

Lappeenranta University of Technology
Faculty of Technology
Degree Program in Mechanical Engineering

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**POSSIBILITY TO ADD A BARRIER LAYER TO A FIBRE TRAY PACKAGE IN
THE MOULDING STAGE**

Examiners: Professor Henry Lindell
Researcher Ville Leminen

ABSTRACT

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Possibility to add a barrier layer to a fibre tray package in the moulding stage

Master's Thesis

2014

53 pages, 43 figures, 7 tables, 3 appendixes

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Keywords: paperboard, skin packaging, tray, coating, lamination

The main objective of the present study was to analyze the best approach on how to coat paperboard trays at the pressing stage. The coating gives the paperboard enhanced barrier and mechanical properties.

The whole process chain of the barrier coating development was studied in the research. The methodology applied includes obtaining the optimum temperature at which good adhesion and bonding is formed between paperboard and skin film. Evaluation of mechanical properties after the coatings; such as cracking, curling and barrier properties was performed.

ACKNOWLEDGEMENTS

This research work was carried out at the Laboratory of Packaging Technology using the LUT Flexible Packaging line in the Department of Mechanical Engineering, Lappeenranta University of Technology, Lappeenranta, Finland, from April 2014 to September 2014. I would like to thank God for all the guidance and help through all my studies and long stay in Finland. I would like to express my sincere and heartfelt gratitude to my examiners Professor Henry Lindell, Ville Leminen and supervisor Panu Tanninen. For the direct guidance, support and assistance during the thesis work.

I also express my great appreciation and gratefulness to my beloved parents and siblings, who have contributed immensely to my success since day one financially, morally and in all directions of life. All I can say is thank you so much.

I appreciate my friends who have in one way or another contributed to the success of this project and supported me throughout my study life.

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LIST OF SYMBOLS AND ABBREVIATIONS

C1S	Coated on One Side
CPET	Crystalline Polyethylene Terephthalate
EVAc	Ethylene Vinyl Acetate
EVOH	Ethyl Vinyl Alcohol
FBB	Folding Box Board
FCB	Folding Carton Board
HD-PE	High Density Polyethylene
HFFS	Horizontal form-fill-seal
MAP	Modified Atmospheric Packaging
MD	Machine Direction
NPS	New Packaging Solutions
OG	Original Gravity
PE	Polyethylene
PE-LD	Low Density Polyethylene
PET	Polyethylene Terephthalate
PP	Polypropylene
PVAc	Polyvinyl Acetate
PVDC	Polyvinylidene Chloride
SBB	Solid Bleached Board
SBS	Solid Bleached Sulphate
SUB	Solid Unbleached Board
TD	Transverse Direction
VSP	Vacuum Skin Packaging
WLC	White Lined Chipboard

1 INTRODUCTION

1.1 Background

Food is anything that can be eaten and digested in the body. It gives energy and nutritional support to our body. The nutrients that we get from food are carbohydrates, fats, proteins, vitamins and minerals. Almost all foods are products of plants and animals. Carbohydrates are organic compounds that are particularly rich in the complex carbohydrate starch. Some examples of carbohydrate rich foods are bread, pasta, cereals, etc. Fat supplies energy to our body and also helps other nutrients to do their jobs. It's also important in keeping normal body function in our system. Proteins consists of a wide group of compounds, and they are usually soluble in organic solvents and insoluble in water. Proteins are made of amino acids. There are about 20 amino acids. Vitamins are organic compounds needed in small quantity to sustain life. We get vitamins from food. The human body either does not produce enough vitamins or none at all. (Morris, 2011.)

Deep drawn plastic coated trays are especially known for packaging of frozen food and modified atmospheric packaging (MAP) which can also be heated in a conventional or microwave oven. These plastic trays are using a lot of raw material and are therefore expensive. Premium raw materials are used to have temperature stability when the packaging is heated in an oven. Further the used plastic materials cannot be based on renewable resources. Such plastic trays are often made from crystallized Polyethylene Terephthalate (CPET), Polypropylene (PP) or other plastic materials and are normally sealed with a film and are often at least partially surrounded by a carton sleeve. For MAP technology, which is well known from the state of the art, the packaged goods are hermetically sealed in a modified atmosphere providing a longer shelf life for fresh food, e.g. for sliced meat, salad or prepared dishes. The package has to be gas, liquid and diffusion proof. The packaging material has to have high barrier quality and low gas permeability. (Morris, 2011, p.386.) A deep pressed paperboard tray is illustrated in figure 1.



Figure 1. Deep pressed paperboard tray. (Knowpap, 2011.)

1.2 Purpose of packaging

Packaging is the art of enclosing a product for distribution, storage, sales and use purposes. The main function of packaging is to meet the needs of consumers and retailers in many ways. The package provides protection, preservation and plays a vital role in making the product stand out from other similar products. (Robertson, 2006, p.3.)

1.2.1 Protection and preservation

Protection of the product is considered as the main function of the package. For majority of food products, the protection provided by the package is an important part of the preservation process. If the protection properties of the package are not fulfilled the content will deteriorate faster than expected. The food or drink packed inside the package requires certain standards in order for it to be hygienic. This requires protection from different environmental effects; such as water, water vapour, gases, odours and other foreign materials. The package must also be able to protect the surrounding environment from the product as well. (Robertson, 2006, p.3-4.)

When people think of packaging the first thing that comes to their mind is protection of the product from environmental influence. The most common type of protection is against contamination of a product by microbes, or protection against the loss of an important component from the product. The other types of protection that a packaging system may

provide are less often considered. For instance, protecting consumers from the dangerous contents of a package or protecting the public at large or the environment from dangerous materials or devices in a package can be a crucial consideration. (Morris, 2011, p.11.)

1.2.2 Communication

Packaging has an important function in communication. As the package is the face of the product, it has to communicate with the consumer. In other words, the package has to help the consumer to decide which item to purchase. It has also high impact in the marketing sector, especially with consumer products. It communicates and interacts with other devices with the help of optical and electronic means, as well as communicating with consumers using printed figures. Every retail food package must include nutritional information in the label. Information is communicated by every package to the consumer. The information can be as simple as label listing the contents and show the source and destination. However, most retails packages contain expensive and elaborative multi-coloured labels, bar codes and radio-frequency tags. (Morris, 2011, p.12.)

1.2.3 Containment

Numerous food items, especially liquids and free flowing solids are contained in packages to facilitate convenient handling and to keep it from spillage or loss. Table salt and sugar are good examples of free flowing solids. Liquid food products include water, milk, fruit juices, and a wide variety of other products. (Järvi-Kääriäinen et al., p.15-16.)

The two main objectives of containment are product compatibility and the ability to provide functional protection. These objectives can be achieved by evaluated choices in closure method, type of material, and sealing system. Defining the sealing system, for example, may involve decisions as to whether lining materials or a linerless closure will resist permeation of the product to standards. Other important variables arise in the interaction of closure and container and how they affect the efficiency of engagement and seal depending on the product's physical form and nature. Small objects are typically grouped together in one package for reasons of efficiency. (Morris, 2011.)

1.3 Packaging solutions

Packaging is an integral part of product, which contains and protects the product during its life cycle. As there are different types of packaging solutions; the most commonly used in food packaging are discussed below.

1.3.1 Skin packaging

Skin packaging is a packaging process that involves placing of a product on a paperboard or plastic substrate material and wrapping heated plastic film over the products. A vacuum draws the film down tightly. This gives the product secure and attractive package. The main components in skin packaging are the plastic film, heat seal coating and a substrate such as paperboard or corrugated board. Once the plastic film is inserted into the skin packaging machine, the board is placed on a vacuum platen and product is placed on the board. Film is held tightly in place by a clamping frame, directly below the heater. (Multivac, 2012.) An example of skin packaged meat product is illustrated in figure 2.



Figure 2. Vacuum skin packaging. (LINPAC, 2013.)

