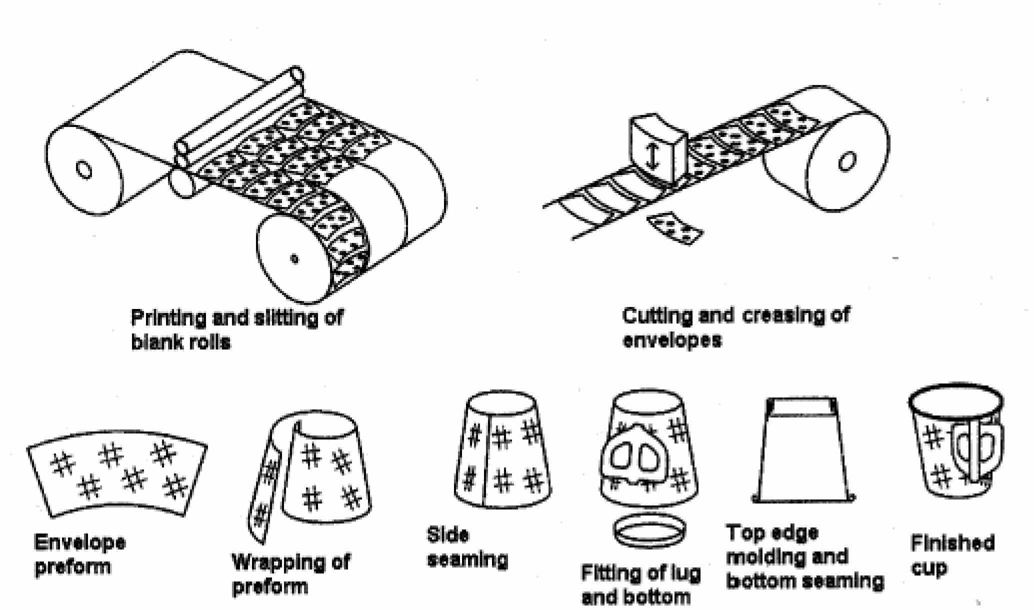

Figure 10. Web fed cup manufacturing process. (Seppälä 1999, 178.)

After printing the rolls are split into smaller rolls and cut and stamped into cup blanks. A cup blank is presented in Figure 11. (Kuikka, 2004, p. 56-57)

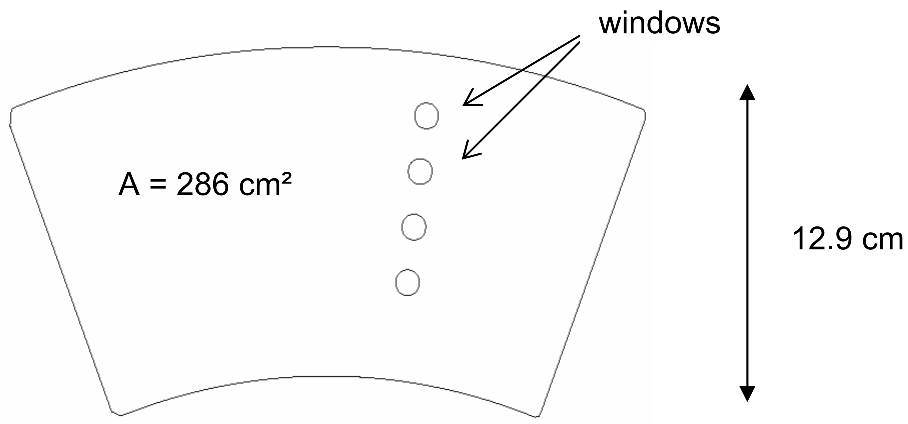

Figure 11. Board blank with windows for a paperboard cup. (Image by Kimmo Väliviita)

Some cup making machines are roll fed and there the cutting and stamping is done directly at cup machine. In a cup making process the cup blank is wrapped round the mandrel and the side seam is made. The bottom of the cup and possible lug is then fitted and seamed. Finally, the top edge is moulded to a so called rim roll. After the product is packed into a cup, it can be closed with a lid. (Kuikka, 2004, p. 56-57)

There is one raw edge in the cup and the end use of the cup determines whether the edge should be protected or not. The raw edge is located at side of the cup where it is seamed. The raw edge is very porous and when the cup has to function as a good gas barrier, the raw edge has to be protected. There are two ways of protect it: by skiving or by using the plastic film. In cup manufacturing process, the leak levels of the cups are the most critical properties which affect the content if the product packed demand high gas barrier. (Kuikka, 2004, p. 56-57)

The cup machine at InnoCentre is a Hörauf BMP 200 cup machine and it is a machine for the production of round paper cups. According to supplier's information the machine's capacity is 160-200 cups per minute. It is a model 2003 and it has tape asembling equipment as a possibility for the raw edge protection. (Stora Enso, 2008) The cup machine is mainly used for manufacturing paperboard cups as drinking cups or as air tight cups.

Before the run, the correct sizes of tools have to be selected and in this work only 12 oz tools were used. When manufacturing cups with a window, the cup machine worked according to the following principle: feeder fed the blanks into the cup machine and blanks moved inside the machine with different suctions or by the aid of suction cups. First the side seam was heat sealed with hot air blower and then the blank continued to bottom fitting where first the right size of bottom was cut with a die cutter. The bottom was attached to the blank again by using hot air blower and a small amount of white oil was used to give needed lubrication. When the bottom of the cup was in place, the rim roll was made and the white oil was used as lubricant. The used pressure was also very important when rim roll was made and with the help of appropriate tooling and a small amount of heat, rim roll could be successfully made. After that a ready cup was ejected from the machine. When manufacturing cups with plastic windows the capacity of the machine was 110 cups per minute in this production run, temperatures in hot air blower making the side seam was 390°C and in bottom fitting 340°C.

2.2 Testing methods for final cups with windows

2.2.1 Grip stiffness

Grip stiffness was tested on the final cups because it was important to know whether the window or windows in the cup had any influence on cup's grip stiffnesses. Also the aim was to find out if the place and the size of the window had any effect on grip stiffness of the cup.

Grip stiffness was measured using Alwetron TCT 5 equipment shown in Figure 12. In the beginning the cups to be tested were conditioned for about 30 minutes and after that cups were marked with the line which was located about one third from the rim roll (3.7 cm). This place was chosen to be the best place for the measurement because it is usually the place where people take the grip of the cup. Before actual measurements an appropriate mould had to be chosen according to cup size and the cup was placed into the mould with the side seam downwards. The cup was also supported from above to be sure it didn't move during measurement. There was a 500 N testing bar above of the cup which was pressed against the line drawn into a cup. In actual measurement the following parameters were used:

- program: Matertest
- maximum stretch: 5 mm
- speed: 0.17 mm/sec

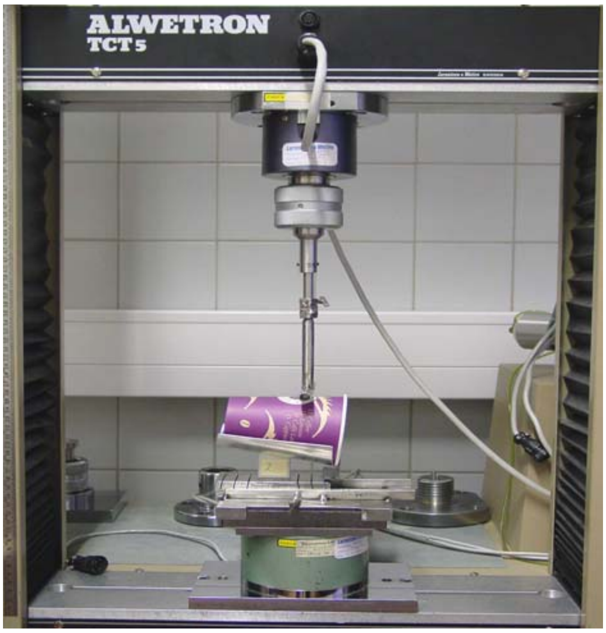

Figure 12. Grip stiffness test arrangement.

The final result was given in unit Newton (N).

2.2.2 Liquid tightness of the window seams

Liquid tightness of window seams between the carton blank and the plastic window were tested by using the 0.2% Tween20 solution. The aim for using Tween20 solution for this test was to be able to lower the surface tension so that liquid could penetrate into the raw edges and all weaknesses in window seam tightness could be observed. The testing method is not based on any standard and the testing solution was a composition of Tween20 solution, water and Amaranth colour. With the help of it the liquid tightness of the window seams could be determined, because there was no raw edge tape used in the cups with windows. The actual test was made so that test solution, which was stored at room temperature, was poured into the cups and and after ten minutes test solution was poured away and the cup was washed. Penetration could be clearly detected in the samples and the places where the seams leaked.

2.2.3 Light transmission

Light transmission of the window and the cup materials was measured with UV-Vis spectrophotometer at wavelength 200-900 nm. The equipment used was a Varian Cary100 Conc with DRA CA-301 spectrophotometer with an integrating sphere at the transmission port. The sample size was about 7 cm x 7 cm and the results were given as transmission %.

2.2.4 Bursting strength of the window material

Bursting strength of the plastic film used in cup windows was measured by using a method which utilises standards ISO 2758 and ISO 2759. In the test, a test piece is placed over a circular elastic diaphragm where it is rigidly clamped but still free to bulge with the diaphragm. Hydraulic fluid is pumped at a constant rate bulging the diaphragm until the test piece ruptures. The bursting strength of the test piece is the maximum value of the applied hydraulic pressure. The results were given in unit kilopascal (kPa).

2.2.5 Moisture permeability

Water vapour transmission rate of the window and cup materials was measured with Mocon Permantran W3/31. Measurement complies with standards ASTM F-1249, TAPPI T557 and JIS K-7129. The amount of transmitted water vapour was measured for the area of the sample and it could be measured at different temperature and humidity conditions. Water vapour transmission of the used materials was measured so that the materials were put inside the equipment were they were conditioned in the conditioning chamber. Conditioning chamber could be adjusted to the wanted temperature and humidity conditions. Determination range was 0.005-1000 g/m²/day when the carrier gas flow was 10 ml/min. Sample size can be five or 50 cm² and results are given in unit g/m²/day.

2.2.6 Oxygen permeability

Oxygen transmission rate of the window and cup materials were measured with the Mocon Ox-Tran 2/20. Measurement complies with standards ASTM D- 3985, ASTM F-1927, DIN 53380, JIS K-7126, ASTM F-1307 and ISO CD 15105-2. Amount of transmitted oxygen, which concentration was 100%, was measured for the area of the sample. Sample size can be five or 50 cm² and results are given in unit cm^3/m²/day.

3. RESULTS, ANALYSIS AND DISCUSSION

Results, analysis and discussion of the experimental part consist of results from pre-tests, window sealing and cup manufacturing.

3.1 Pre-tests

Critical limits and shapes for the windows were determined based on the pre-tests. It was already noticed after pre-tests that big star shapes were the most critical ones of selected window forms because of the sharp edges. When cupboard blank was folded those sharp edges inside the window didn’t curve with the blank but stayed in their original shape. Outer spikes however did curve with the blank. The big customer shape windows were also quite critical because the inner part had tendency to stay in its original place and not curve with the blank.

According to pre-tests could be stated that all windows which situated along the main fibre direction of the board weakened the cup structure more than windows cut more in cross direction.

3.2 Window sealing

Hot bar sealing

In hot bar sealing dwell time had a significant effect on the sealing result. In this case, one second gave the best results – plastic film sealed with the blank and didn't melt the film too much. It has to be noticed that this is valid only in laboratory scale tests. If the dwell time was above two seconds it could be noticed on the film that it had melted too much and its outlook had changed from opaque to "grain" and unclear. In that case hot bars left clear marks of melting PE into blanks outside the film area as well. If the dwell time was below one second, the used film didn't have enough time to attach to the cup blank. Despite one second seemed to be a proper dwell time for the film to attach to the blank, the appearance of the film suffered also in the area of the window. This was due to the used sealing bar because it was hot all over and the temperature set on the bar transferred on the whole bar length into the film and the blank and window holes included. That's why could melting be observed in window area as well.

Some curling of the sealed blanks occurred also in hot bar sealing. Curling was very strong especially in those test points were the size of the window was quite big and the window was located near the sides of the blank. Curling was discovered to be stronger if the temperature difference between the sealing bars was big. In Figure 13 an example of blank is illustrated.

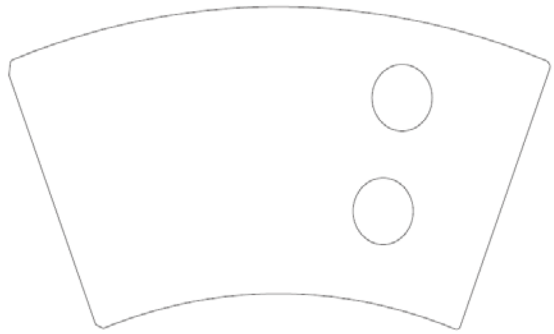

Figure 13. Example of the sample which curled very heavily in hot bar sealing.

Laser seaming

The air gap between the blank and plastic film seemed to cause the biggest problems in laser seaming. Used jigs had to be sculptured so that they could be used with different geometries. Due to that in smaller geometries plastic film tended to leave the crease and because of that different kind of ways had to be utilised how to remove those creases before seaming. Also used parameters had to be changed for the each geometry. Selected parameters could suit well for one kind of geometry but for the other the same parameters could cause a very different situation. It was also very important how the order was determined according to which the laser run the beam and the turning and stopping points of the beam was set. Difficulties were caused also by setting the sealable blank into a jig so that the laser beam performed the seal in right place and if it was not done successfully, this resulted to holes in the film. If the laser beam was programmed to wipe over the window area, there could be seen melting marks in the windows just like in hot bar sealing.

3.3 Cup manufacturing

After sealing the window film in place, blanks were tested in actual cup machine. The aim was to evaluate how these blanks behaved in real cup manufacturing process and which of the window shapes did work or didn't work and why. There were alltogether 820 blanks prepared for this cup manufacturing phase to get information about runnability of the machine considering the place and size of the window. One question of interest was also to find out whether the seaming method had any role how windows formed in the final cup or if it had any effect on machine runnability. Detailed information concerning each test point can be found on appendixes 3, 4 and 5.

Cups were classified regarding their runnability and final outlook into three categories: acceptable cups, problematic cups and unacceptable cups. This classification doesn't take into account the possible defects caused by seaming i.e. hot bar seaming marks or laser seaming marks in the window film.

Acceptable cups

Pictures of cups which run well at cup machine can be seen in Figure 14. Cups were formed nicely and the outlook of the windows was acceptable. However, there was found some hot bar or laser seaming marks in the windows depending on the seaming method used and small wrinkling in rim roll. In addition small wrinkling could be observed in some windows.

In acceptable cups windows had shapes of rectangles and circles but there were also one star, one ellipse and one customer shape. Windows were located either between 2.9 cm to 7.6 cm left from the side seam or between 2.6 cm to 7.5 cm right from the side seam. In these cups windows were placed between 1.1 cm to 9.3 cm down from the rim roll. Total window areas changed between 1.13 cm^2 and 10.5 cm^2.

More detailed information of each cup can be found on appendix 3.

Figure 14. Acceptable cups after cup machine.

Problematic cups

Besides the acceptable cups there were a few cups which run quite well at the cup machine, but the outlook of the cups were not acceptable. Pictures of these cups can be seen in Figure 15. Some windows were wrinkled badly because they were located right in the place of a suction cup and some windows were placed so near the rim roll that the structure of the cup suffered.

With the problematic cups windows had shapes of squares, rectangles and circles. Windows located either between 2.0 cm to 10.9 cm left from the side seam or between 3.5 cm to 9.8 cm right from the side seam. In these cups windows were placed between 0.5 cm to 9.8 cm down from the rim roll. Total window areas changed between 5.0 cm^2 and 12.5 cm^2.

Detailed information can be found on each cup separately in appendix 4.

Figure 15. Problematic cups at cup machine.

Unacceptable cups

There were also test points which didn't work at cup machine at all. Pictures of such cups can be seen in Figure 16. There were five cup types which passed as whole cups through the machine but however they were quite badly damaged.

Figure 16. Some examples of unacceptable cups after cup machine.