The packaging process starts by film heating and then clamping frame lowers down the heated film over the product and wraps it together with the board. The contact between the hot film and the board instantly become one and gives a transparent clear view of the product. The details of the skin packaging process are given in figure 3. (CN-thermoforming, 2014)

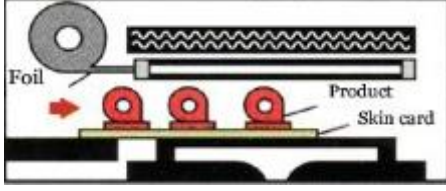
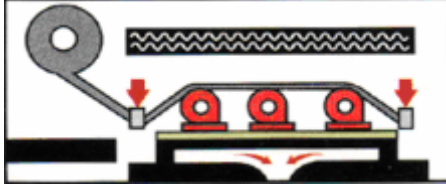
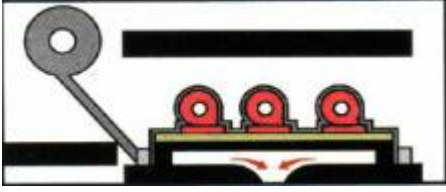
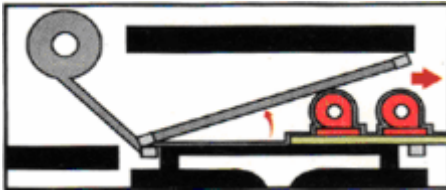
Illustration	Process
	<ol style="list-style-type: none"> 1. Heating of the skin film after placing the product and board onto the vacuum plates of the skin packaging machine.
	<ol style="list-style-type: none"> 2. Film is heated until it becomes formable and flexible, and lowered down over the product over the board. The heat helps activate the adhesives to get better bonding.
	<ol style="list-style-type: none"> 3. Vacuum is applied below the board to get good contact between the film and the board.
	<ol style="list-style-type: none"> 4. Packed product is moved out of the machine.

Figure 3. Skin packaging process. (CN-thermoforming, 2014.)

1.3.2 Tray lidding

PET is typically used as a lid to cover frozen single-serve food packaging in CPET trays. PET film has a huge advantage because of its ability to withstand a wide temperature range and is able to be used in both conventional oven and microwave. This market has a unique requirement in such a way that the film must seal to the tray, but must be peelable after heating. (Knowpap, 2011.) The principle of a tray lidding machine is given in figure 4.

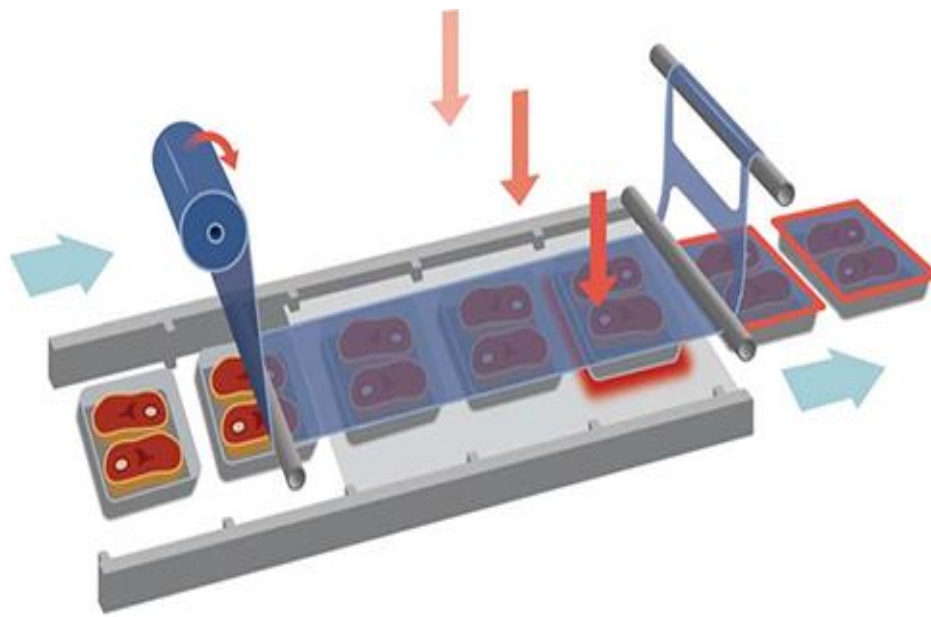


Figure 4. Tray lidding process. (Cryovac, 2013.)

1.3.3 Horizontal Form-Fill-Seal (HFFS)

As the name indicates, Form-Fill-Seal (FFS) machines are packaging machines that form, fill and seal a package on the same machine. HFFS is one of the main types of form fill seal machines. The process starts by edge sealing of the film in feed, followed by filling, heat sealing and cutting packs. (Knowpap, 2011.) The principle of filling and sealing process in HFFS line is given in figure 5.

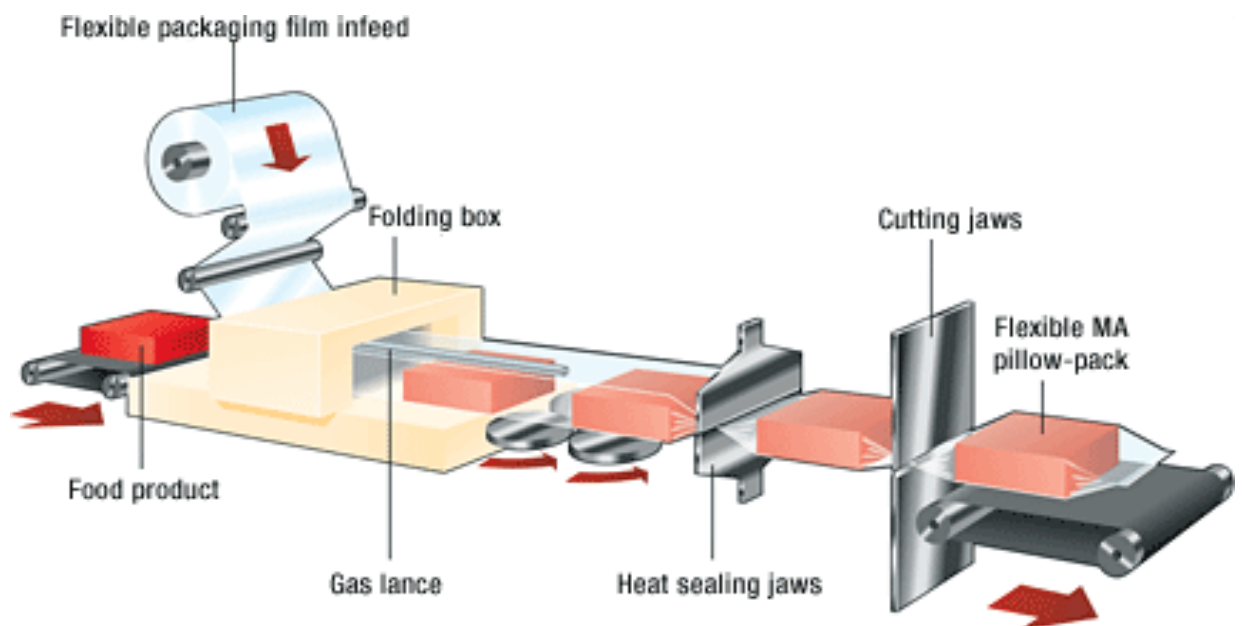


Figure 5. Horizontal Form-Fill-Seal process. (Cryovac, 2013.)

1.3.4 Vertical Flow Fill Seal (VFFS)

Vertical Flow Fill Seal is a packaging system which uses flexible packaging material to form a tube which is then filled vertically with product and sealed in a sequence of operations whilst the film is transported vertically downwards. VFFS are used in the consumer products industry for a wide variety of packaging applications. Various products like salt, tea, sugar, spices, snack food, wafers, detergents and candies are placed into formed pouches and then sealed. The pouch material is flexible and typically heat-sealable plastic. Paper is also used and sealed by glue. (Knowpap, 2011.) The functional principle of VFFS machine is given in figure 6.

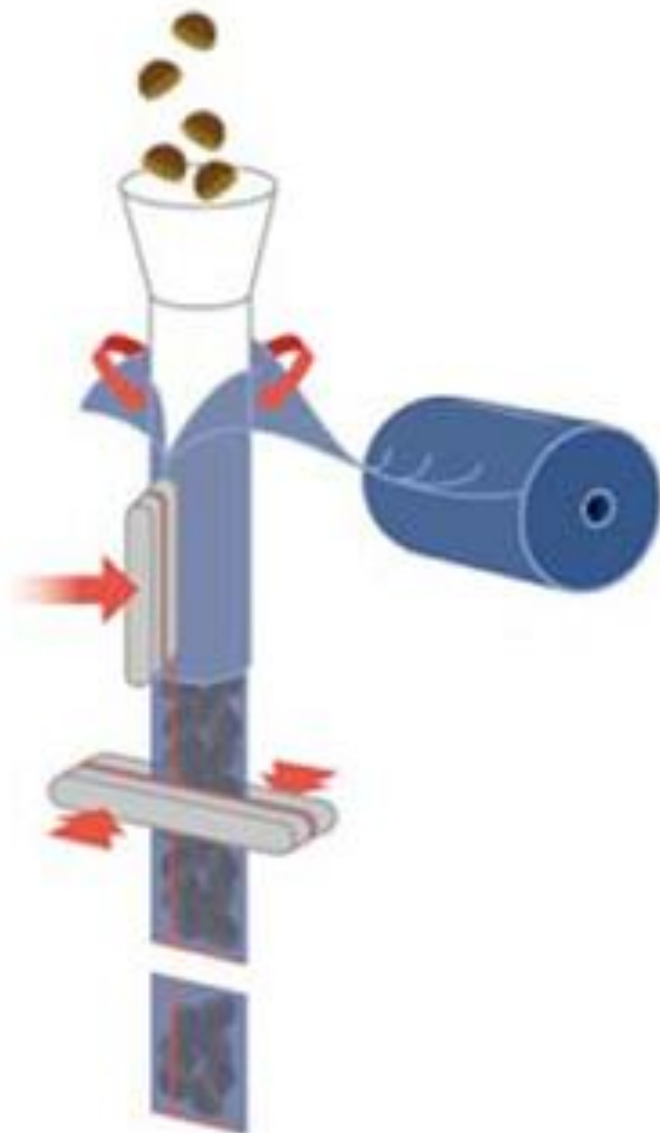


Figure 6. Vertical Flow Fill Seal process. (Cryovac, 2013.)

1.3.5 Thermoforming of plastics

Thermoforming process involves heating of thermoplastic sheet material to a certain temperature and forming it into a shape. The thermoplastic is drawn by a vacuum, pressure and mechanical assist into an open mould. Typical applications of thermoforming are in trays, bowls, and blister covers. Dairy products and frozen food items are very often packed internally using sheet and film. In many cases, food item is filled inside the formed trays, and sealed with a lid. (Morris, 2011, p.165.) Basic principle of thermoforming line is demonstrated in figure 7.

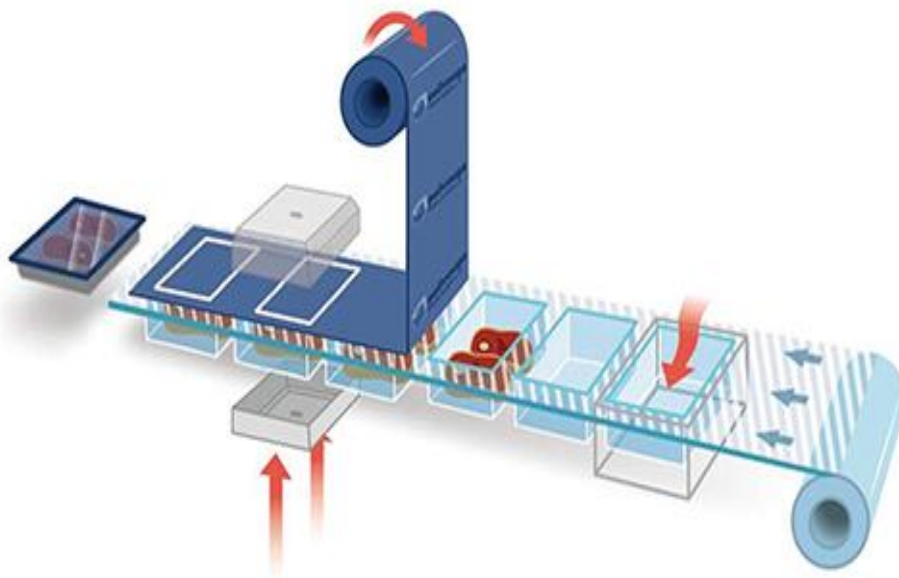


Figure 7. Thermoforming process. (Cryovac, 2013.)

1.3.6 Press forming of paperboard

Paperboard pressing is a process used to produce fibre trays. The main principle of paperboard pressing is placing a pre-cut fibre-based material into a mould and pressing it together. This gives the fibre material the desired shape. Its preferred if the fibre material is plastic coated because it gives good barrier property to the pressed tray. The plastic coating has also the ability to give good rigidity to the tray corners as the plastic material cools. This process is widely used in paperboard tray manufacturing. (Tanninen, 2014.)

1.4 Properties of Food

1.4.1 Thermal properties of food

Specific heat, thermal conductivity and thermal diffusivity are the three important thermal properties of food. Specific heat is the amount of heat needed to increase the temperature of 1 kg of a material by 1°C. The specific heat of compressible gases is usually quoted at fixed pressure, but in some applications where the pressure changes or high-pressure processing, it is quoted at constant volume. Thermal conductivity is a measure of heat conductivity in a material. It is the amount of heat transfer through unit thickness of a material per second at a constant temperature difference across the material. Thermal diffusivity is used to calculate time temperature distribution in materials undergoing heating or cooling. It's affected by the composition, especially by the moisture content. (Brody, 1995.)

1.4.2 Energy Balances

An energy balance states that “the amount of heat or mechanical energy entering a process = the total energy leaving with the products and wastes + stored energy + energy lost to the surroundings”. Energy losses to the environment may be ignored if the heat losses are minimized. (Fellows, 2003, p.27.)

1.4.3 Density and specific gravity

The density of a material is the amount of mass divided by its volume; and has units of kilogram per cubic meter. Density is not constant and changes with temperature and pressure. Higher temperature reduces the density of materials. The density of food is important during size reduction and mixing equipment process. It's also important in separation process. Density is extremely important in case of fluids. Specific gravity is broadly used instead of density in brewing and other alcoholic fermentations. The density of gases is dependent on the pressure and temperature. (Fellows, 2003, p.10.)

1.4.4 Hurdle technology

The hurdle technology introduces different kinds of preservation techniques that can be used in order to accomplish reliable food preservation methods and assure safety of the food products in their shelf-life. Preservation is done for example by combining heat,

reduced moisture content and anti-microbial chemicals. These techniques ensure the removal or controlling of pathogens in the food products. The most important hurdles used in food preservation are temperature, water activity, acidity, redox potential, preservatives and competitive microorganisms. Some hurdles affect the quality of the foods, because they have anti-microbial properties and at the same time improve the flavour of the products. The same hurdle could have a positive or negative effect on foods, depending on its intensity. (Fellows, 2003, p.57.)

1.5 Paper and Paperboard Packaging

In today's technology a wide range of paper and paperboard products are used. Paper and paperboard products are found in many areas such as supermarkets, post offices, fast food, dispensing machines, pharmacies, etc. The products can be found at a point of sale as a primary packaging and in distribution as a secondary packaging. Paper and paperboard are made of a network of cellulose fibres. There are different types of paper and paperboards classified based on their appearance, strength and other properties. The amount of fibres used and how they are processed are also important factors in classifying paper and paperboards. Paper and paperboard can be used at a wide temperature range as storage for frozen foods and also in conditions of microwave and conventional ovens. (Kirwan, 2003, p.241-242.)

Corrugated fibre board accounts for almost 63% of the paperboard tonnage used in packaging. Since most products are shipped in corrugated fibreboard boxes, the price is sensitive to the overall economy's performance. A period of growth directly increases the demand for boxes by every industry, causing suppliers to reach full production capacity, which leads to higher prices. Paperboard packing prices are also affected by the cost of wood and energy. Energy is a large component of the production cost. (Lennersten, 1998.)

The deformation of paperboard beyond the elastic limit shows the elastic-plastic behaviour. This indicates that the force applied is no longer proportional to the deformation. When the force is removed from the paperboard the paperboard does not get back its original shape. The elastic limit is typically around 0.2% relative elongation. (Lennersten, 1998.) The elastic behaviour of paperboard is illustrated in figure 8.