Windows, which were located at the middle of the blank, no matter of the size or shape, didn’t work at all in the cup machine and they were jammed right from the start. When such blanks were fed into the machine, windows seemed to be located in the place were feeder sucked the blanks and sthe ealing had made that point a bit thicker causing difficulties in runnability. Also blanks which contained big windows were stuck at the feeder. Examples of such blanks are in Figure 17.

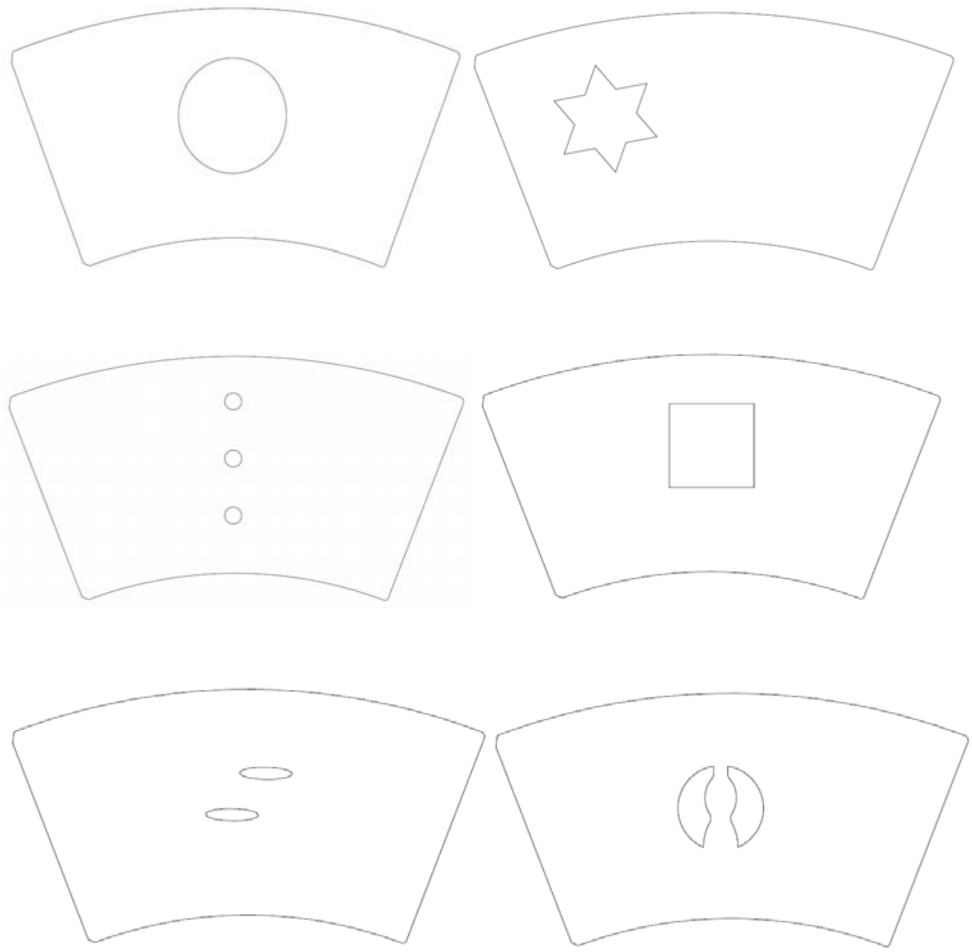

Figure 17. Windows located in the middle of the blank or which were big in size didn't run at all.

Detailed information can be found on each cup separately in appendix 5.

Area of the window

The area of a cupboard blank surface was calculated and in this 350 ml cup size the area was 286 cm². This was calculated because it was important to know how big window could be cut into that size of a cup without any forming problems or structure failures. This was determined on each of the window model separately.

Total area of 12.5 cm^2 was the size of the biggest windows in 350 ml cup which could successfully be made and run without any disturbances at cup machine. This is 4.4% of the whole cup blank area. If the hole for the window(s) was bigger than this it caused runnability problems. However this is hard to say for sure whether bigger windows could not be run at the machine due to the fact that plastic film sealed on the cup blank increased blank's thickness and this caused the situation that blanks caught into the feeder causing a jam in the very beginning. This was observed very clearly with those test points where the window(s) was in the middle of the blank.

Place of the window

If the window was located less than 1.2 cm away from the rim roll, there were problems with rim roll forming. The nearer the window was to the rim roll the more severe were the problems. In those cases cups didn't look good outside. Windows which located further from rim roll had also difficulties in rim roll forming, because a very few rim rolls looked very good after finishing. It seems that it was due to excessively vertical pressure which was directed at cup blank and because of the window vertical structure of the cup was weakened.

In cupboard blanks there are certain areas which need to be left untouched because otherwise cup suffers. There are also areas which needed to be left for the bottom making, side seaming and rim roll forming. In Figure 18 these areas are marked with different colours: blue areas are needed for bottom, side seam and rim roll, green areas are those where windows could situate without runnability problem at cup machine and red areas are those where windows caused immediately problems at cup machine.

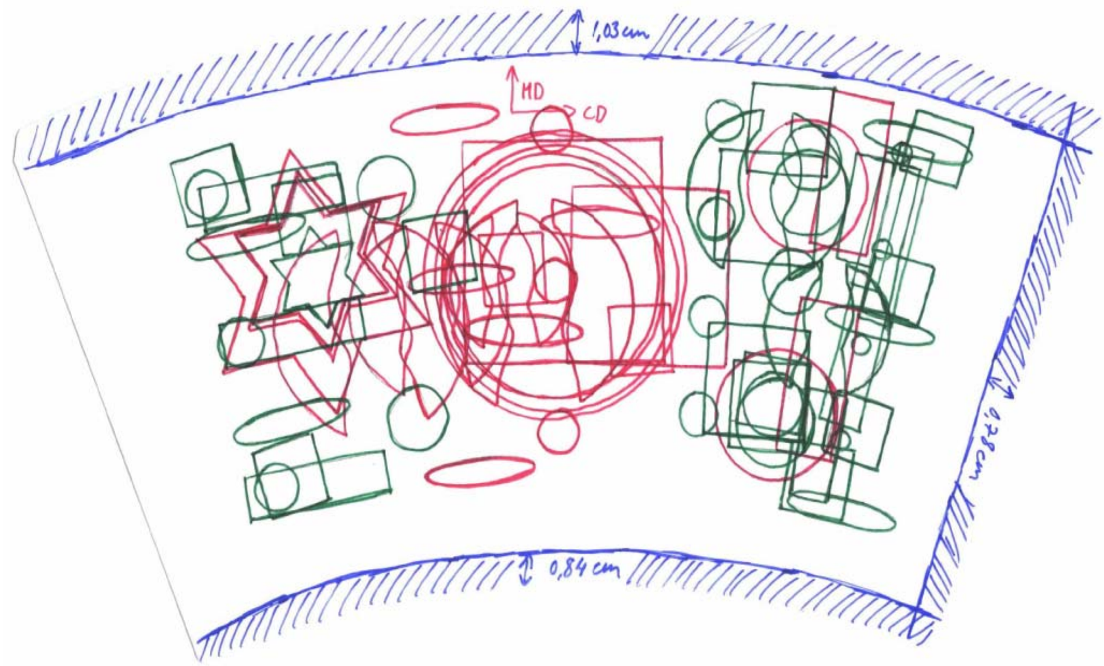

Figure 18. Map of the suitable and unsuitable places of windows. Blue areas are needed for bottom, side seam and rim roll, green areas are suitable areas for windows and red areas are areas where windows cannot be placed without problems at cup machine.

It could also be observed that the worst place for the window was in the middle of the blank and the best places were the areas near blank sides. However, in side areas big windows caused runnability problems by jamming the feeder. Smaller windows run without any problems. Also it could be noticed that there were a few windows placed quite near the rim roll area. In those cases blanks could be run at the cup machine without any problems, but the appearance of final cups might not be very good due to problems in rim roll forming or structure failures.

This Masters of Thesis can be applied directly to the cup machine at Stora Enso InnoCentre, Imatra, but because of the fact that every cup machine is unique, these results cannot be applied as such to other cup machines. Some hints can be drawn.

Amount of the windows

Based on the test runs it can be said that cup blanks will withstand better with windows, if there are two or more of them in the same blank and they are not in same line with each other. It is also better to have two separate smaller windows than one big window due to the structural weakening.

3.4 Results of laboratory tests

Grip stiffness

Grip stiffnesses were measured of the cups with plastic windows. The aim for these tests was to evaluate whether the window would weaken the grip stiffness when compared to solid cups. Only such cups were measured which had good rim rolls and in this way results can be compared with each other. Results per each test item can be found in Figure 19.

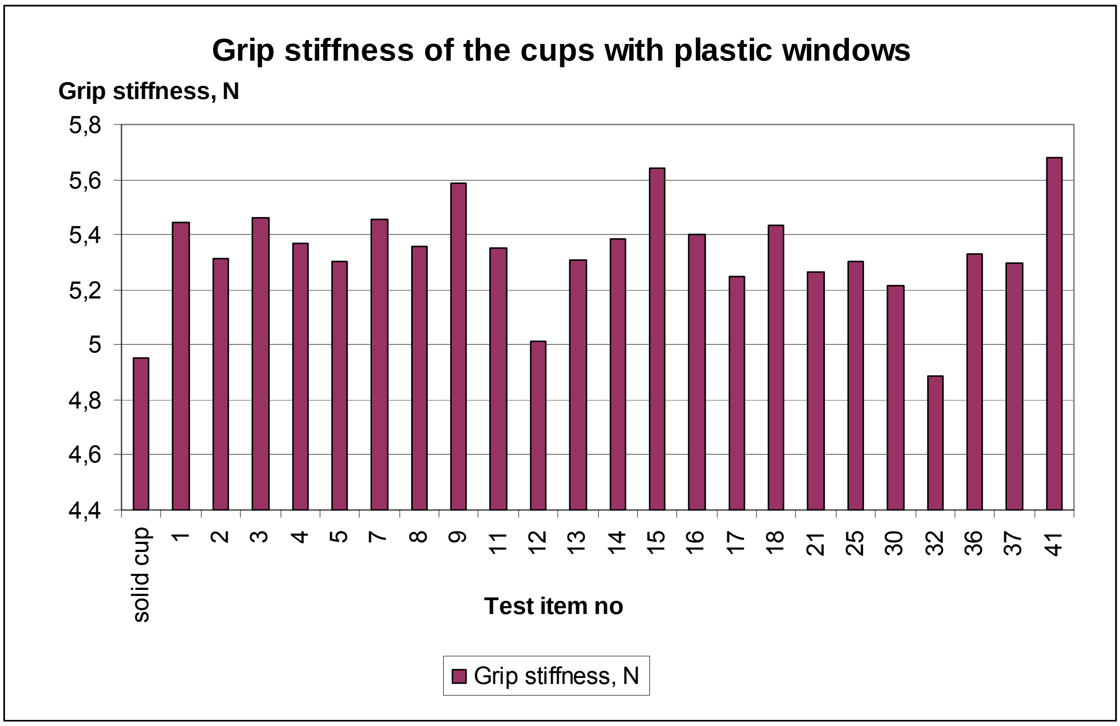

Figure 19. Grip stiffness results per test item.

Detailed results of these analyses can be seen on the appendix 7.

According to the results there were not significant differences between solid cup and cups with windows. Differences between cups were very small and they have no significant importance regarding the final application. The following test items were categorized as acceptable cups: 3,4,5,8,11,14,15,16,18,25,36 and 41, as problematic cups: 1,2,7,9,13,17,32 and 37 and as unacceptable cups: 2,12,30,32 and 40 which couldn't even be measured.

Grip stiffness of the cups was also compared with the size of the windows. This was done in order to know whether the size of the window has any impact on grip stiffness of the final cup. Results can be found in Figure 20.

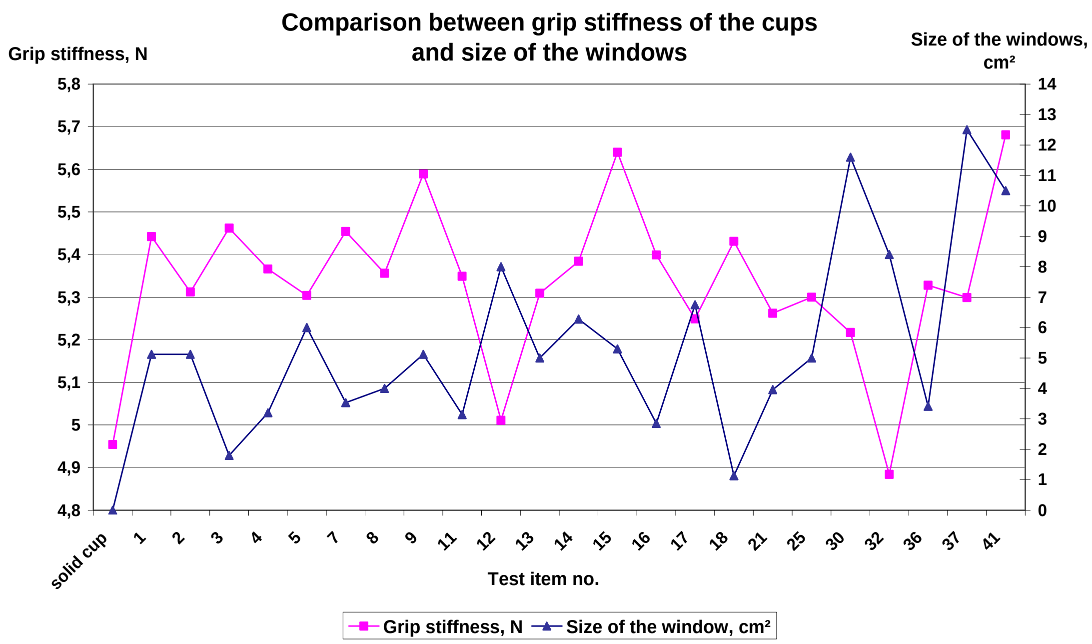

Figure 20. Comparison between grip stiffness and size of the window.

Based on the results in Figure 20 it can be said that of all succeeded cups grip stiffness was the lowest in such test item which had the biggest window. But in opposite, the cups which had smallest windows or no window at all didn't however have the best grip stiffnesses. Because the diffrerences between grip stiffnesses of cups were so small it can be stated that size of the window doesn't have any impact on the grip stiffness.

Bursting strength

Materials were tested independently how they can withstand pressure before bursting. There were two different samples tested: a cupboard blank and a film used as a window film material. Results can be found in Table 7.

Table 7. Bursting strengths and –indexes of the cupboard and film materials.

	Bursting strength, kPa	**Bursting index, $kPam^2/g$**
Cupboard material	56.5	3.21
Film material	5.8	2.17

According to the results plain cupboard blank is able to withstand pressure over nine times more than a film used. More detailed information can be found in appendix 6.

As a result it is clear that plastic film in the window is the weakest link when subjected to pressure. This same effect was noticed also at the cup machine where the blank with a plastic window was moved with the help of suction cups. If the suction cup was placed right above the window it bursts causing runnability problems at the machine or bad outlook for the window.

Tightness of the cups

Liquid tightness

Liquid tightness of the seams was tested from three cups per each test point. Cups which were sealed with hot bar sealer, withstood test liquid very well and window seams were liquid tight. On the other hand cups with laser seams were the ones which had great difficulties in liquid tightness and only one test point where laser seaming was used withstood testing liquid in the same way than hot bar sealed cups. All other laser sealed test points failed in the test right at the beginning or after a few minutes. Detailed results of these analyses are found in the appendix 8.

The main reason why the window films sealed with laser were not tight was because there was air remaining between the cup blank and plastic film. Laser beam is very sensitive with the air gap and this can be seen on the results. Also all parameters have to be right considering the sealable materials. Geometry have to be drawn for laser by taking into consideration the geometry of sealable area, in which order the laser beam seals that particular geometry and effect of chosen parameters in stopping and turning points. In Figure 21 the window seams after hot bar sealing and laser sealing can be seen.