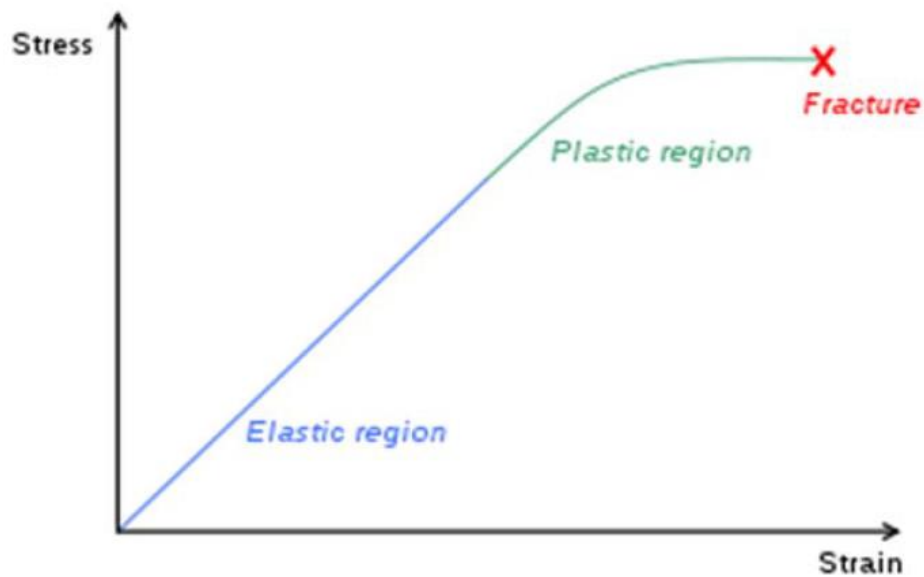


Figure 8. Elastic and plastic behaviour of typical paperboard. (Chen, 2008.)

Paperboards can be considered as orthotropic based on the fibre properties and the manufacturing process it goes under. Which means that the materials will have different properties in three orthogonal principal directions; MD (machine direction), CD (cross machine direction) and ZD (thickness direction). (Lennersten, 1998.) This principle is illustrated in figure 9.

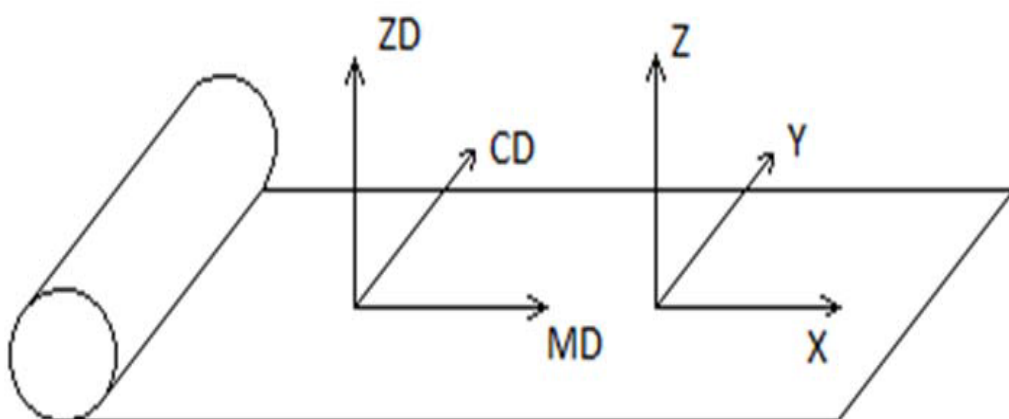


Figure 9. Principal material direction of paperboard. (Chen, 2008.)

1.5.1 Paperboard Grades

- Linerboard – board having at least two plies, the top layer being of relatively better quality; usually made on a Fourdrinier machine with 100% virgin pulp furnish
- Food board - board used for food packaging having a single-ply or multi-ply construction, usually made from 100% bleached virgin pulp furnish
- Folding boxboard – multi-ply board used to make folding boxes: middle plies are made from mechanical pulp sandwiched between two layers of virgin chemical pulp
- Chipboard – multi-ply board made from 100% recovered fibre
- Baseboard – board that will ultimately be coated or covered. (Kiviranta, 2000.)

1.5.2 Barriers properties

Every package has to provide barrier properties from foreign particles and foreign matters such as oxygen, water vapour, dust, etc. When designing a package, it's essential to consider permeability. For instance, there are some packages that contain moisture or oxygen absorbers which help extend shelf life of the product. 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.)

1.5.3 Manufacturing Process

Paperboard manufacturing has a long history. The paper industry has transformed from labour manual operations, one sheet at a time to large-scale, computerized and efficient manufacturing processes. As the first paper was made in China round the year 105 AD. It was made of cellulose fibre from flax, cotton and other plants. The basic paper manufacturing process starts by separation of cellulose fibres out from natural and renewable raw materials. The fibres are suspended in water. Most of the water is drained and dried to get wet fibres. A single sheet of paper is composed of fine layers of cellulose fibres connected to each other. There are two main types of paperboards: single ply and multi ply boards. Paperboards are usually made in several layers by repeated application of dilute fibre suspension to get a good quality. The multi-layered material is mostly used as a packaging material and in graphical applications. (Iggesund, 2004.) The paperboard manufacturing process is illustrated in figure 10.

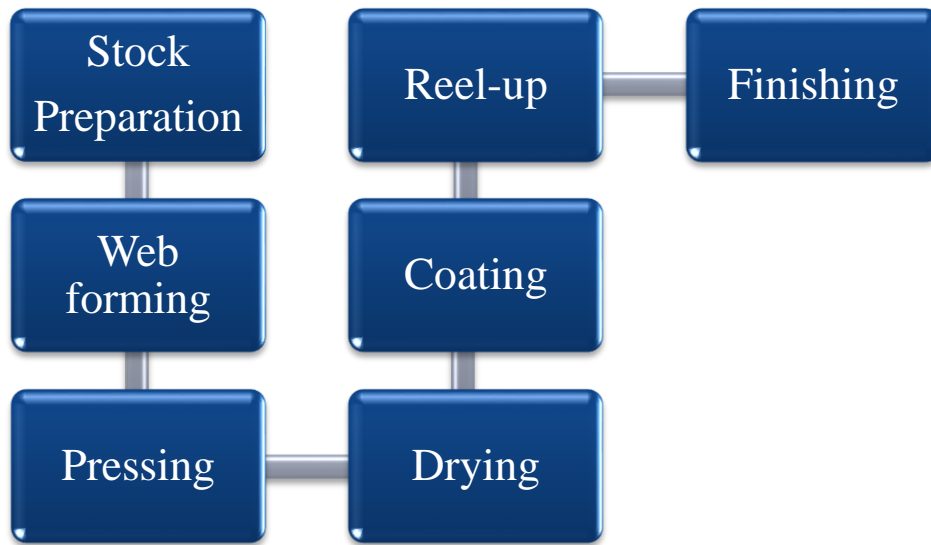


Figure 10. Paper and paperboard manufacturing process. (Kirwan, 2003.)

1.5.4 Coating

Coating is the application of one or more coating layers to the original fibre web. Coating can be applied up to three layers and dried by using infrared heaters and passing it over steam heated dryers. White pigmented coatings are applied on a machine to one or both sides of papers and paperboards. The pigment contains minerals such as calcium carbonate, adhesives, and china clay in a water suspension. Some widely used techniques are the application by roll or jet and the metering with air knife, blade or bar. (Kirwan, 2003, p.248.) In figure 11 is an example of coating structure of paperboard.

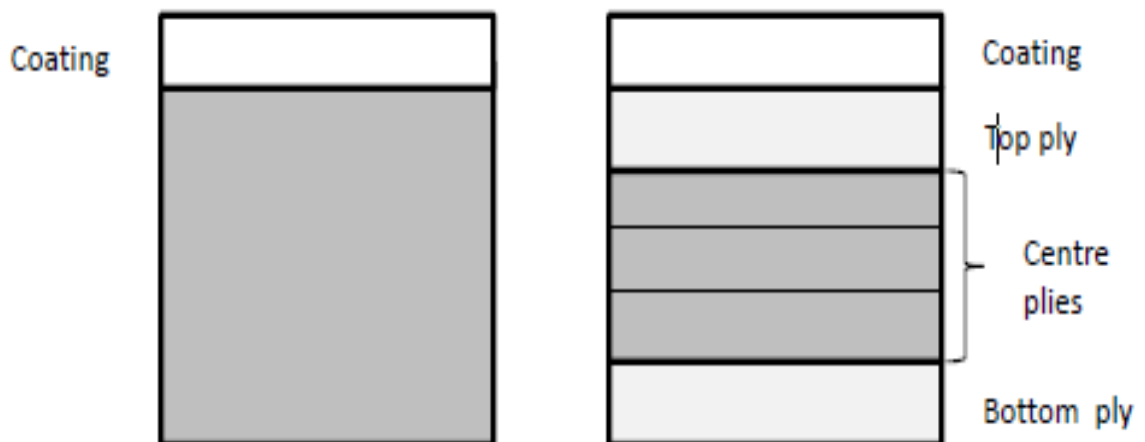


Figure 11. Example of the cross-section of two different paperboard designs. (Iggesund, 2004.)

Coating is the simplest method of adding other functions to paper. The active function materials such as CMCH, PVDC, PE, wax, etc. are either applied from a solvent solution, water based dispersion or as a solid, in molten state. (Kirwan, 2003.)

Solvent-based coatings

This type of coating is applied to the paper so that the surface does not start peeling under high temperature heat sealing process. The solvent-based coating is applied to the paper using gravure technique and it is mainly comprised of varnish. The varnish could be UV cured; it could possess high gloss and heat resistance. (Kirwan, 2003, p.92.)

Water-based coating

Water-based coating is another type of coating using roll application. This is a non-contact technique by which an air knife is used to maintain the coating weight and smoothness. The coating machine enables several applications to be applied and dried in one pass giving a total coating weight of 30g/m². (Kirwan, 2003, p.92.)

1.5.5 Additives

Paper and paper board producers use surface additive to get better functional and visual properties of the product. It improves properties like print gloss and opacity, and open up possibilities to reduce total cost of operations and maximizing quality and consistency. (Kemira, 2014.)

1.5.6 Paper coating lubricant

Lubricants are used to enhance the coating colour flow properties, increase coating quality and improve smoothness. Improved smoothness reduces the friction between the machine and coating colour. Flow properties can be enhanced by using sulfonated oils and polyethylene glycol coatings. Whereas, calenderability and brush finishability can be improved by using stearates and various wax emulsions. (Knowpap, 2011.)

1.5.7 Types of Paperboard

Solid Bleached Board (SBB)

This type of paperboard is made from a chemical pulp. The term SBS (Solid Bleached Sulphate) is sometimes used to describe this product and method of pulp production. The

SBS board is pure and hygienic and therefore suitable for aroma and flavour sensitive food items. It has an excellent surface and printing characteristics. It can be die cut, creased, folded and glued with no difficulty. Therefore it's useful for wide area of applications. Some applications of SBB are in chocolate packages, frozen foods, cheese, etc. (Kirwan, 2003, p.251.) In figure 12 is the cross-section of a SBB presented.

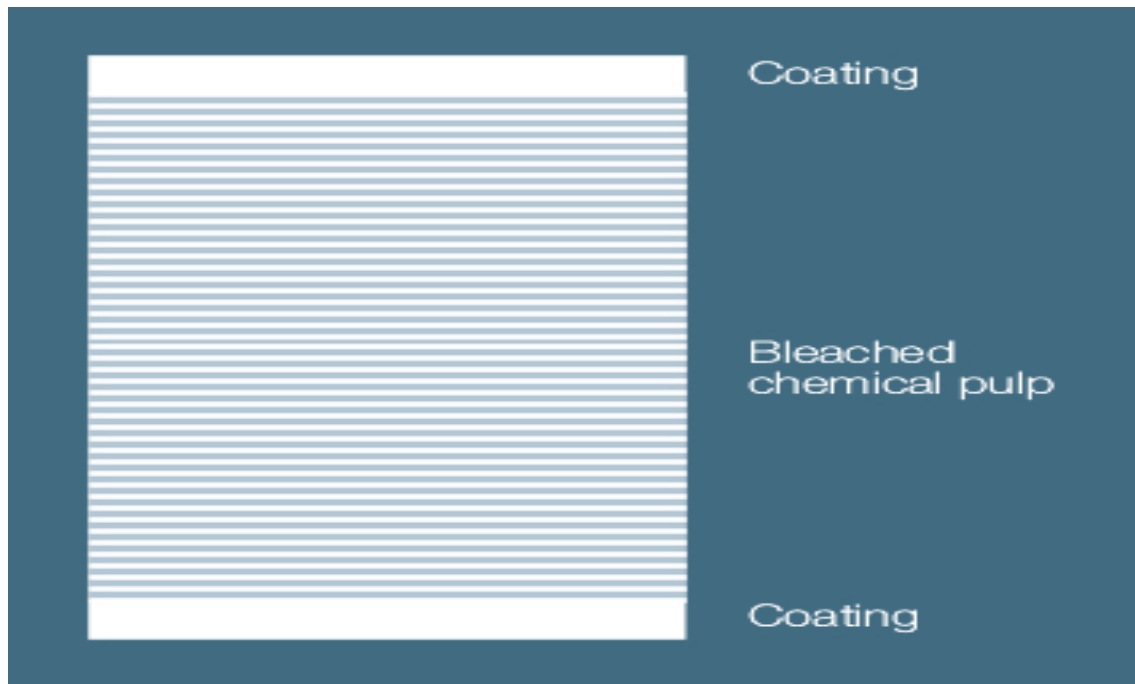


Figure 12. Solid Bleached Board (SBB) layers. (Iggesund, 2004.)

Folding Box Board (FBB)

This board is made of bleached chemical pulp at the top layer, mechanical pulp in the middle layer and bleached chemical pulp at the lower layer. The top layer is usually coated with a white mineral pigment coating. The lower layer is bleached with a translucent chemical pulp and there for has cream colour. The cross-section of Folding Box Board is illustrated in figure 13. (Iggesund, 2004)

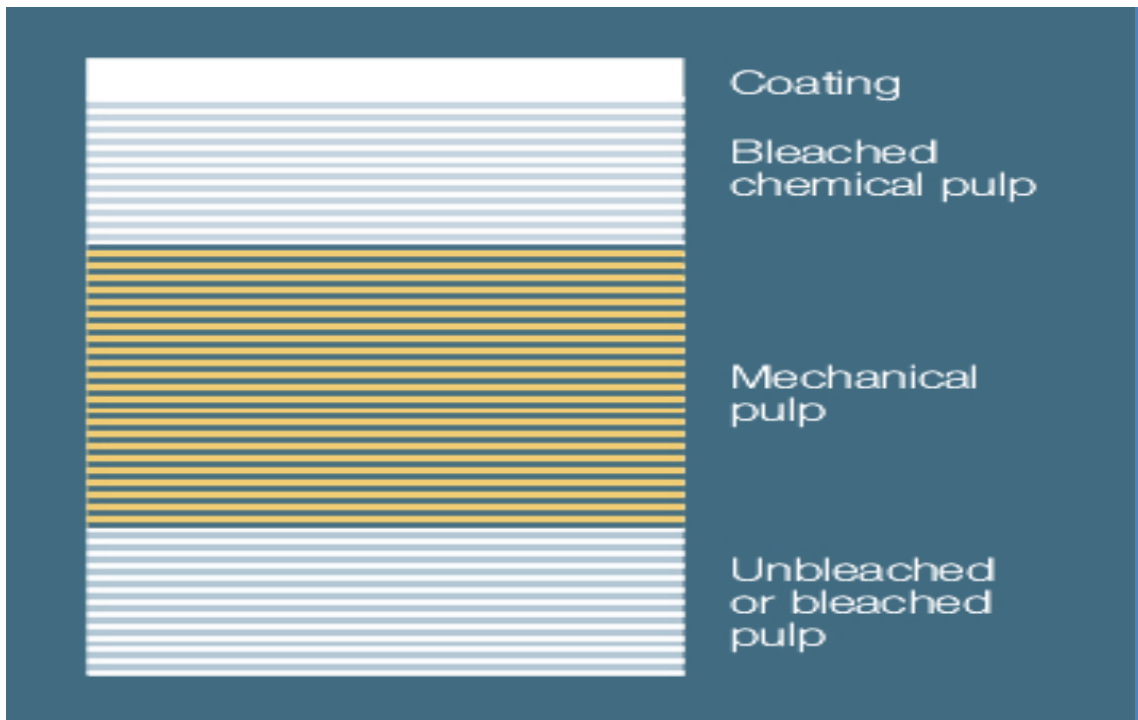


Figure 13. Folding Box Board (FBB) layers. (Iggesund, 2004)

Solid Unbleached Board (SUB)

Also, known as coated solid unbleached board has three layers of synthetic pigment coatings on top and reverse side. It is 100% virgin and unbleached. The unbleached chemical pulp can sometimes be replaced by the recycled fibres. The fundamental function of solid unbleached board coating is to improve the printing surface. (Kirwan, 2003, p.251.) In figure 14 is an illustration of the cross-section of a Solid Unbleached Board.