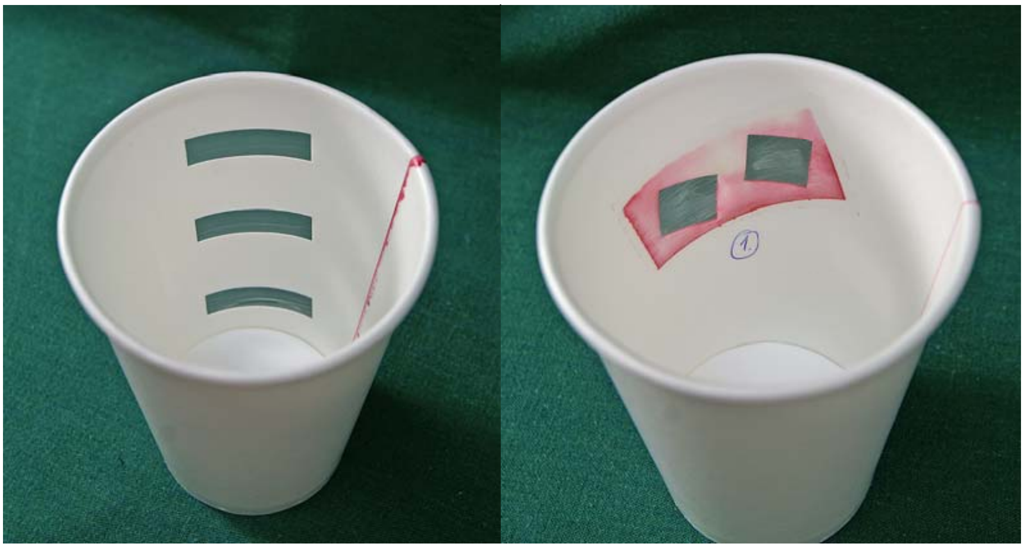

Figure 21. On the left hot bar sealed cup with liquid tight seams and on the right laser seamed cup with leaky seams. Liquid tightness was tested by using 0.2% Tween20 solution in temperature of 23°C for ten minutes.

<u>Light tightness</u>

Light transmission was measured through solid cup material and plastic film used as window material. Results can be found in Figure 22. Based on those measurements it can be said that regarding visible light wavelengths (400-700 nm) solid cup material transmits light between 3.2-9.3% and plastic film 75-

76.5%. In UV-light wavelengths both materials start to transmit light and especially in UV-C area (200-280 nm) light protection properties of film material decrease at increasing speed.

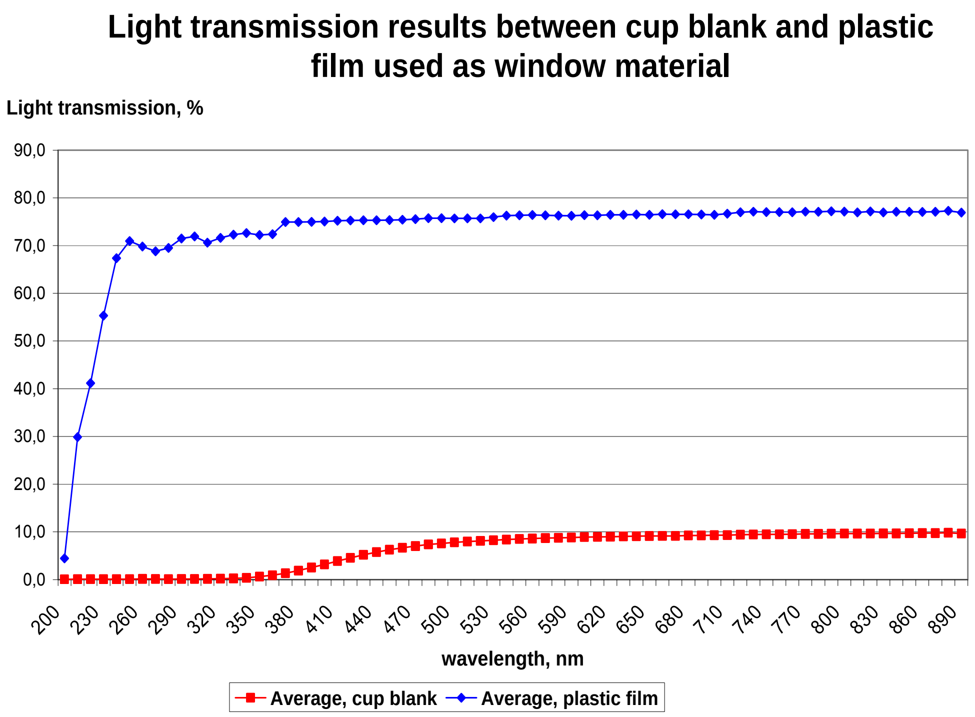

Figure 22. Light transmission results at a cup blank and a plastic film used as window material measured with integrated sphere.

According to the results above, it can be stated that cup material gives much better light protection to the foodstuff when compared to the plastic film used as window material. The bigger the window in cup is, the more light can be transmitted through the window and the easier the food packed inside the cup starts to deteriorate.

It is a common knowledge that light and oxygen are bad for the foodstuff packed. It causes different kinds of changes in the product quality and reduces shelf life remarkably. In food stores attention should be paid a lot to location of foodstuffs considering lighting and what kind of packages are used. Lighting rises the temperature of foodstuffs when placed near the light source and light intensity causes other quality changes. In addition, the packaging manufacturer has to know the demands of the food packed to be able to use right kind of materials.

Oxygen and water vapour tightness

Oxygen and water vapour permeabilities were also compared between the film and cupboard blank material by using measured values and the results are in Table 8.

Table 8. Comparison of water vapour and oxygen transmission rates between used film and cup blank material.

Water vapour and oxygen tranmission rates					
Materials	**Grammage, g/m²**	**Caliper, µm**	**WVTR 23°C/50% RH, g/m²/day**	**WVTR 38°C/90% RH, g/m²/day**	**OTR 23°C/60% RH, cm3/m²/day**
Window film : LDPE 33µm/tie/EVOH 5 µm/tie/LDPE 33 µm	**63.5**	**~71**	**<1**	**4**	**<1**
Cup blank : Cupforma Classic Barr AT (LDPE30+250+42EB58)	**338**	**410**	**<1**	**<3**	**< 5**

According to these results measured water vapour transmission rate at 38°C/90% RH was higher in window film than cup blank material. On the other hand oxygen transmission rate is higher in cup material than in the film. Based on these results the plastic window does not decrease the oxygen or water vapour tightness of the cups in their normal applications.

Effect of the windows to DSD fees

Cups were evaluated also according to DSD licence fees. The product which was used as base material for the cups was Cupforma Classic Barr AT (code PE30+250+42EB58). This product had a basis weight of 338 g/m² and it has total plastic amount 88 g/m². Cup, which volume is 350 ml, has an area of 0.0304 m² (bottom included). Based on this information, the weight of one cup can be calculated:

$$\frac{338\ g}{1\ m^2} = \frac{X}{0.0304\ m^2}$$

$$X = 10.275\ g$$

It is also known that product has plastic altogether 88 g/m² of the total weight 338 g/m². With the help of that it can be calculated how many percentages there are plastic in 350 ml cup:

$$\frac{88\ g/m^2}{338\ g/m^2} * 100\% = 26\%$$

According to DSD rules Cupforma Classic Barr AT 350 ml paperboard cup contains > 5% plastic and it can be considered as composite material. In this case the licence fee is 101.4 cent/kg (G.7, Other composites).

When the 350 ml paperboard cup made of the product Cupforma Classic Barr AT PE30+250+42EB58 weighs 10.275 grams, the total licence fee can be calculated:

0.010275 kg * 101.40 cent/kg = 1.04 cent + VAT 19% = 1.24 cent.

When some of the cup weight is replaced with lighter plastic material the whole structure of the cup with window is lighter than a solid cup. Window area reduces the the total weight and due to being plain plastic it has a different DSD fee, 129.6 cent/kg (G.5, Plastic). If DSD fee is calculated for example for a 350 ml cup consisting of Cupforma Classic Barr AT material which has 15 cm² window of used plastic film, DSD fee for a final cup with window is 1.19 cent including VAT 19%.

So based on these calculations, extra DSD fees have to be paid for a basic paperboard cup manufactured of materials mentioned above and even without a plastic window. But if the whole structure of a cup with window becomes lighter due to the window, weight related DSD fees decrease.

Because sustainability is the big issue today and will be in the future, this has to be taken into consideration also when making this kind of new packaging solution. Customers demand a sustainable packaging to have good protection properties and to be inert with good converting and printing properties. Also they demand that packaging saves non-renewable resources and it can be recycled. Paperboard cups with windows manufactured of polymer coated board have both pros and cons in the area of sustainability. In this case there are a lot of plastic used in the structure of paperboard cups and the amount of plastic exceed the limits put by DSD. Extra fees have to be paid and depending on the size of the window in cup, the amount of extra DSD payments can be calculated. However if this kind of package is compared with pure plastic cup with the same size, DSD fees are lower. Another advantage compared with pure plastic cup is that wood is a natural resource and it has smaller carbon footprint than plastic.

So why use paperboard cup with plastic windows and not just plain AT-cup? Windows make the outlook of plain paperboard cup better by making it livelier. Windows can make the plain AT-cup to look more appealing for the consumers when the cups are placed on the market shelf. Because consumers are known to make the purchase decision within a few seconds companies will need their products to stand out when compared with others. Then based on the results of different market studies consumers prefer to see the product packed to be able to feel that they are not misled in any way. If they can see the product they feel they are not paying for extra air or bad quality. Also before this Masters of Thesis work, one survey was conducted in which different kind of paperboard packages with windows were collected mainly from Europe and not a single one was a paperboard cup with a window.

4. CONCLUSION

In this Masters of Thesis work the aim was to develop a paperboard cup with a plastic window. The main target was to create an instruction manual how this kind of cup with a window has to be produced without decreasing the tightness and other barrier properties of cupboard material used as a base board. The focus was on designing a shape of the window and finding critical limits for the size, shape and location of the window in the final paperboard cup.

There are several things which have to be taken into account when making cups with windows:

Used materials

High barrier materials have to be used which don't decrease air tight properties of the final cup.

Window film sealing

The window film has to be seamed tightly into the cup blank because seams need to be tight as well. In this Masters of Thesis work this was achieved by using hot bar sealing.

Window shapes

Windows can have different shapes but the most critical ones were discovered to be window forms which had sharp edges like big star shapes, also big customer shapes caused problems because the inner part had a tendency to stay in its original place. Other shapes worked well.

Window location

The best location for windows was near the sides of cup blank and the worst was in the middle of the blank. However, big windows couldn't be placed near the sides either due to heavy curling of the blank. Also very important is to not locate the windows along the machine direction of the board because it was found to weaken the final cup structure. Windows cannot be placed nearer than 1.2 cm away from rim roll because it caused difficulties in rim roll forming.

Window size

When thinking about the size of the window, they cannot take more than 4.4% of the whole cup area without causing any difficulties in cup machine runnability.

Targets set for this work were reached but there remained some things which still need to be improved. By utilising these critical limits for the size, shape and location found in this work several other shapes for the windows could be made. Outlook of square and rectangular windows could be improved by curving the edges to adapt cup's curves. This can easily be conducted on the computer.

The hot bar sealing method was the best sealing method for the plastic film used. However when sealing with hot bars, heat marks could be observed from the windows and this decreased the outlook of final cups. This can be improved by using heat sealing bars which are fit according to the windows so that plastic film will be heat sealed near the windows but not on top of them. To decrease blank curling optimal sealing conditions are important.

Best liquid tightness results could be received by hot bar sealing, but with laser seaming liquid tightness is also possible to achieve, only right kind of parameters have to be found. In this study there were a lot of different variations of windows and this caused difficulties in finding and stabilising right parameters for optimal sealing. By decreasing the amount of different window variations and focusing only with a few, it would be easier to find right parameters. By developing laser seaming a better appearance of windows can be received and more customiced shapes could be sealed.

By adjusting the cup machine it would be possible to improve the rim rolls and their appearance. When forming a rim roll certain amount of vertical pressure and lubrication are needed and by finding optimal pressure it would be possible to decrease malforming and bumpy rim rolls. Also by modifying the used cup machine also cup blanks with bigger windows could be tested but this demands excluding the raw edge taping equipment. This way the situation where blanks stuck on the feeder could be prevented.

Bursting strength was much weaker in the film used in windows when compared with board material. Low bursting strength was one of the weak points when thinking about cups with windows made of the studied materials. Bursting strength of the window film could be increased by selecting a stronger film or utilising nanomaterials in the film which improve the film toughness. The other weak point of the used film was its light transmission property. This could also be improved by using suitable nanomaterials.

Based on these results received from this study, the following points can be recommended for the further studies:

- window film attachment with lamination
- window film attachment with hot bar sealing method where such sealing bars are used which are fitted according to selected window geometry and no heat can effect on the window part
- search of right parameters for laser seaming for a window with certain geometry
- to find tougher film which has good transparency but lower light transmission property
- running cup blanks containing bigger windows by other cup machine with different feeder

REFERENCES

Ahvenainen, R. New approaches in improving the shelf life of minimally processed fruit and vegetables. Trends Food Sci. Technol., 7, pp. 179-187, 1996.

Ahvenainen-Rantala, Raija. Elintarvikkeiden pakkaukselle asettamat vaatimukset. Pakkausalan peruskurssi, Forssa, p. 1, 2007.

Aurela, Birgit, Weber, Assi, Kinnunen, Karita. Oy Keskuslaboratorio Oy, unpublic report, 2008.

Barras, A. Nanotechnology for food Packaging – Increasing Shelf Life.p.1, 7.12.2006.

Bekbölet, M. Light effects on food. J. Food Prot. 53 (5), p.430-440, 1990.Food Chem. 49 (5), p. 2277-2282, 2001.

BfR - Federal Institute for Risk Assessment, visited at 22.4.2008. Available at: http://www.bfr.bund.de/cd/template/index_en

Bosset, J., Gallmann, P. and Sieber, R. Influence of light transmittance of packaging materials on the shelf-life of milk and dairy products – a review. Food Packaging and Preservation. Malouthi, M. (Ed.), Chapman & Hall, London, 1994.

Brody, A.L and Budny, J.A. Active food packaging (M.L.Rooney Ed.), p. 174-192, Blackie Academic and Professional, Glasgow, UK., 1995.

Colchin, L.M., Owens, S.L., Lyubachevskaya, G., Boyle-Roden, E., Russek-Cohen, E. and Rankin, S. Modified atmosphere packaged cheddar cheese shreds: influence of fluorescent light exposure and gas type on color and production of volatile compounds. J.Agric.

Coltro, L., Padula, M., Segantini Saron, E., Borghetti, J. and Penteado Buratin, A.E. Evaluation of a UV-absorber added to PET bottles for edible oil packaging. Packag.Technol. Sci. 16, p. 15-20, 2003.

Conrad, K.R., Davidson, V.J, Mulholland, D.L., Britt, I.J and Yada, S. Influence of PET and PET/PEN blend packaging on ascorbic acid and color in juices exposed to fluorescent and UV-light. J.Food SCI. 70(1), p. E19-E25, 2005.

Day, B.P.F. Active packaging of foods. CCFRA New Technologies bulletin, 17, p. 23, 1998.

Day, B.P.F. Active packaging. Food Packaging Technology. Coles, R., McDowell, D. and Kirwan, M. (Ed.), CRC Press, 2003, chapter 9.

Der Grüne Punkt – Duales System Deuchland Gmbh, 2008. Available at : http://www.gruener-punkt.de/index.php?id=1623&L=1

ElAmin, Ahmed. Nanoscale particles designed to block UV-light. 18.10.2007. Available at: www.foodproductiondaily.com

Eskola Jari, Suoranta Juha, *Johdatus laadulliseen tutkimukseen*, Osuuskunta Vastapaino, Tampere, 2000.

Fabech, B., Hellstrom, T., Henrysdotter, G., Hjulmand-Lassen, M., Nilsson, J., Rudinger, L., Sipiläinen-Malm, T., Solli, E., Svensson, K., Thorkelsson, Á.E. and Tuomaala, V. Active and Intelligent Food Packaging, A Nordic report on the legislative aspects. TemaNord 2000:584, pp.31-32, 2000.

Frederiksen, C.S., Haurgaard, V.K., Poll, L. and Becker, E.M. Light-induced quality changes in plain yoghurt packed in polylactate and polystyrene. Eur. Food Res. Tech. 217(1), p. 61-69, 2003.