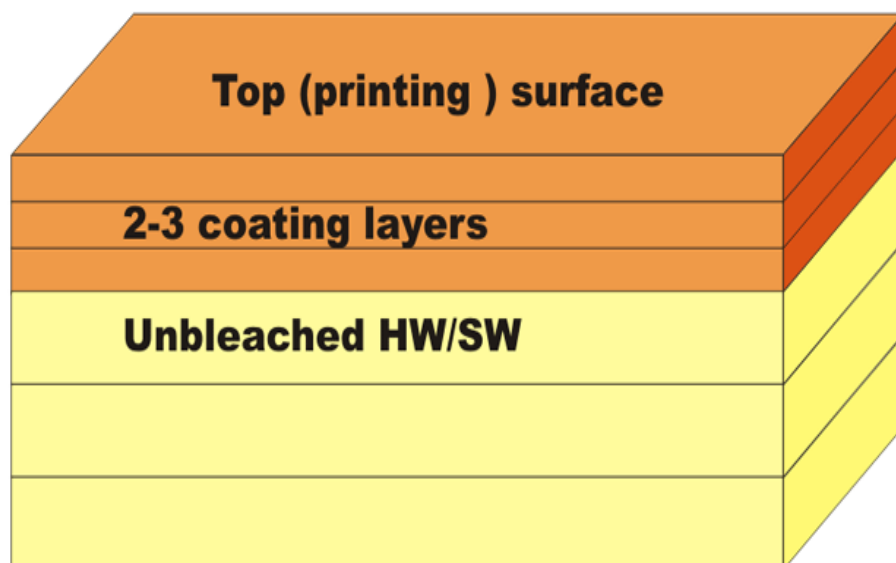


Figure 14. Solid Unbleached Board. (Knowpap, 2011.)

White Lined Chipboard (WLC)

The white lined chipboard is manufactured in a number of layers with selected grades of raw materials. Typically, it consists of bleached chemical pulp on the top or printing surface. There are two to three layers of coatings. The second layer is made of bleached chemical whereas the middle layers are unbleached recycled pulps containing mixed paper or carton waste. The bottom layer consists of recycled pulp which is specially selected. This type of paper is used in many applications such as in the packaging of cold and chilled foods, dried food, cereal, etc. (Robertson, 2006, p.183.) Cross-section of White Lined Chipboard is illustrated in figure 15.

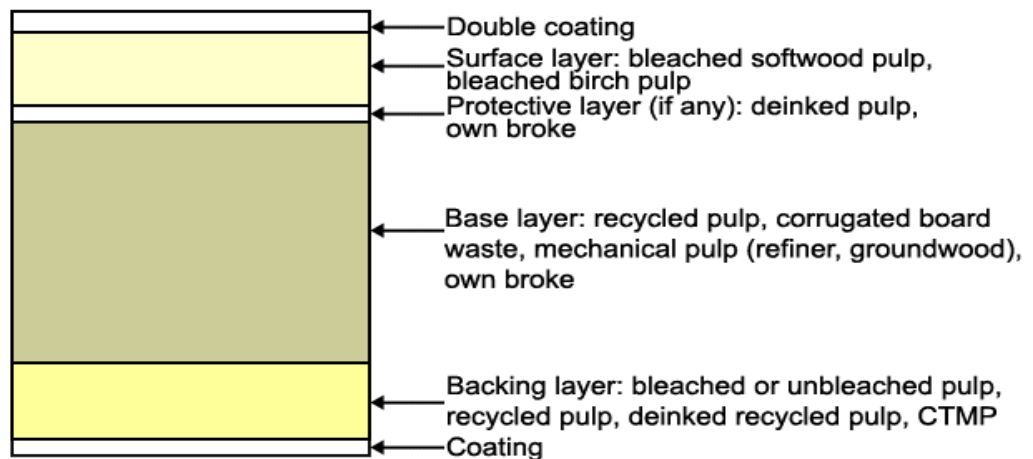


Figure 15. White Lined Chipboard. (Know pap, 2014.)

1.6 Paperboard-Plastic Joining

Packaging materials are characterized based on many factors such as barrier properties, strength and ability to withstand abuse during filling and shipment process. The material used in the package is classified based on the package function. For example, from the barrier function point of view, there are two categories of films. The first category is the type of film used as a barrier layer; this film keeps the entry of liquid or gasses on one side. The second category consists of semi-permeable membranes which allow certain materials to pass through but block others. (Ebnesajjad, 2012, p.72.)

1.6.1 Extrusion Coating

Extrusion coating is formed when molten polymer is applied as a thin film on to a moving substrate such as paper, paperboard, metal foil or plastic film and then cooled. The coated substrate then passes between a set of counter rotating rolls that press the coating onto the substrate to ensure complete contact and adhesion. Extrusion laminating, also known as sandwich laminating is a process related to extrusion coating by which extrusion coated layer is used as an adhesive layer. While the pressure rolls are hot a second layer is applied and pressed in the extrusion coating. The coated layer has also moisture barrier properties. A typical polymer used in this process is PE. (Liesl, 2003, p.20-21.)

The polymer layer gives the fibre material water vapour barrier, gas barrier, oil barriers, grease barriers, aroma barrier and heat sealability properties. Co extrusion coating is composed of several layers of different polymers. Extrusion coating has many applications in liquid packaging, flexible packaging, rigid packaging, etc. The principle of extrusion coating is presented in figure 16. (Kuusipalo, 2007.)

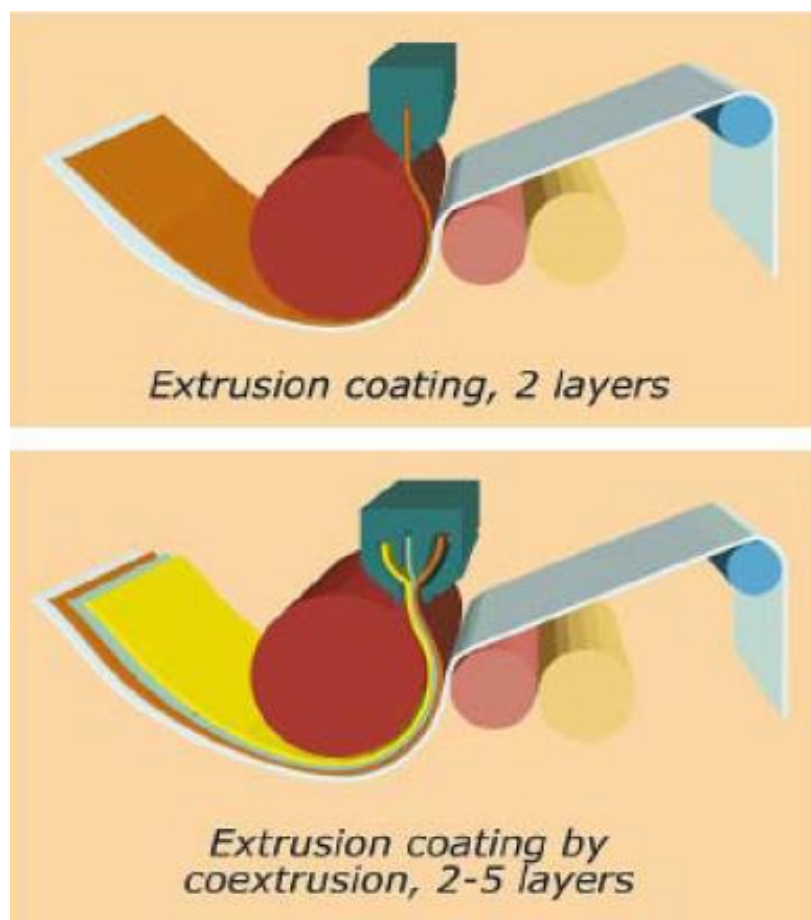


Figure 16. Extrusion coating. (Kuusipalo, 2007.)

1.6.2 Hot melt

Hot melts are solid adhesives which are activated upon heating above their softening point. When applied on the paperboard in molten form it contains thermoplastics, waxes and modifiers. 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 EVAc polymer due to its good specific adhesion property. Hot melt adhesives creates a strong and rigid bond. The strength depends on the mechanical stress, temperature, relative humidity, cohesion and adhesion. Hot melts adhesive systems are also easy to apply, low in cost and possess short setting time in the bonding process.

(Lahtinen, p.5.)

1.6.3 Lamination

Lamination is a process of coating a printed document by applying a film. The coating could be on either one side or both sides. The main purpose of lamination is sealing an item or an object in between two pieces of a thin plastic film either by heating or cold press. It protects the object or item from liquid penetration. (Kuusipalo, 2007.)