Garber, C. Nanotechnology food coming to a fridge near you. Available at: www.nanowerk.com. 28.12.2006

Gregory, J.F. Vitamins, In Food Chemistry, 3rd ed., Fennema, O.R., Ed., Marcel Dekker, New York, chapter 8, 1996.

Halliday, J. Consumers against nanotech in food, says BfR. pp. 1-2. 20.12.2007.

Hao, E. and Lian, T. Layer-by-Layer Assembly of CdSE Nanoparticles Based on Hydrogen Bonding. Langmuir, 16, p. 7879-7881, 2000.

Harju-Eloranta, Päivi. Internal document. Stora Enso Oyj, 2007.

Hautala, M., Fysiikkaa maatalous-metsätieteellisen tiedekunnan tarpeisiin. 2.uudistettu painos. Maa-ja kotitalousteknologian julkaisuja 1. Helsingin yliopisto, maa-ja kotitalousteknologian laitos, Helsinki, 1998.

Heikkilä, Mari I., Valo, pakkaukset ja elintarvikkeet, Pakkausteknologia-PTR, Helsinki, pp. 1-2, 5-22, 2005.

Helén, Harry, Turvallinen ja toimiva elintarvikepakkaus-seminaari, University of Helsinki, Department of Food Technology. 23.9.2008.

Hirsjärvi Sirkka, Hurme Helena, *Tutkimushaastattelu - Teemahaastattelun teoria ja käytäntö*, Yliopistopaino, Helsinki, 2000.

Hong, C.M., Werndorff, W.L. and Bradley, R.L.Jr. Factors affecting light-induced pink discoloration of annatto-colored cheese. J. Food Sci. 60(1), p. 94-97, 1995.

Huhtakangas, P. Elintarvikepakkaukset käyvät yhä tarpeellisemmiksi.

Kehittyvä elintarvike, pp. 50-51. 4/2007.

Hurme, E., Ahvenainen, R. and Nielsen, T. Technical report: Active and smart packaging of food. Nordic Network on Minimal Processing. VTT Biotechnology and Food Research & SIK, 31 pp, 1998.

Huttunen, J. Kuluttajien suhtautuminen elintarvikepakkausten läpinäkyvyyteen.pp. 4-5, 2007.

Huttunen, Jukka. Laserhitsaus. Laserle Oy, 2008. http://www.laserle.fi/laserhitsaus.htm

Häikiö, I., Ingalsuo, T. and Riihikoski, J. Elintarvikkeiden pakkaaminen – pakkauksen tehtävät. Available at http://koti.mbnet.fi/pakkaus/sivut/paktehtava1.shtml, 2007.

Jensen, P.N., Danielsen, B., Bertelsen, G., Skibsted, L.H. and Andersen, M.L. Storage stabilities of pork sratchings, peanuts, oatmeal and muesli: comparison of ESR spectroscopy, headspace-GC and sensory evaluation for detection of oxidation in dry foods. Food Chem. 91, p. 25-38, 2005.

Järvelä, K. "As simple and handy as possible" – Consumers' views on grocery packaging. Association of Packaging Technology and Research – PTR ry, ISBN 951-898837-4, pp. 16-19, 75, 2004.

Järvi-Kääriäinen, Terhen, Leppänen-Turkula, Annukka. Pakkaaminen. Pakkausteknologia-PTR ry. p.15-16, 2002.

Järvi-Kääriäinen, Terhen, Ollila, Margareetta. Toimiva Pakkaus. Pakkausteknologia-PTR ry. p.57, 2007.

Kemira. UV-Titan for plastics brochure, 2005. p. 1-6

Kuikka, Jussi. Design of adjustable packaging line – Master's thesis. Lappeenranta University of Technology, department of Mechanical Engineering. 81 p. + App. 2004.

Kujanpää, Veli. Presentation of lasers at NPS course. 2007. p. 46-47.

Kusterer, John M. What wavelengths goes with a color? Atmospheric Science Data Center, 2007. Available at:
http://eosweb.larc.nasa.gov/EDDOCS/Wavelengths_for_Colors.html

Kuusipalo, Jurkka. Presentation of cutting, creasing, scoring and embossing at NPS course. 2007. Tampere University of Technology. Institute of Paper Converting. p. 1,17.

Kuusipalo, Jurkka. Presentation of heat sealing at NPS course. 2007. Tampere University of Technology. Institute of Paper Converting. p. 1,3,5,7,10,17,36.

Kuusipalo, Jurkka. Presentation of Coating and Laminating at NPS course. 2007. Tampere University of Technology. Institute of Paper Converting. p. 23

Labuza, T.P. & Breene, W.M. Applications of "active packaging" for improvement of shelf-life and nutritional quality of fresh and extended shelf-life foods. Journal of food processing and preservation, 13, pp. 1-69, 1989.

Lahtinen, Kimmo, Nevalainen, Katja. Gluing of fiber based food packaging materials. Institute of Paper Converting, Tampere University of Technology. p. 5.

Leinonen, Jaana. Kemira PP-presentation: Kemira Pigments Oy. 06.04.2004. p. 8.

Lennersten, M. The influence of Light and Packaging Materials on Oxidative Deterioration in Foods: A Literature Review. SIK-Report 620. Chalmers

University of Technology, Department of Food Science, Gothenburg. 1995.

Lennersten, M. Light-induced lipid oxidation and colour changes in foods. Influence of wavelength and packaging material. SIK-rapport 620. Chalmers university of technology, department of food science and SIK – The Swedish institute for food and biochemistry, Göteborg, Sweden, 1998.

Lennersten, M. and Lingnert, H. Influence of different packaging materials on lipid oxidation in potato crisps exposed to fluorescent light. Lebensm. Wiss. Technol. 31, p. 162-168, 1998.

Lindell, Henry. Intelligence in Packaging. Summer School 2008, Lappeenranta University of Technology. p.1-29, 2008.

Lindeman, Ilpo. Logistiikkaketjun asettamia vaatimuksia pakkauksille – Jakelu ja varastointi. Pakkausalan peruskurssi, Forssa. p. 1-9, 2007.

Linx Printing Technologies Ltd., 2006. Data sheet. Available at: http://www.linxglobal.com/uploadeddocuments/Datasheets/Linx_500SL_Data sheet.pdf

Mark, H.F. et al. Encyclopedia for polymer science and engineering, 2nd edition, pp. 177-192, 317-318, John Wiley & Sons, New York, 1985.

Massey, Liesl K., Permeability properties of plastics and elastomers: a guide to packaging and barrier materials, 2nd Edition, p. 40, William Andrew Publishing, USA, 2003.

Merta, Juha. Oy Keskuslaboratorio, unpublic report, p.15-16, 2006.

Mestdagh, F., De Meulenaer, B., De Clippeleer, J., Devlieghere, F. and Huyghebaert, A. Protective influence of several packaging materials on light oxidation of milk. J. Dairy Sci. 88, p. 499-510, 2005.

Miikki, Nina. Personal discussion, 11.12.2008.

Moore, Graham. Nanotechnology in Packaging. Pira International Ltd., p.53, 2004.

Moore, Graham. Nanotechnology in the Paper, Printing and Packaging Industries. Pira International Ltd., p.29-32, 2004.

Mortensen, G. Prevention of light-induced quality changes in havarti cheese by optimal packaging. PhD Thesis. The Royal Vaterinary and Agricultural University, Department of Dairy and Food Science, Fredriksberg C, Denmark, 2002.

Mortensen, G., Sørensen, J. and Stapelfeldt, H. Effect of light and oxygen transmission characteristics of packaging materials on photooxidative quality changes in Havarti cheeses. Pack. Sci. Tech. 15(3). p. 121-127, 2002a.

Mortensen, G., Sørensen, J. and Stapelfeldt, H. Effect on modified atmosphere packaging and storage conditions on photooxidation of sliced Havarti cheese. Eur. Food Res. Tech. 216 (1), p. 57-62, 2003.

Mortensen, G., Sørensen, J., Danielsen, B. and Stapelfeldt, H. Effects of specific wavelengths on light-induced quality changes in Havarti cheese. J. Dairy Res. 70, p. 413-421, 2003.

Mortensen, G. Evaluation of photooxidative quality changes in dairy products – a critical appraisal. Presentation on IAPRI World conference on packaging, 2004.

Mortensen, G., Bertelsen, G., Mortensen, B.K., Stapelfeldt, H. Light-induced changes in packaged cheese – a review. Int. Dairy Journal 14, p. 85-102, 2004

Määttä, Päivi. Pakkauslinjoissa käytettäviä liitosmenetelmiä. Internal report, Stora Enso. Imatra. 5p.2003.

Nakamura, H. and Hoshino, J. Techniques for the preservation of food by employment of an oxygen absorber. Mitsubishi Gas Chemical Co., Tokyo, Ageless Division, pp. 1-45, 1983.

Nelson, K. and Cathcart, W. Transmission of Light Through Pigmented Polyethylene Milk Carton Materials. Journal of Food Protection, 46 (4), pp. 309-314, 1983.

Niininen, Mervi. Internal document. 2007. p. 2-4

Nova Chemicals. Product Summary, Extrusion Coatings, Polyethylene Product Data Sheets, 2001. Available at:
www.novachemicals.com/04_products/04_polyethylene_f.html

Patton, D. Australian nanotech firm promises better food packaging film. Available at: www.foodproductiondaily.com. 12/10/2006.

Piili, Heidi. Presentation of lasers at NPS course. 2007. p. 31-33, 35-36.

Regulation (EC) No 1935/2004 of the European Parliament and of the Council. Available at: http://eur-lex.europa.eu/fi/index.htm.

Regulation (EC) No 72/2002 of the European Parliament and of the Council. Available at: http://eur-lex.europa.eu/fi/index.htm.

Rijk, R.Active and Intelligent Packaging Systems and the Legislative Aspects. TNO – Nutrition And Food Research, p. 7, 2001.

Robertson, Gordon L. Food Packaging: Principles and Practice. 2nd Edition, Taylor & Francis Group, p. 3-4, 2006.

Rooney, M.L. Active packaging in polymer films. In: Active food packaging. Blackie Academic & Professional, pp. 74-110, 1995.

Rooney, M.L. Active packaging: science and application. Engineering and Food for the 21st Century. Welti-Chanes, J., Barbosa-Canovas, G.V. and Aguilera, J.M. (Ed.), CRC, Boca Raton, chapter 32, 2002.

Seppälä, M.J. (Ed.) & al. Kemiallinen metsäteollisuus 3: Paperin ja kartongin jalostus. Opetushallitus. p.178, ISBN-952-13-0606-8, 1999.

Shimoni, E., Anderson, E.M. and Labuza, T.P. Reliability of time-temperature indicators under temperature abuse, J. Food Sci., 66, pp. 1337-1340, 2001.

Smith, J.P, Ramaswamy, H.S. and Simpson, B.K. Developments in food packaging technology. Part 2: Storage aspects. Trends in Food Science & Technology, 11, pp. 111-118, 1990.

Stora Enso, Internal documents, 2008.

Strobel, J.M. and Gagnon, D.R. Enzyme loaded hydrophilic porous structure for protecting oxygen sensitive products & method for preparing the same. US patent 5766473. 1998.

Song, Yoon S. and Hepp, Mark A. US Food and Drug Administration approach to regulating intelligent and active packaging components. In Innovations in Food Packaging (Jung H. Han Ed.), p. 481, 2005.

Soon, Y.O. and Hepp, M.A. Innovations in food packaging. Article 26: US Food and Drug Administration approach to regulating intelligent and active packaging components. Elsevier Ltd. pp. 475-481, 2005.

Tanninen, Panu. Presentation of Die cutting operations at NPS course. 2007. p. 10,12,16-18, 28-30.

Tewari, G., Jayas, D.S., Jeremiah, L.E. and Holley, R.A. Absorption kinetics of oxygen scavengers. Int. J.Food Science Technol., 37, p. 209-217, 2002.

The Dow Chemical Company. Blown film and Cast film. Available at: www.plastics.dow.com, 2007.

The Environmental Register of Packaging PYR Ltd. Available at: http://www.pyr.fi/.

Truelove, S. Transparent Food Packaging May Reduce Shelf Life. Available at: http://www.medicalnewstoday.com/articles/80584.php, 2007.

Tschech, Andreas. Food Contact Substances, Authorisation in Europe and USA. RCC Product Certification Services, Switzerland. 2005.

Uggla, Rolf, Toivonen, Lauri, Nikkanen, Arvi, Järvinen, Hannele, Laamanen, Jouko, Viluksela, Pentti. Oy Keskuslaboratorio, unpublic report, 1981. p. 4

Vermeiren, L., Devlieghere, F., Debevere, J., Smolander, M., Hurme, E., Ahvenainen, R., Rijk, M.A.H., van Beest, M.D., de Kruijf, N. Literature review of FAIR-project Actipack. An in-depth review of technologies, legislation, market and consumer needs and trends in active and intelligent packaging in relation to current European food packaging regulations. VTT, p. 1, 1999.

Willhoff, E.M.A. Packaging for Preservation of Snack Food. In Snack Food, Booth, R.G (Ed.), Van Nostrand Reinhold, New York, pp. 349-372, 1990.

Vähä-Nissi, M. Oy Keskuslaboratorio, unpublic report. pp.2-3, 2005

Appendix 1. Paperboard cup with a window – plan for trials and tests

Ikkunallinen AT kuppi, koeajosuunnitelma

* TAVOITE: Valmistaa ikkunallinen kartonkikuppi, jossa voidaan säilyttää erilaisia kuivia/rasvaisia elintarvikkeita, esim. juustoraastetta, karkkeja, snackseja jne. Ensisijainen tavoite on luoda ohjeistus ikkunallisen kupin tekoon: minkä kokoinen/muotoinen ikkuna saa olla aihiossa, missä se saa sijaita jne.

* KUPPIEN KOKO JA MATERIAALI: 350 ml, Cupforma Classic Barr AT 250 g/m²

* IKKUNOIDEN LEIKKAUS: Ikkunat leikataan AT kuppi arkkiaihionäytteistä mallileikkurilla / IC

* IKKUNAMALLIEN MÄÄRÄ: Tehdään kuudella eri muodolla (neliö, ympyrä, suorakaide, tähti, soikio ja asiakasmalli) hahmotelmia ikkunoiksi erikokoisina ja eri kohdissa aihiota. Valituista muodoista suunnitellaan ikkunoita, joihin saadaan tarvittaessa mitta-asteikko tai ne voivat toimia pelkästään koristeena ja tuotteen paljastajina. Ikkunat sommitellaan kuppiaihioon siten, että kaikki ikkunat pystytään peittämään yhdellä muovikalvosuikaleella.

Kustakin muodosta tehdään erikokoisia ikkunoita ja sijoitellaan niitä eri kohtiin aihiota. Hahmotelmia tehdään 20 kpl/malli eli ne voidaan leikata viidestä arkkiaihiosta. Kaikkiin hahmotelmiin kiinnitetään kuumapalasaumaamalla/lasersaumaamalla (TK) tämän jälkeen valittu muovikalvo, ja ne ajetaan kupeiksi IC:n kuppikoneella.

* TESTATTAVA MUOVIKALVO JA SEN PAKSUUS:

LDPE – EVOH – LDPE, paksuus 71 µm

Tämän jälkeen hahmotelmakupit tarkastetaan visuaalisesti ja niistä mitataan alla olevat mittaukset tutkimuskeskuksella.

1) Otejäykkyys
2) Materiaalin valonläpäisy, ikkuna vs. kartonki
3) Puhkaisulujuus, ikkuna vs. kartonki
4) Vesihöyrynläpäisy kalvosta
5) Hapenläpäisy kalvosta
6) Sauman lujuus
7) Ikkunan saumojen tiiveys Tween20 liuoksella

Appendix 2. Laser seaming parameters used.

Laser seaming parameters				
Sample no.	Focus difference, mm	Energy, W	Mark speed, m/s	Energy density, J/mm²
1	+20	47.5	0.99	0.069
2	+20	47.5	0.99	0.069
3	+20	47.5	0.99	0.069
4	+20	47.5	0.99	0.069
5	+20	47.5	0.99	0.069
6	+20	47.5	0.99	0.069
26	+20	47.5	0.45	0.150
27	+20	47.5	0.765	0.089
28	+20	47.5	0.855	0.079
29	+20	47.5	0.855	0.079
30	+20	47.5	0.81	0.084
31	+20	47.5	0.81	0.084
32	+20	47.5	0.765–0.855	0.089–0.079
33	+20	47.5	0.81	0.084
34	+20	47.5	0.81	0.084

Appendix 3. Detailed information about acceptable cups with windows.

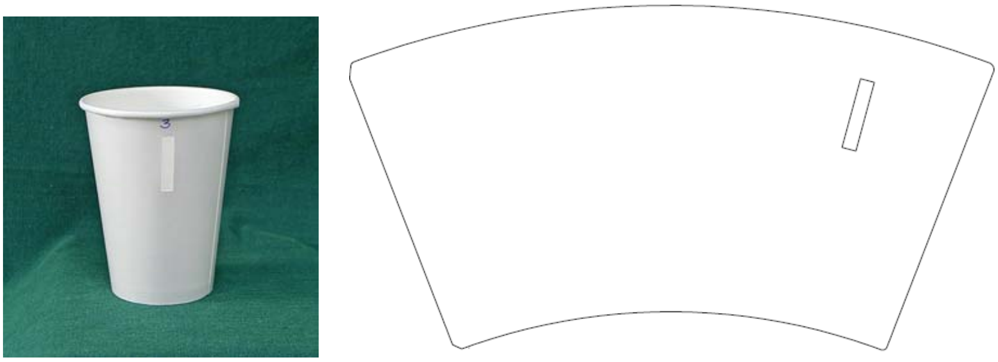

Figure 23. Test point no. 3

Test point no.	3
Place of the window	One rectangle window between 4.1 cm to 3.5 cm left from the side seam and between 1.4 cm to 4.4 cm down from the rim roll.
Size of the window	3.0 cm * 0.6 cm. Total area 1.8 cm².
Window size of the cup area	0.63%
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film looks good in windows, laser seaming marks can be seen on the window.
Comments about the rim roll forming	Rather good, small wrinkling can be observed.
Sealing method used	Laser
Grip stiffness	5.46 N

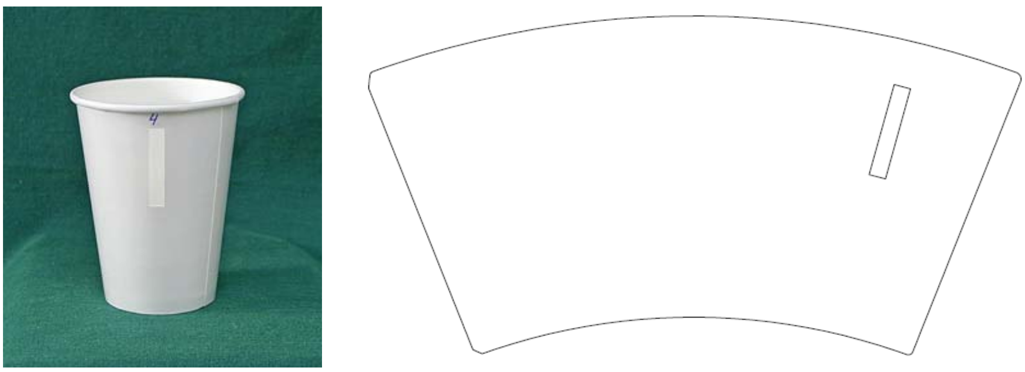

Figure 24. Test point no. 4

Test point no.	4
Place of the window	One rectangle window between 3.7 cm to 2.9 cm left from the side seam and between 1.2 cm to 5.2 cm down from the rim roll.
Size of the window	4.0 cm * 0.8 cm. Total area 3.2 cm².
Window size of the cup area	1.12 %
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film wrinkled in windows, laser seaming marks can be seen on the window
Comments about the rim roll forming	Rather good, small wrinkling can be observed.
Sealing method used	Laser
Grip stiffness	5.37 N

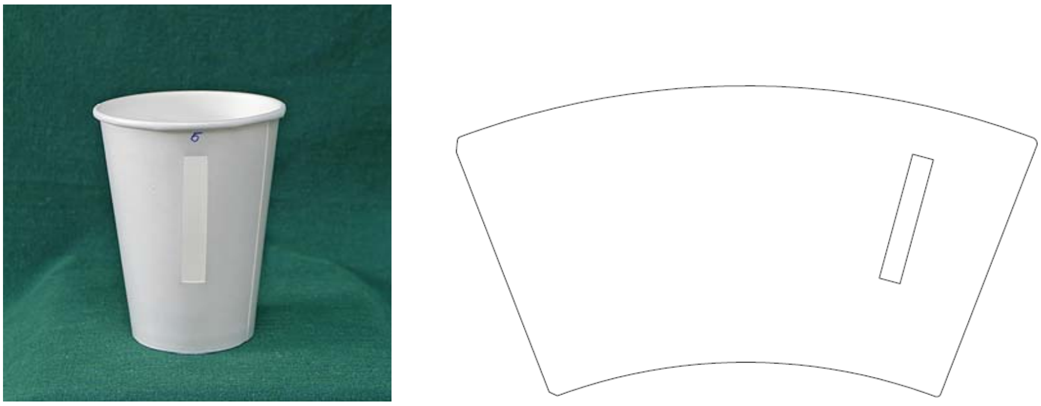

Figure 25. Test point no. 5

Test point no.	5
Place of the window	One rectangle window between 4.0 cm to 3.0 cm left from the side seam and between 1.6 cm to 7.6 cm down from the rim roll.
Size of the window	6.0 cm * 1.0 cm. Total area 6.0 cm².
Window size of the cup area	2.10 %
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film wrinkled in windows, laser seaming marks can be seen on the window, film is not attached quite well into longer sides of the window.
Comments about the rim roll forming	Rather good, small wrinkling can be observed.
Sealing method used	Laser
Grip stiffness	5.30 N

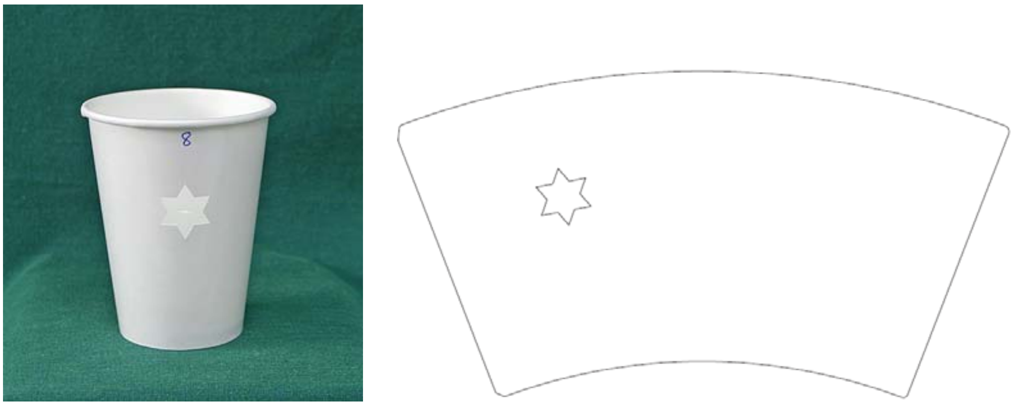

Figure 26. Test point no. 8

Test point no.	8
Place of the window	One star shape window between 5.0 cm to 7.3 cm right from the side seam and between 3.0 cm to 5.6 cm down from the rim roll.
Size of the window	Total area about 4.0 cm².
Window size of the cup area	1.4 %
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film wrinkled in windows. Hot bar seaming marks can be seen observed. Film is curled with the window.
Comments about the rim roll forming	Rather good, small wrinkling can be observed.
Sealing method used	Hot bar
Grip stiffness	5.36 N

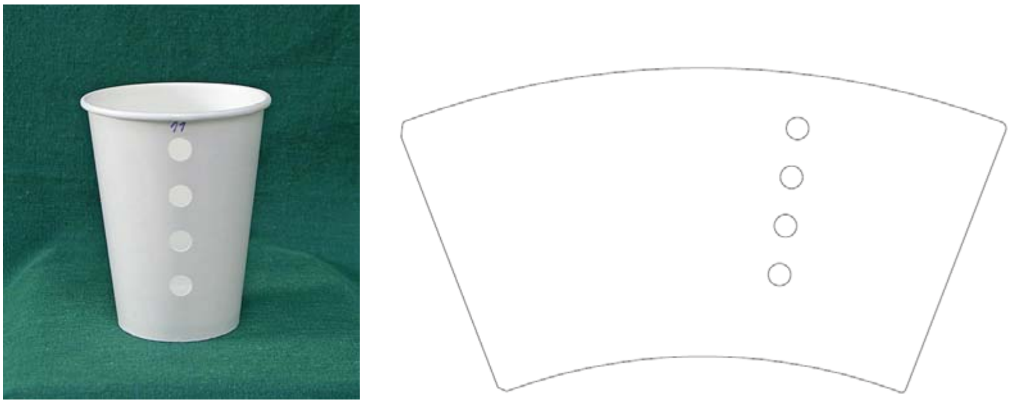

Figure 27. Test point no. 11

Test point no.	11
Place of the window	Four circle windows between 6.6 cm to 7.6 cm left from the side seam and between 1.1 cm to 8.9 cm down from the rim roll.
Size of the window	r = 0.5 cm. Total area 3.14 cm².
Window size of the cup area	1.10 %
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film wrinkled in windows. Hot bar seaming marks can be seen on the windows.
Comments about the rim roll forming	Rather good, small wrinkling can be observed.
Sealing method used	Hot bar
Grip stiffness	5.35 N

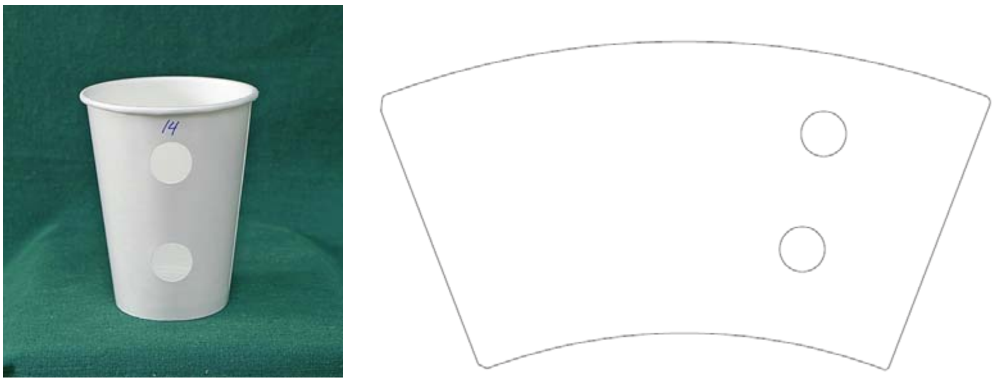

Figure 28. Test point no. 14

Test point no.	14
Place of the window	Two circle windows between 4.6 cm to 6.6 cm left from the side seam and between 1.8 cm to 9.0 cm down from the rim roll.
Size of the window	r = 1.0 cm. Total area 6.28 cm².
Window size of the cup area	2.20 %
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film wrinkled in windows, lower window wrinkled worse than upper one. Hot bar seaming marks can be seen on the windows.
Comments about the rim roll forming	Rather good, small wrinkling can be observed.
Sealing method used	Hot bar
Grip stiffness	5.38 N

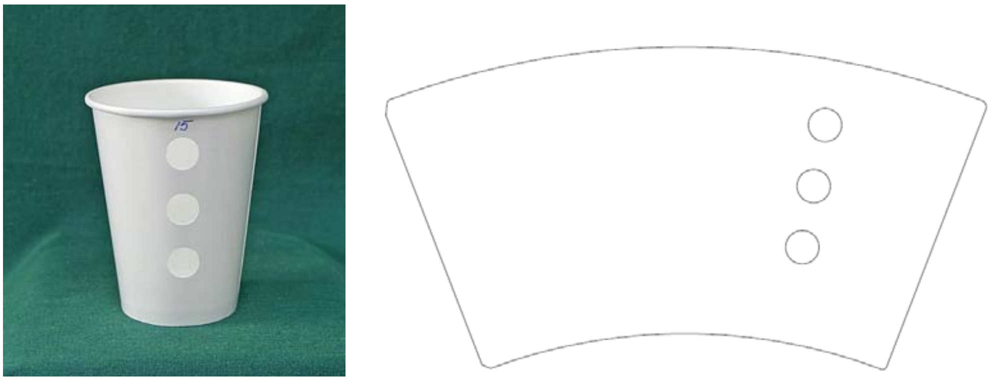

Figure 29. Test point no. 15

Test point no.	15
Place of the window	Three circle windows between 4.9 cm to 6.4 cm left from the side seam and between 1.4 cm to 8.6 cm down from the rim roll.
Size of the window	r = 0.75 cm. Total area 5.30 cm².
Window size of the cup area	1.85 %
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film wrinkled in windows, lower window wrinkled worse than the other two. Hot bar seaming marks can be seen on the windows.
Comments about the rim roll forming	Rather good, small wrinkling can be observed especially above the nearest window.
Sealing method used	Hot bar
Grip stiffness	5.64 N

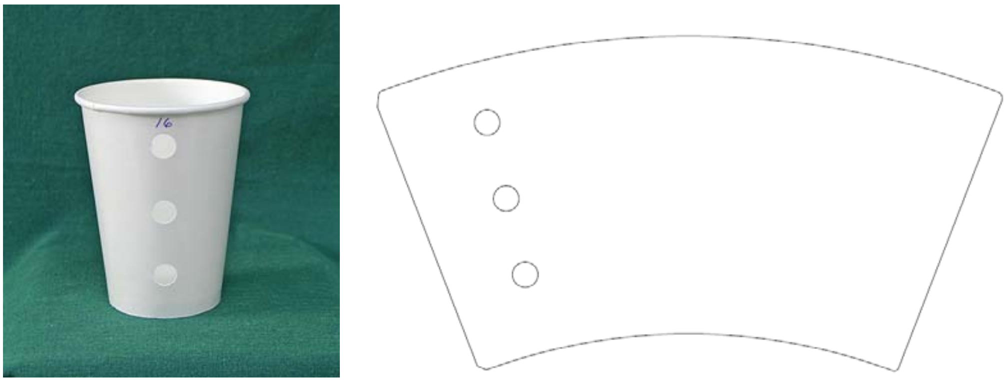

Figure 30. Test point no. 16

Test point no.	16
Place of the window	Three circle windows between 3.6 cm to 4.3 cm right from the side seam and between 1.4 cm to 9.3 cm down from the rim roll.
Size of the window	r = 0.55 cm. Total area 2.85 cm².
Window size of the cup area	1.0 %
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film wrinkled in windows, lower window wrinkled worse than the other two. Hot bar seaming marks can be seen on the windows.
Comments about the rim roll forming	Rather good, small wrinkling can be observed.
Sealing method used	Hot bar
Grip stiffness	5.40 N

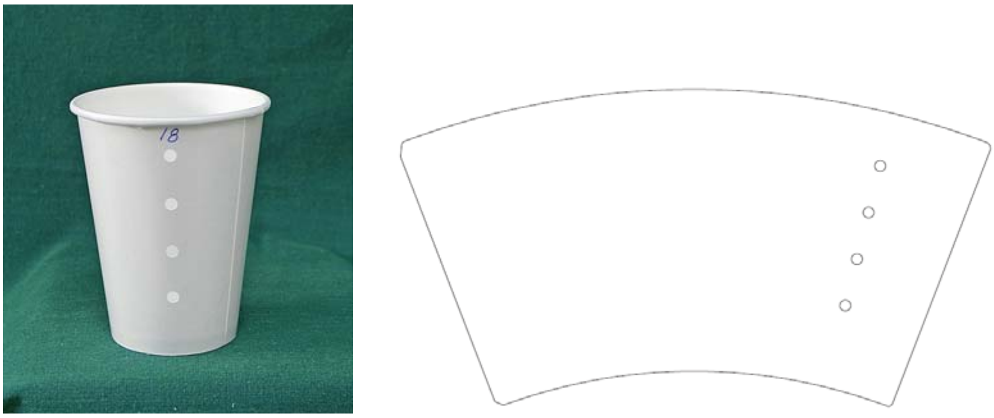

Figure 31. Test point no. 18

Test point no.	18
Place of the window	Four circle windows between 3.1 cm to 3.7 cm left from the side seam and between 1.4 cm to 8.6 cm down from the rim roll.
Size of the window	r = 0.3 cm. Total area 1.13 cm².
Window size of the cup area	0.4 %
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film a bit wrinkled in windows. Hot bar seaming marks can be seen on the windows.
Comments about the rim roll forming	Rather good, small wrinkling can be observed.
Sealing method used	Hot bar
Grip stiffness	5.43 N