During paperboard lamination melted resin is formed into thin hot film, which is coated onto a moving paperboard. Then the coated substrate passes between a set of counter rotating rolls to ensure complete contact and adhesion between the coating material and the substrate. (Kuusipalo, 2007, p. 23.) The principle of extrusion lamination is presented in figure 17.

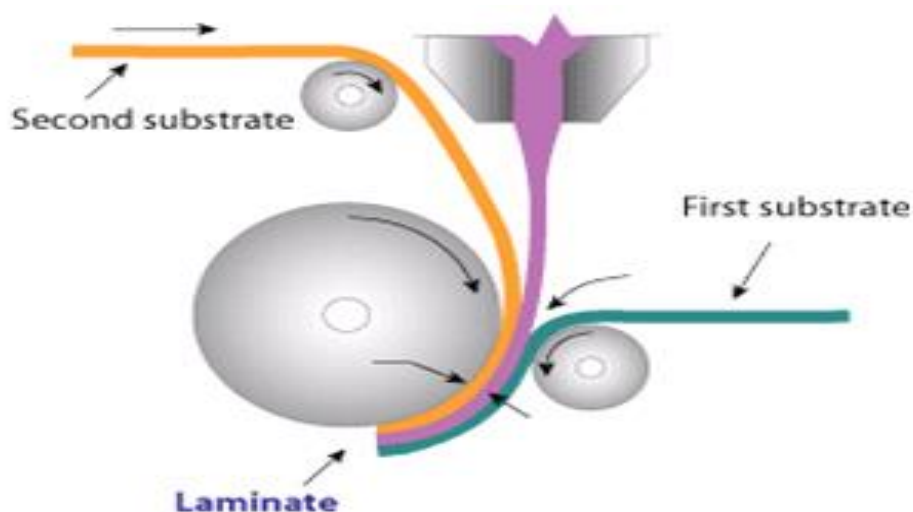


Figure 17. Extrusion lamination process. (Safe pack, 2014.)

Various laminating films

a. PET – Polyethylene Terephthalate – Also known as polyester is usually made via casting process which gives it a crystalline nature when laminated with a paperboard. The crystalline nature gives the possibility of the forming die to be heated to certain degree around 125-135 degree Celsius. This offers less dwell time and higher speed of lamination. During PET lamination; a roll of PET film and paperboard are unwound at the same time and goes under a pressing die with glue applied on either side. A very important factor in PET lamination is the correct amount and type of adhesives must be used in order to get a good bondage between the film and substrate. Otherwise, the heat, dwell and pressure combined with the moisture in the substrate may cause the film to delaminate from the substrate. If a printing is to be applied on either side the type of adhesive used may need some modification before laminating. It's almost impossible to get a fibre tear adhesion if clay coating is on the surface before laminating. PET coated board can be used in microwave and conventional ovens up to 200°C for 30 minutes. (Gralex, 2011.)

b. LDPE – Low Density Polyethylene – LDPE can be applied in lamination in the same manner as PET. The only difference is that the adhesive used is different from the one in PET lamination due to its different nature. The right amount and type of adhesives should be utilized in order to get a fibre tear bond between the film and substrates to avoid delaminating from the paperboard. It can be challenging to press LDPE coated paperboard on forming machines due to its low melt temperature. For that reason, it's essential to prevent heat transfer through the material to the die and to prevent heat transfer to the LDPE through the substrate by applying thicker substrate. Good quality trays are formed at lower temperatures and with higher dwell time. LDPE laminated boards are suitable for microwave use only to re-warm cooked food. (Gralex, 2011.)

c. HDPE – High Density Polyethylene - HDPE can also be laminated with the same methods as described above. Similarly, a different type of adhesive material is used due to its different nature. It's also very important that the right type and amount of adhesive is used in order to get good bonding between HDPE and the substrate. Otherwise, the combined effect of heat, dwell and pressure with the moisture could cause the film to delaminate from the paperboard. Although HDPE is much better than LDPE, coating can stick to the dies during press forming in heated conditions. It's suggested that lower

temperature and higher dwell times are used in order to get good quality tray laminate. HDPE laminated trays are used for microwave use only for short time re-warming. (Gralex, 2011.)

d. PP – Polypropylene - PP materials come in different forms and gives high gloss to the laminate. It's much easier to laminate PP using a forming machine than the above materials since heat transfer is not a big issue. PP forming is suggested at lower temperature and higher dwell time than PET to get good quality trays. The trays can handle higher temperature with most foods and can be used only in microwaves. (Gralex, 2011.)

1.6.4 Gluing

There are several things to take into account when choosing the right kind of glue for a package. For instance, the type of product, packaging material, temperature, humidity and equipment used has to be considered. The glue used for food item packaging has to be water-soluble, harmless and approved for food packaging use. This means that there shouldn't be any kind of change caused, if the glue comes in contact with the food. Commonly used glue types are starch based, dextrin, casein or synthetic polymers. They can be used at room temperatures and often need some time to dry before seeing good result. (Kuusipalo, 2007, p.17.)

1.6.5 Ultrasonic sealing

Ultrasonic sealing method is similar to high-frequency induction heating which is used to seal corners of plastic-coated paperboard trays. In this process, acoustic vibration causes mechanical wave motion and this oscillation results in friction between the particles which generates heat. It is a reliable and high-speed sealing process and requires exceptionally low energy. This method affects only the surfaces. 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 energy breaks the particles to smaller pieces. (Kuusipalo, 2007, p.36.)

1.6.6 Heat sealing

Heat sealing is a process of joining thermoplastic surfaces using heat and pressure. When a plastic surface is heated, the crystalline structures starts to melt. The materials to be joined

become amorphous when the temperature of both materials is at the same level. After that, molecules from the two materials start to join with the help of pressure and time. When the material is cooled a firm bond can be formed. The basic construction requires compatible heat-sealing polymers on the face, top or print side, and the reverse side. This is usually provided by extrusion coatings low-density polyethylene (LDPE). Polyethylene and polypropylene are extrusion coated to the paperboards to heat seal when the containers are formed. (Kuusipalo, 2007, p.1.) The basic mechanism of heat sealing is presented in figure 18.

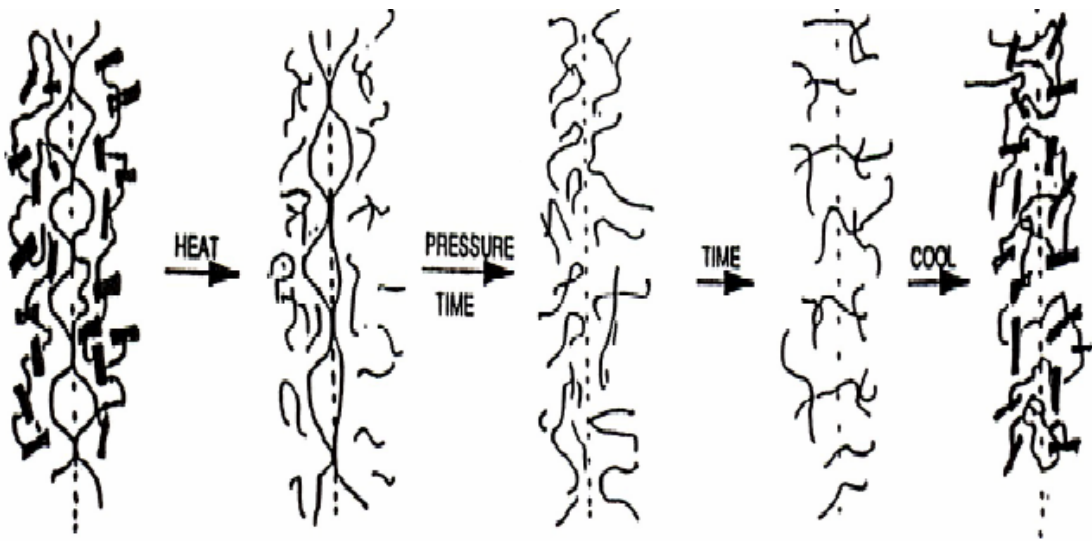


Figure 18. Basic principle of heat sealing. (Kuusipalo, 2007, p.3.)

2 MATERIALS AND METHODS

2.1 Paperboard material

In this section the materials and methods used for the empirical work done in this thesis are presented.

2.1.1 Trayforma Natura

Trayforma Natura boards are pure and safe food packaging materials with exceptional formability and printability. Trayforma Natura offers an excellent combination of design, protection and user convenience, from freezer to oven to table. Trayforma Natura offers material options that have been developed to warm up or heat prepared and semi-prepared foods in their original packaging, in either a microwave or conventional oven. This dual ovenability is a convenience that is highly appreciated by time-pressured consumers. Trayforma Natura boards are easily convertible and extremely stable, offering many opportunities for shelf differentiation. They are specially developed for use as pressed or folded trays, bowls and plates. The structure of Trayforma Natura Board is given in figure 19. (Stora Enso, 2013.)