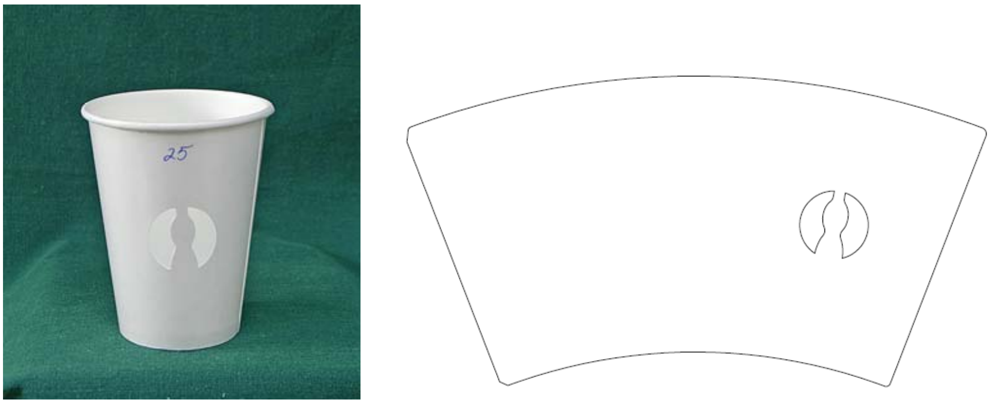

Figure 32. Test point no. 25

Test point no.	25
Place of the window	One customer shape window between 3.6 cm to 6.8 left from the side seam and between 4.1 cm to 7.1 cm down from the rim roll.
Size of the window	Total area about 5.0 cm².
Window size of the cup area	1.75 %
Runnability at cup machine	Good, no problems.
Comments about the window	Hot bar seaming marks can be seen on the windows.
Comments about the rim roll forming	Rather good, small wrinkling can be observed.
Sealing method used	Hot bar
Grip stiffness	5.30 N

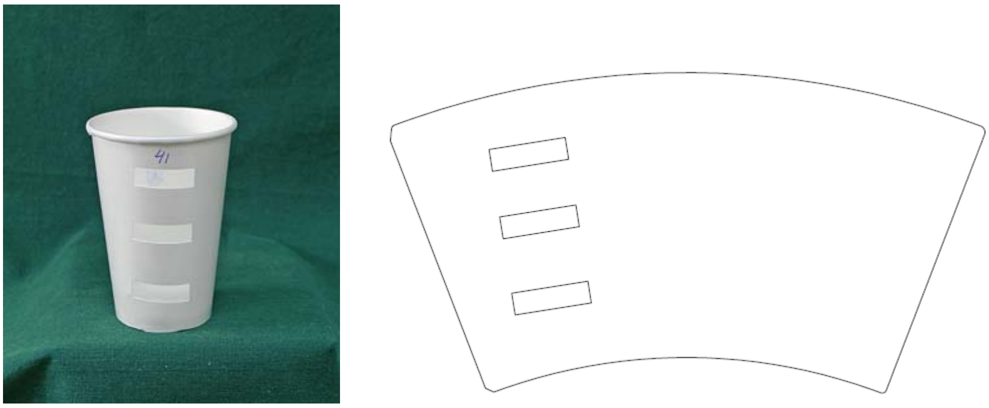

Figure 33. Test point no. 41

Test point no.	41
Place of the window	Three rectangle shape windows between 2.6 cm to 7.5 cm right from the side seam and between 1.6 cm to 9.2 cm down from the rim roll.
Size of the window	3.5 cm * 1.0 cm. Total area 10.5 cm².
Window size of the cup area	3.67 %
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film looks quite good in windows. Some hot bar sealing marks can be observed.
Comments about the rim roll forming	Rather good, small wrinkling can be observed.
Sealing method used	Hot bar
Grip stiffness	5.68 N

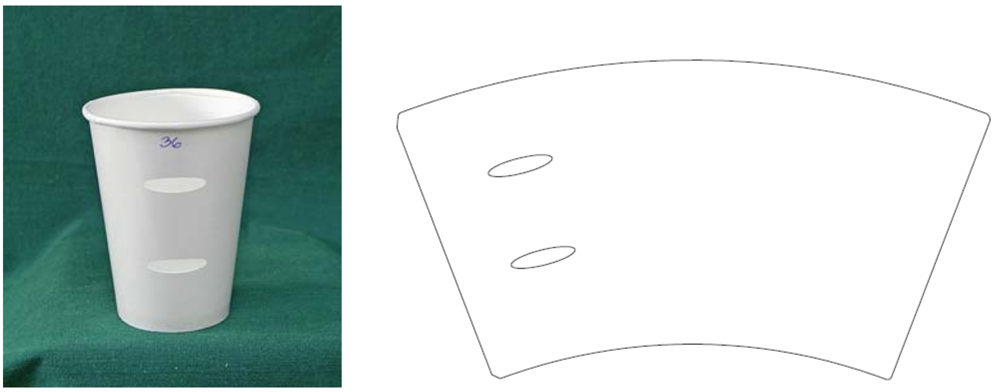

Figure 34. Test point no. 36

Test point no.	36
Place of the window	Two ellipse shape windows between 3.1 cm to 6.1 right from the side seam and between 2.8 cm to 7.8 cm down from the rim roll.
Size of the window	A=π*a*b, a=1.55 cm, b=0.35. Total area 3.41 cm².
Window size of the cup area	1.19 %
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film looks quite good in windows. Some hot bar sealing marks can be observed.
Comments about the rim roll forming	Rather good, small wrinkling can be observed.
Sealing method used	Hot bar
Grip stiffness	5.33 N

Appendix 4. Problematic cups and their blanks.


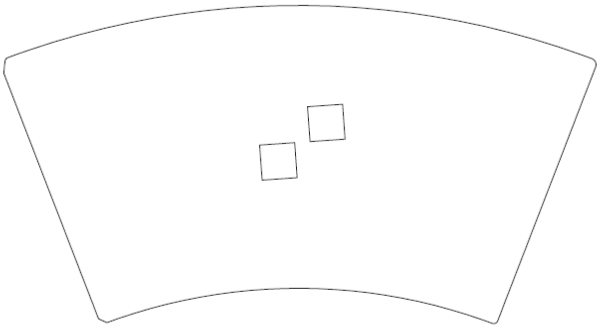

Figure 35. Test point no. 1

Test point no.	1
Place of the window	Two square windows between 5.8 cm to 9.8 cm right from the side seam and between 2.1 cm to 5.0 cm down from the rim roll.
Size of the window	1.6 cm * 1.6 cm. Total area 5.12 cm².
Window size of the cup area	1.79%
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film a bit wrinkled in windows, laser seaming marks can be seen on the window, could be holes in the windows
Comments about the rim roll forming	Rim roll is rather good, small wrinkling can be observed.
Sealing method used	Laser
Grip stiffness	5.44 N


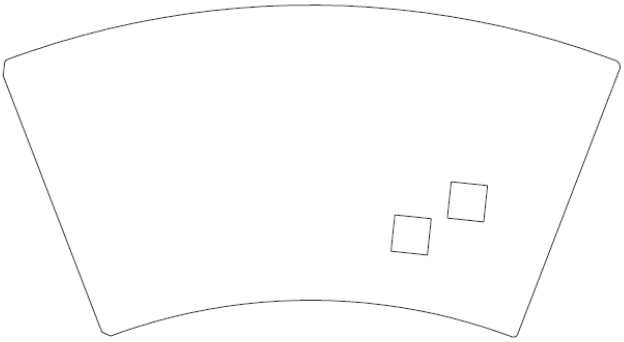

Figure 36. Test point no. 2

Test point no.	2
Place of the window	Two square windows between 5.9 cm to 4.0 cm left from the side seam and between 6.4 cm to 9.8 cm down from the rim roll.
Size of the window	1.6 cm * 1.6 cm. Total area 5.12 cm².
Window size of the cup area	1,79 %
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film wrinkled in windows, laser seaming marks can be seen on the window, almost all windows have holes and usually lower window have bigger hole than the upper one
Comments about the rim roll forming	Rather good, small wrinkling can be observed.
Sealing method used	Laser
Grip stiffness	5.31 N

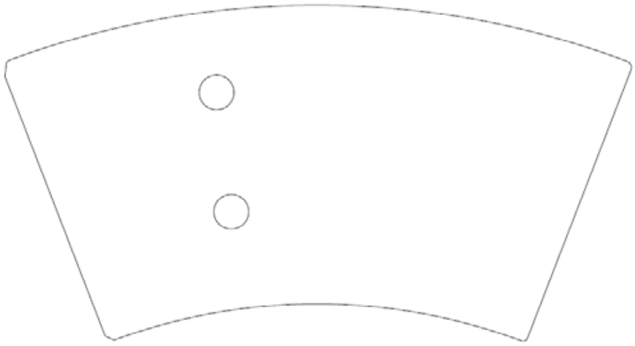

Figure 37. Test point no. 7

Test point no.	7
Place of the window	Two circle windows between 7.7 cm to 9.2 cm right from the side seam and between 2.0 cm to 8.7 cm down from the rim roll.
Size of the window	r = 0.75 cm. Total area 3.53 cm².
Window size of the cup area	1.23 %
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film wrinkled in windows, more on the lower window than the upper one. Hot bar seaming marks can be seen on the windows.
Comments about the rim roll forming	Rather good, small wrinkling can be observed.
Sealing method used	Hot bar
Grip stiffness	5.45 N

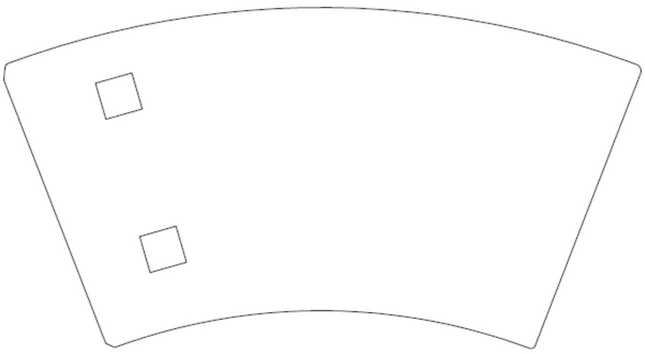

Figure 38. Test point no. 9

Test point no.	9
Place of the window	Two square windows between 3.5 cm to 5.1 cm right from the side seam and between 1.2 cm to 9.6 cm down from the rim roll.
Size of the window	1.6 cm * 1.6 cm. Total area 5.12 cm².
Window size of the cup area	1.79 %
Runnability at cup machine	Problems in rim roll forming.
Comments about the window	Plastic film wrinkled in windows, more on the lower window than the upper one. Hot bar seaming marks can be seen on the windows.
Comments about the rim roll forming	Difficulties in rim roll forming, wrinkling can be observed especially above the windows. In some cases runnability suffered in this phase. Sturucture didn't withstand rim roll forming.
Sealing method used	Hot bar
Grip stiffness	5.59 N

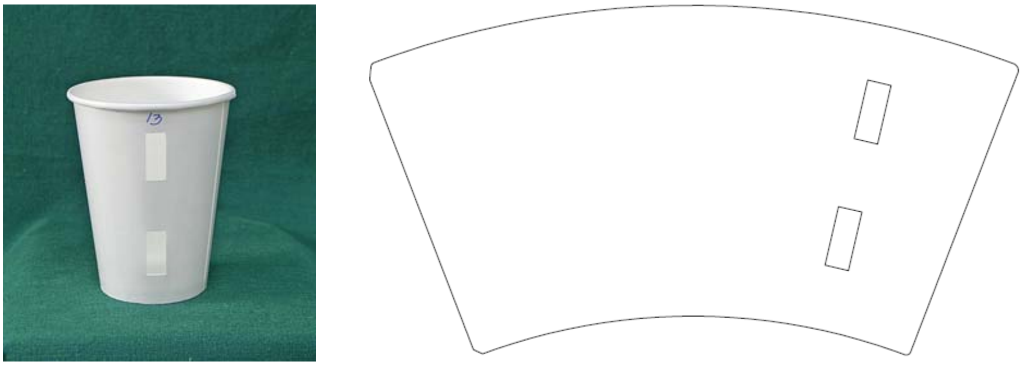

Figure 39. Test point no. 13

Test point no.	13
Place of the window	Two rectangle windows between 3.7 cm to 4.7 cm left from the side seam and between 1.6 cm to 9.5 cm down from the rim roll.
Size of the window	1.0 cm * 2.5 cm. Total area 5.0 cm².
Window size of the cup area	1.75 %
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film wrinkled in windows, lower window suffered more than upper one. Hot bar seaming marks can be seen on the window. Could be holes in the windows and some tear marks can be seen on the corners of lower window.
Comments about the rim roll forming	Rather good, small wrinkling can be observed.
Sealing method used	Hot bar
Grip stiffness	5.31 N

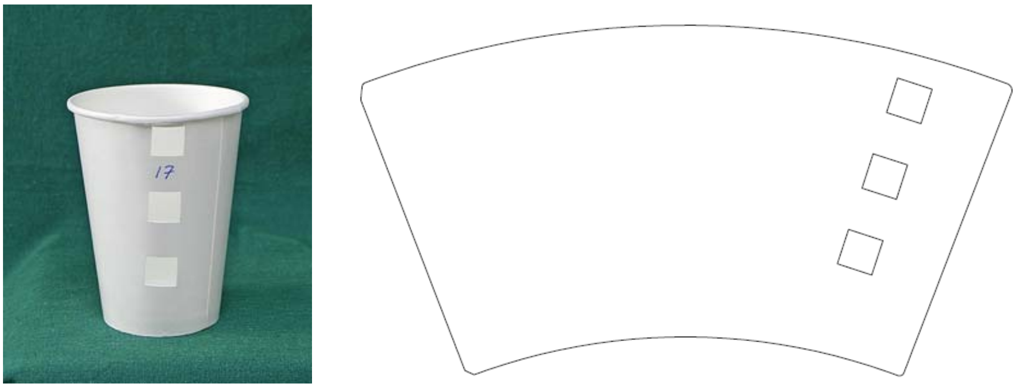

Figure 40. Test point no. 17

Test point no.	17
Place of the window	Three square windows between 2.0 cm to 3.6 cm left from the side seam and between 0.5 cm to 8.4 cm down from the rim roll.
Size of the window	1.5 cm * 1.5 cm. Total area 6.75 cm².
Window size of the cup area	2.36 %
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film wrinkled in windows, lower and upper windows wrinkled worse than the middle one. Hot bar seaming marks can be seen on the windows.
Comments about the rim roll forming	Difficulties in rim roll forming, wrinkling can be observed especially above the windows. Almost in all cases runnability suffered in this phase. Sturucture didn't withstand rim roll forming.
Sealing method used	Hot bar
Grip stiffness	5.25 N

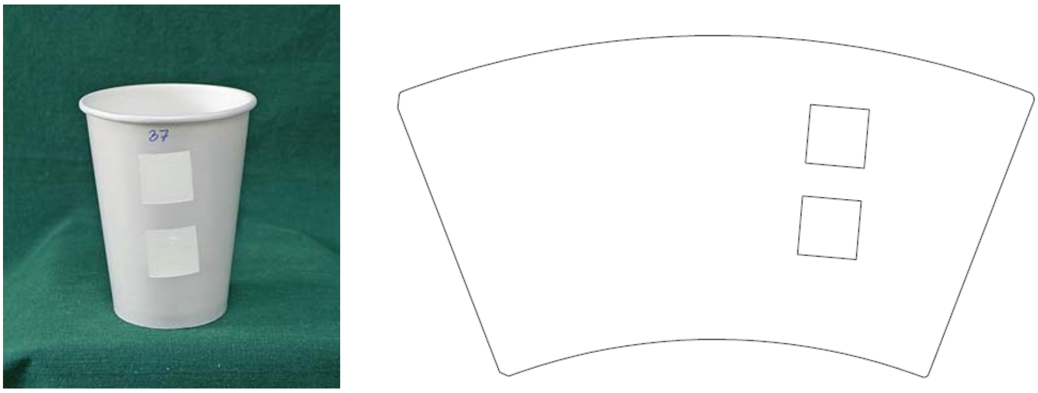

Figure 41. Test point no. 37

Test point no.	37
Place of the window	Two square windows between 6.6 cm to 10.9 cm left from the side seam and between 1.9 cm to 8.3 cm down from the rim roll.
Size of the window	2.5 cm * 2.5 cm. Total area 12.5 cm².
Window size of the cup area	4.37 %
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film a bit wrinkled in windows. Hot bar seaming marks can be seen on the windows.
Comments about the rim roll forming	Rather good, small wrinkling can be observed.
Sealing method used	Hot bar
Grip stiffness	5.30 N

Appendix 5. Unacceptable cups.

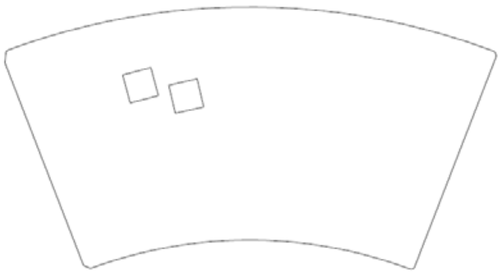

Figure 42. Test point no. 6

Test point no.	6
Place of the window	Two square windows between 10.1 cm to 14.0 cm right from the side seam and between 3.9 cm to 7.3 cm down from the rim roll.
Size of the window	1.6 cm * 1.6 cm. Total area 5.12 cm².
Window size of the cup area	1.79 %
Runnability at cup machine	Place of the window prohibited running. Jammed feeder.
Comments about the window	-
Comments about the rim roll forming	-
Sealing method used	Laser

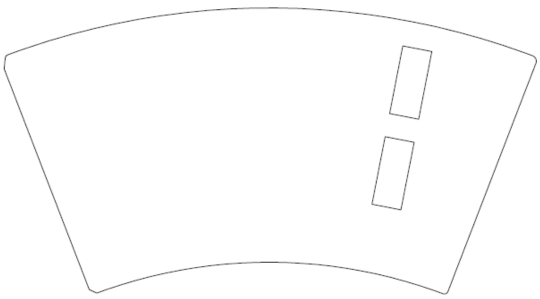

Figure 43. Test point no. 10

Test point no.	10
Place of the window	Two rectangle windows between 3.8 cm to 5.3 cm left from the side seam and between 0.3 cm to 8.6 cm down from the rim roll.
Size of the window	1.5 cm * 3.5 cm. Total area 10.5 cm².
Window size of the cup area	3.67 %
Runnability at cup machine	Place of the window prohibited running. Jammed feeder.
Comments about the window	-
Comments about the rim roll forming	-
Sealing method used	Hot bar

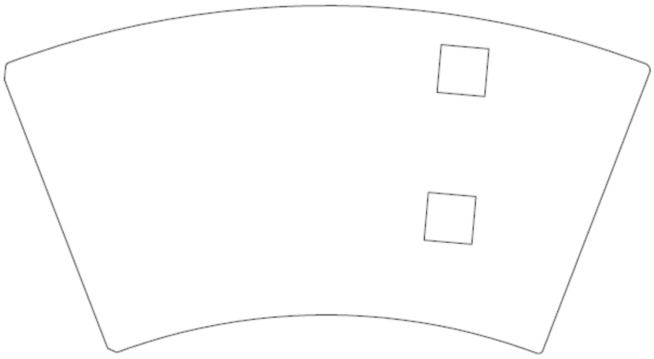

Figure 44. Test point no. 12

Test point no.	12
Place of the window	Two square windows between 5.1 cm to 7.1 cm left from the side seam and between 0.3 cm to 8.2 cm down from the rim roll.
Size of the window	2.0 cm * 2.0 cm. Total area 8.0 cm².
Window size of the cup area	2.80 %
Runnability at cup machine	Problems in rim roll forming.
Comments about the window	Plastic film wrinkled badly in both windows. Hot bar seaming marks can be seen on the windows.
Comments about the rim roll forming	Difficulties in rim roll forming, wrinkling can be observed especially above the windows. Almost in all cases runnability suffered in this phase. Sturucture didn't withstand rim roll forming.
Sealing method used	Hot bar
Grip stiffness	5.01 N

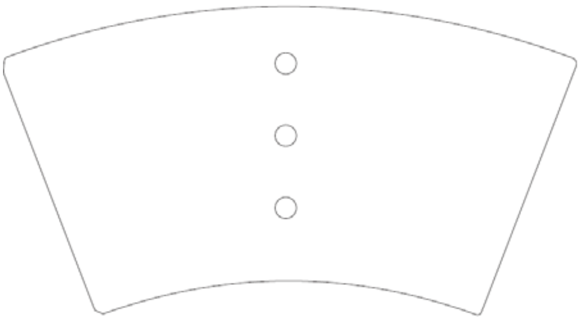

Figure 45. Test point no. 19

Test point no.	19
Place of the window	Three circle shape windows between 9.8 cm to 13.4 right from the side seam and between 1.5 cm to 9.3 cm down from the rim roll.
Size of the window	$A=\pi*r^2$, r=0.5 cm. Total area 2.36 cm².
Window size of the cup area	0.83 %
Runnability at cup machine	Place of the window prohibited running. Jammed feeder.
Comments about the window	Plastic film a bit wrinkled in windows. Hot bar seaming marks can be seen on the windows.
Comments about the rim roll forming	-
Sealing method used	Hot bar

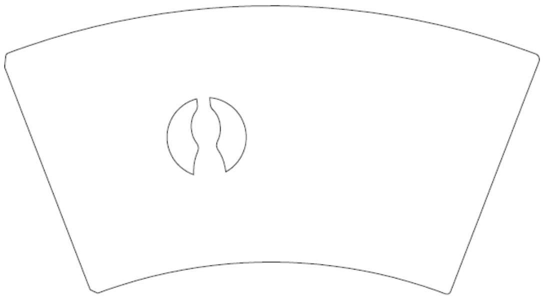

Figure 46. Test point no. 20

Test point no.	20
Place of the window	One customer shape window between 6.6 cm to 10.5 cm right from the side seam and between 3.9 cm to 7.7 cm down from the rim roll.
Size of the window	Total area about 7.2 cm².
Window size of the cup area	2.52 %
Runnability at cup machine	Place of the window prohibited running. Jammed feeder.
Comments about the window	Plastic film looks quite good in windows. Some hot bar sealing marks can be observed.
Comments about the rim roll forming	-
Sealing method used	Hot bar

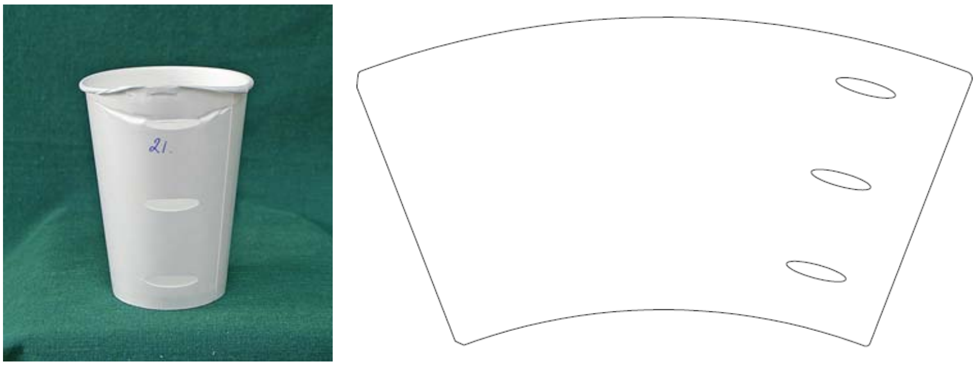

Figure 47. Test point no. 21

Test point no.	21
Place of the window	Three ellipse shape windows between 6.6 cm to 11.8 right from the side seam and between 1.1 cm to 9.1 cm down from the rim roll.
Size of the window	A=π*a*b, a=1.4 cm, b=0.3. Total area 3.96 cm².
Window size of the cup area	1.38 %
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film looks quite good in windows. Some hot bar sealing marks can be observed.
Comments about the rim roll forming	Problems in rim roll forming near the upper window.
Sealing method used	Hot bar
Grip stiffness	5.26 N

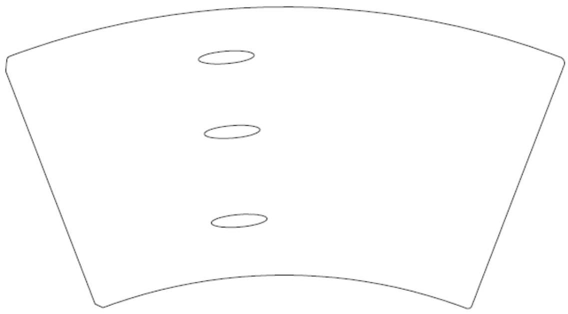

Figure 48. Test point no. 22

Test point no.	22
Place of the window	Three ellipse shape windows between 6.6 cm to 11.8 right from the side seam and between 1.1 cm to 9.1 cm down from the rim roll.
Size of the window	A=π*a*b, a=1.35 cm, b=0.3. Total area 3.82 cm².
Window size of the cup area	1.34 %
Runnability at cup machine	Place of the window prohibited running. Jammed feeder.
Comments about the window	Plastic film looks good in windows.
Comments about the rim roll forming	-
Sealing method used	Hot bar

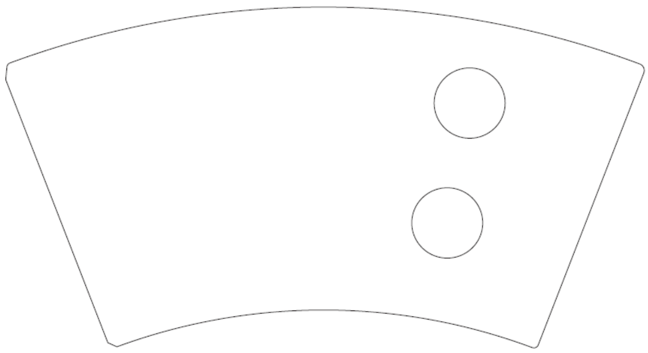

Figure 49. Test point no. 23

Test point no.	23
Place of the window	Two circle shape windows between 3.4 cm to 7.2 left from the side seam and between 1.0 cm to 9.2 cm down from the rim roll.
Size of the window	A=π*r², r=1.5 cm. Total area 14.14 cm².
Window size of the cup area	4.94 %
Runnability at cup machine	Place of the window prohibited running. Jammed feeder.
Comments about the window	Hot bar seaming marks can be seen on the windows.
Comments about the rim roll forming	-
Sealing method used	Hot bar

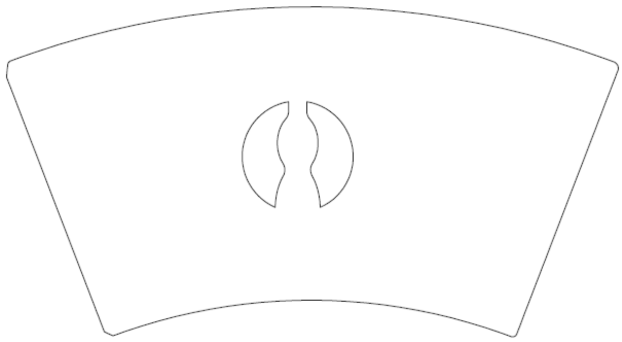

Figure 50. Test point no. 24

Test point no.	24
Place of the window	One customer shape window between 9.0 cm to 12.1 right from the side seam and between 3.8 cm to 6.8 cm down from the rim roll.
Size of the window	Total area about 5.0 cm².
Window size of the cup area	1.75 %
Runnability at cup machine	Place of the window prohibited running. Jammed feeder.
Comments about the window	Hot bar seaming marks can be seen on the windows.
Comments about the rim roll forming	-
Sealing method used	Hot bar

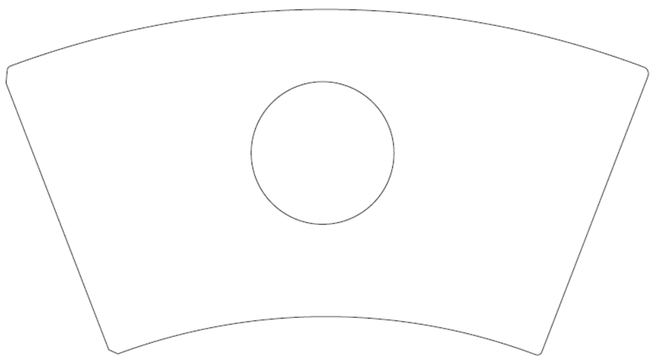

Figure 51. Test point no. 26

Test point no.	26
Place of the window	One circle shape window between 8.7 cm to 14.9 right from the side seam and between 2.3 cm to 8.3 cm down from the rim roll.
Size of the window	$A=\pi*r^2$, r=3.0 cm. Total area 28.27 cm².
Window size of the cup area	9.88 %
Runnability at cup machine	Place of the window prohibited running. Jammed feeder.
Comments about the window	Plastic film looks good in windows.
Comments about the rim roll forming	-
Sealing method used	Laser

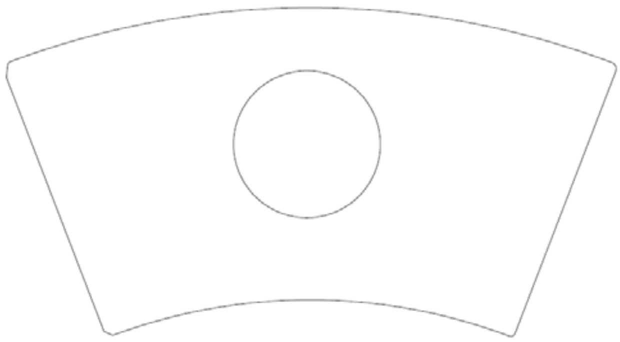

Figure 52. Test point no. 27

Test point no.	27
Place of the window	One circle shape window between 8.6 cm to 15.1 right from the side seam and between 2.1 cm to 8.5 cm down from the rim roll.
Size of the window	A=π*r², r=3.25 cm. Total area 33.18 cm².
Window size of the cup area	11.6 %
Runnability at cup machine	Place of the window prohibited running. Jammed feeder.
Comments about the window	Plastic film looks good in windows.
Comments about the rim roll forming	-
Sealing method used	Laser

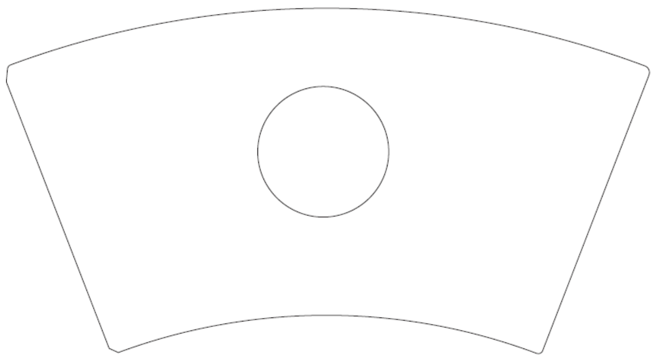

Figure 53. Test point no. 28

Test point no.	28
Place of the window	One circle shape window between 9.0 cm to 14.8 right from the side seam and between 2.6 cm to 8.1 cm down from the rim roll.
Size of the window	A=π*r², r=2.7 cm. Total area 22.90 cm².
Window size of the cup area	8.01 %
Runnability at cup machine	Place of the window prohibited running. Jammed feeder.
Comments about the window	Plastic film looks good in windows.
Comments about the rim roll forming	-
Sealing method used	Laser

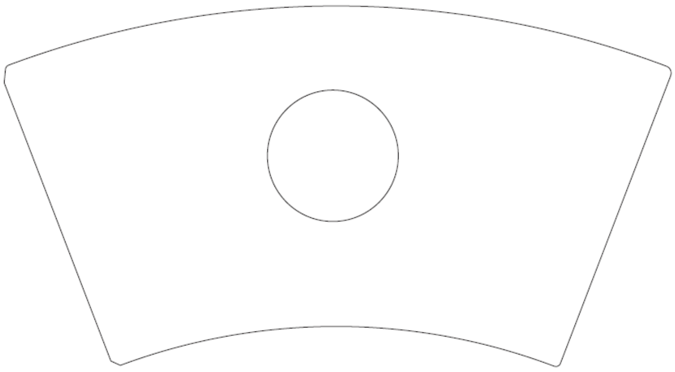

Figure 54. Test point no. 29

Test point no.	29
Place of the window	One circle shape window between 9.6 cm to 14.8 right from the side seam and between 2.7 cm to 8.0 cm down from the rim roll.
Size of the window	A=π*r², r=2.65 cm. Total area 22.06 cm².
Window size of the cup area	7.71 %
Runnability at cup machine	Place of the window prohibited running. Jammed feeder.
Comments about the window	Plastic film looks good in windows.
Comments about the rim roll forming	-
Sealing method used	Laser

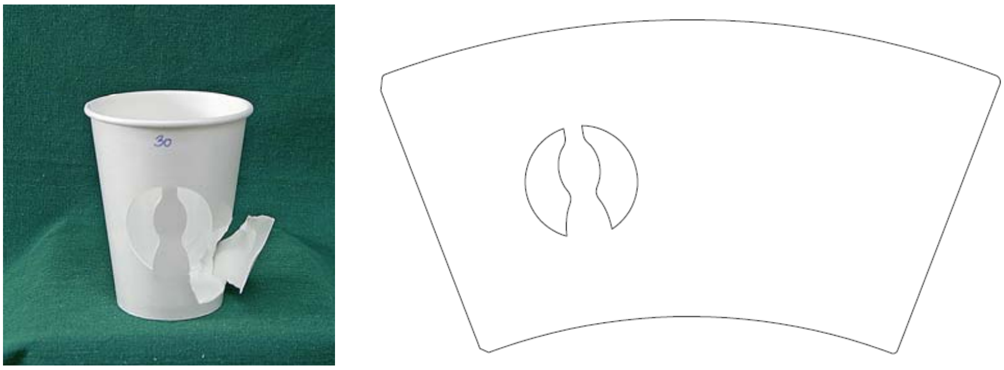

Figure 55. Test point no. 30

Test point no.	30
Place of the window	One customer shape window between 4.5 cm to 9.3 right from the side seam and between 3.6 cm to 8.3 cm down from the rim roll.
Size of the window	Total area about 11.6 cm².
Window size of the cup area	4.06 %
Runnability at cup machine	Place of the window prohibited running. Only two blanks got through, but they were torn badly. Jammed feeder.
Comments about the window	Plastic film looks good in windows.
Comments about the rim roll forming	-
Sealing method used	Laser
Grip stiffness	5.22 N

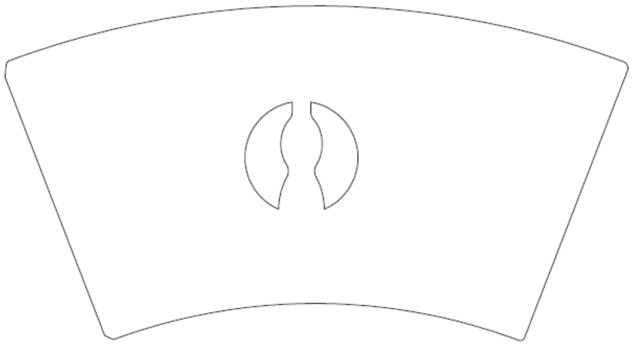

Figure 56. Test point no. 31

Test point no.	31
Place of the window	One customer shape window between 8.8 cm to 13.6 right from the side seam and between 3.6 cm to 8.2 cm down from the rim roll.
Size of the window	Total area about 12.0 cm².
Window size of the cup area	4.20 %
Runnability at cup machine	Place of the window prohibited running. Jammed feeder.
Comments about the window	Plastic film looks good in windows.
Comments about the rim roll forming	-
Sealing method used	Laser

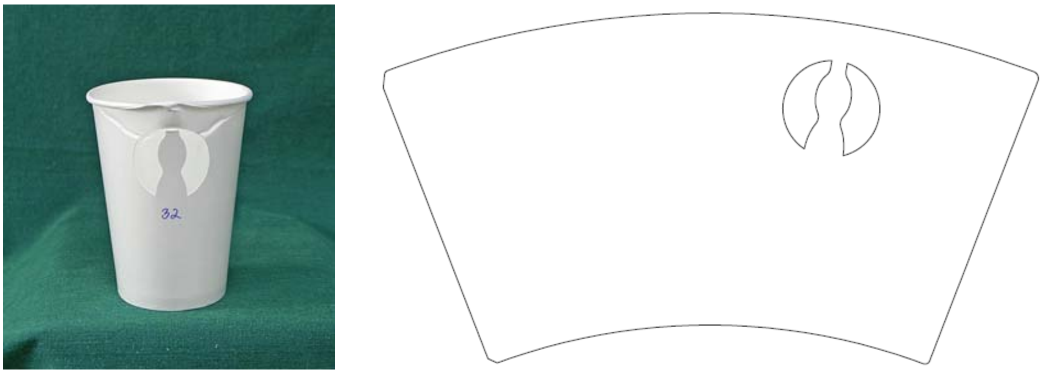

Figure 57. Test point no. 32

Test point no.	32
Place of the window	One customer shape window between 5.7 cm to 9.6 left from the side seam and between 0.8 cm to 4.7 cm down from the rim roll.
Size of the window	Total area about 8.4 cm².
Window size of the cup area	2.94 %
Runnability at cup machine	Good, no problems.
Comments about the window	Plastic film looks good in windows despite of small laser seaming marks.
Comments about the rim roll forming	Problems in rim roll forming, cup structure failed above the window.
Sealing method used	Laser
Grip stiffness	4.88 N

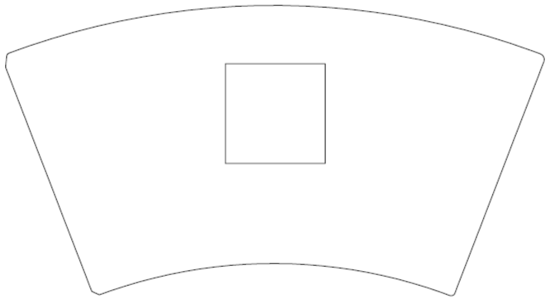

Figure 58. Test point no. 33

Test point no.	33
Place of the window	One square window between 9.9 cm to 14.9 cm right from the side seam and between 2.2 cm to 7.2 cm down from the rim roll.
Size of the window	5.0 cm * 5.0 cm. Total area 25 cm².
Window size of the cup area	8.74 %
Runnability at cup machine	Place of the window prohibited running. Jammed feeder.
Comments about the window	Plastic film looks good in windows.
Comments about the rim roll forming	-
Sealing method used	Laser

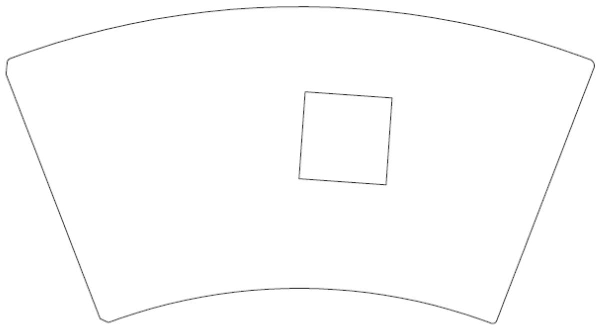

Figure 59. Test point no. 34

Test point no.	34
Place of the window	One square window between 11.0 cm to 17.1 cm right from the side seam and between 3.2 cm to 7.3 cm down from the rim roll.
Size of the window	4.0 cm * 4.0 cm. Total area 16 cm².
Window size of the cup area	5.59 %
Runnability at cup machine	Place of the window prohibited running. Jammed feeder.
Comments about the window	Hot bar seaming mark can be seen on the windows.
Comments about the rim roll forming	-
Sealing method used	Hot bar, laser

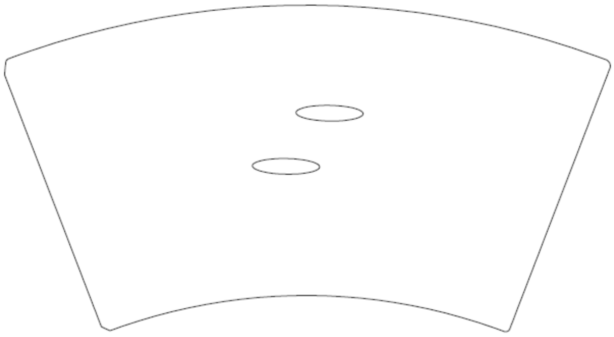

Figure 60. Test point no. 35

Test point no.	35
Place of the window	Two ellipse shape windows between 9.2 cm to 15.1 right from the side seam and between 4.2 cm to 6.8 cm down from the rim roll.
Size of the window	A=π*a*b, a=1.55 cm, b=0.35. Total area 3.41 cm².
Window size of the cup area	1.19 %
Runnability at cup machine	Place of the window prohibited running. Jammed feeder.
Comments about the window	Plastic film looks good in windows.
Comments about the rim roll forming	-
Sealing method used	Hot bar

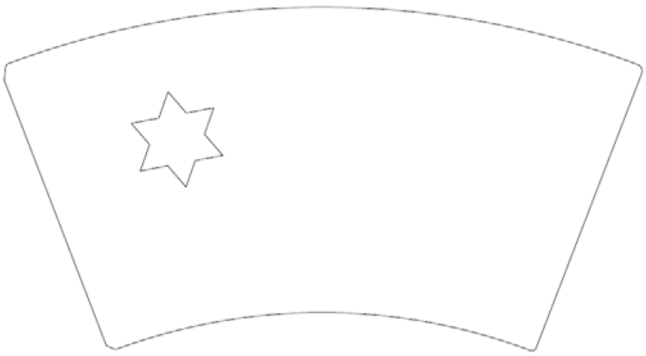

Figure 61. Test point no. 38

Test point no.	38
Place of the window	One star shape window between 4.0 cm to 8.0 cm right from the side seam and between 2.2 cm to 6.3 cm down from the rim roll.
Size of the window	Total area 8.06 cm².
Window size of the cup area	2.82 %
Runnability at cup machine	Place of the window prohibited running. Blank was quite curled. Jammed feeder.
Comments about the window	Plastic film looks quite good in windows. Some hot bar sealing marks can be observed.
Comments about the rim roll forming	-
Sealing method used	Hot bar

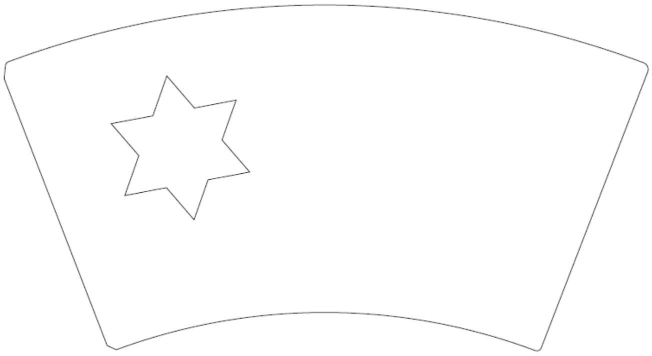

Figure 62. Test point no. 39

Test point no.	39
Place of the window	One star shape window between 3.1 cm to 8.9 cm right from the side seam and between 1.7 cm to 8.9 cm down from the rim roll.
Size of the window	Total area 18.3 cm².
Window size of the cup area	6.40 %
Runnability at cup machine	Place of the window prohibited running. Blank was very curled. Jammed feeder.
Comments about the window	Plastic film looks quite good in windows. Some hot bar sealing marks can be observed.
Comments about the rim roll forming	-
Sealing method used	Hot bar

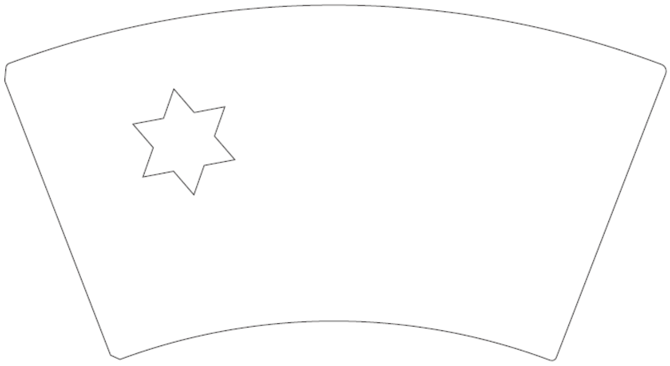

Figure 63. Test point no. 40

Test point no.	40
Place of the window	One star shape window between 3.8 cm to 8.2 cm right from the side seam and between 2.2 cm to 6.5 cm down from the rim roll.
Size of the window	Total area 8.54 cm².
Window size of the cup area	3.0 %
Runnability at cup machine	Place of the window prohibited running. Blank was quite curled. Jammed feeder.
Comments about the window	Plastic film looks quite good in windows. Some hot bar sealing marks can be observed.
Comments about the rim roll forming	-
Sealing method used	Hot bar

Appendix 6. Differences in bursting strengths of used materials.

Table 9. Bursting strengths between cupboard blank and plastic film used in windows.

Bursting strength results for the cupboard and film materials																
	Individual results															
Grammage, g/m²	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**		
Cupboard material	330																
Window film	66																
Bursting strength, kPa	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**AVG**	**STDEV**
Cupboard material	1087	1135	1088	1074	1025	1107	969	1018	1055	1024	1001	1118	1088	1056	1061	**1060**	**46.12**
Window film	148	154	133	145	152	141	136	138	149	146	142	145	143	139	143	**144**	**5.79**

Appendix 7. Grip stiffnesses measured from the cups with windows.

Table 10. Grip stiffnesses measured with cups with a plastic window.

Grip stiffnesses of the cups with plastic windows				
Test item no	Grip stiffnesses measured, N			Average, N
solid cup	4,76	5,07	5,04	4,95
1	5,10	5,64	5,59	5,44
2	5,26	5,42	5,26	5,31
3	5,46	5,34	5,58	5,46
4	5,36	5,41	5,33	5,37
5	5,38	5,32	5,21	5,30
7	5,63	5,37	5,37	5,45
8	5,13	5,53	5,40	5,36
9	5,38	5,63	5,75	5,59
11	5,46	5,21	5,38	5,35
12	4,89	4,82	5,32	5,01
13	5,42	5,35	5,16	5,31
14	5,38	5,21	5,56	5,38
15	5,76	5,59	5,57	5,64
16	5,41	5,42	5,37	5,40
17	5,46	5,09	5,20	5,25
18	5,83	5,24	5,23	5,43
21	5,30	5,25	5,23	5,26
25	5,32	5,33	5,25	5,30
30	5,38	5,06	-	5,22
32	5,17	5,08	4,41	4,88
36	5,37	5,26	5,35	5,33
37	5,23	5,42	5,25	5,30
41	5,64	5,66	5,75	5,68

Appendix 8. Liquid tightness of the seams.

Table 11. Tightness of seams tested with 0.2% Tween20 solution.

Liquid tightness of the seams			
Test point	**Liquid tightness**	**Seaming method**	**Penetration places**
1	leaky	laser	window seams
2	leaky	laser	window seams
3	tight	laser	
4	leaky	laser	window seams (especially seam near the rim roll)
5	leaky	laser	window seams (especially seam near bottom)
7	tight	hot bar	
8	tight	hot bar	
9	tight	hot bar	
11	tight	hot bar	
12	tight	hot bar	
13	tight	hot bar	
14	tight	hot bar	
15	tight	hot bar	
16	tight	hot bar	
17	tight	hot bar	
18	tight	hot bar	
21	tight	hot bar	
25	tight	hot bar	
30	leaky	laser	window seams (a hole in plastic film due to excess amount of heat)
32	leaky	laser	window seams (especially seam near the rim roll)
36	tight	hot bar	
37	tight	hot bar	
41	tight	hot bar	
solid	tight	-	