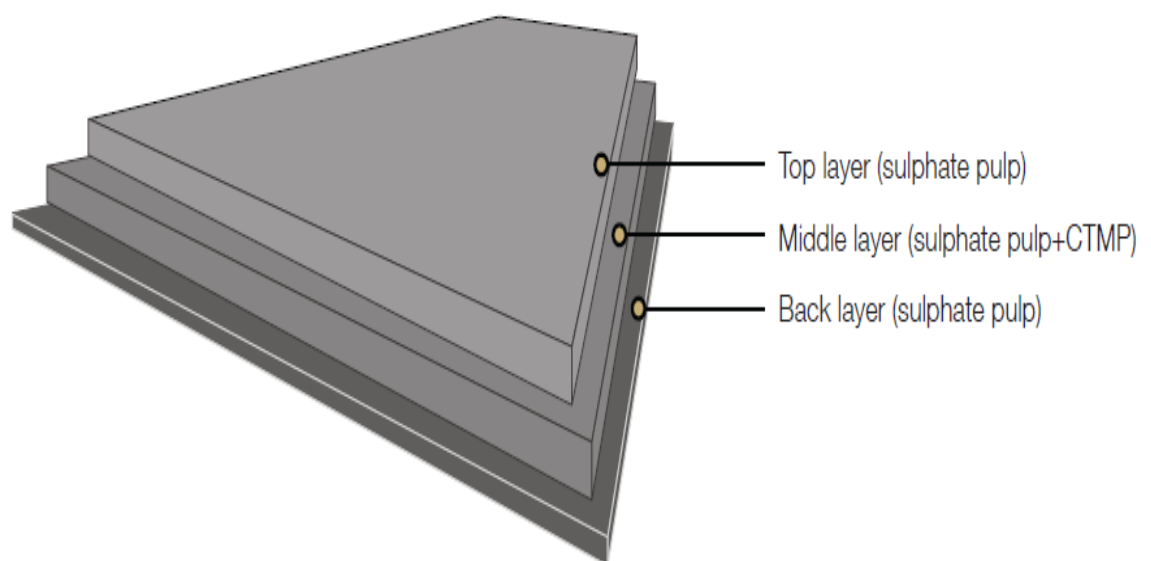


Figure 19. Trayforma Natura Tray board. (Stora Enso, 2013.)

Some of the technical data and specifications for Trayforma Natura paperboard are presented in table 1.

Table 1. Specifications for Trayforma Natura (Stora Enso, 2013).

Property / Unit	
Grammage, g/m ²	350
Thickness, μm	460
Bending resistance L&W 15° MD, mN	560
Bending resistance L&W 15° CD, mN	190
Moisture, %	9.5
Brightness D65/10, Top	85
Surface Smoothness, Bendtsen, ml/min, Top	600
Surface Smoothness, Bendtsen, ml/min, Reverse	750
Stretch CD, %	6.0

2.1.2 Performa Natura PE

In addition to the Stora Enso Trayforma Natura paperboard, PE laminated three layer paperboard was used in order to compare and contrast the coating possibility. Performa Natura board is used in food packaging and for pharmaceutical purposes. Usually it's coated with a suitable barrier to provide protection against moisture, grease or oxygen, depending on the specific requirements of the product packed. The structure of Performa Natura PE board is illustrated in figure 20. (Stora Enso, 2013.)

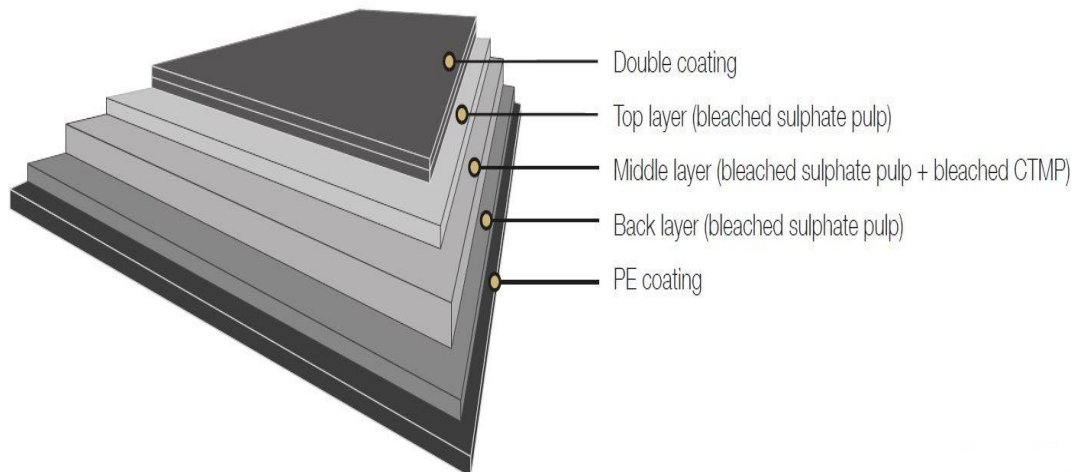


Figure 20. Performa Natura PE board. (Stora Enso, 2013.)

Some of the technical data and specifications for Trayforma Natura paperboard are presented in table 2.

Table 2. Specifications for Performa Natura PE (Stora Enso, 2013).

Property / Unit	
Grammage, g/m ²	210
Thickness, μm	273
Bending resistance L&W 15° MD, mN	120
Bending resistance L&W 15° CD, mN	55
Moisture, %	6.5
Brightness D65/10, Top	85

2.2 Coating films

The coating films were provided by Südpack. Südpack Verpackungen GmbH & Co. KG is a plastic packaging solutions provider based in Germany. The company's product portfolio includes multi-layer films, flexible films, top films, re-sealable films, cheese maturing solutions, technical films, rigid films, packaging printing, convenience films, and plastics cans. Südpack's product caters to food, non-food and medical markets. Its products have wide applications in MAP and production tests through different packaging machines for small production runs and mock-ups. Südpack operates production facilities in France, Germany and Switzerland. (Südpack, 2014)

MULTIFOL GVA 90

MULTIFOL GVA90 has coextruded high barrier multilayer film with the structure PA/PE/EVOH/PE. It has an excellent transparency and flexibility. The film has a broad sealing range, excellent oxygen barrier and good mechanical behaviour, as well as high toughness and high impact resistance. The film is mainly used on form-fill-seal-thermoforming machines for flexible packaging and vacuum packaging. This materials used corresponds to the relevant legislation, especially the Germany Food Packaging Law. The technical features are given in table 3. (Südpack, 2014)

Table 3. MULTIFOL GVA 90 technical description (Südpack, 2014).

Aspect	Value	Unit
Thickness	90	µm
Sealing range	115 – 155	C
Tensile strength (MD)	20 – 40	N/mm ²
CO ₂ -permeability	7	cm ² /m ² d bar
Oxygen-permeability	2	cm ² /m ² d bar
Water vapour permeability	< 2	g/m ²
Stock temperature	20-25	°C

MULTIFOL SV 100

MULTIFOL SV100 is a multilayer PE sealable skin film. This material is used in skin packaging process due to its good elasticity behaviour. It can resist heating during skin packaging; it also cools down fast and solidifies. MULTIFOL SV 100 is a thicker material and has higher sealing range compared to MULTIFOL GV 90. The technical specifications are given in table 4. (Südpack, 2014)

Table 4. MULTIFOL SV 100 technical description (Südpack, 2014).

Aspect	Value	Unit
Thickness	100	μm
Sealing range	150 – 195	C
CO ₂ -permeability	<6	cm ² /m ² d bar
Oxygen-permeability	<2	cm ² /m ² d bar
Water vapour permeability	< 2	g/m ²
N ₂ -permeability	<1	cm ² /m ² d bar
Stock temperature	20-25	°C

2.3 Blank Geometry

Manufacturing of models and small-batch production was done using Kongsberg XE-10 sample cutter machine. The machine gives accurate and good quality cut and creases from a CAD drawing. Tray blanks were cut and creased into the geometry presented in figure 21. The tray blank has an area of 480.2 cm² and dimensions of 28.5 cm x 19.8cm. The area was kept constant for all test pieces. The blank geometry is illustrated in figure 21.

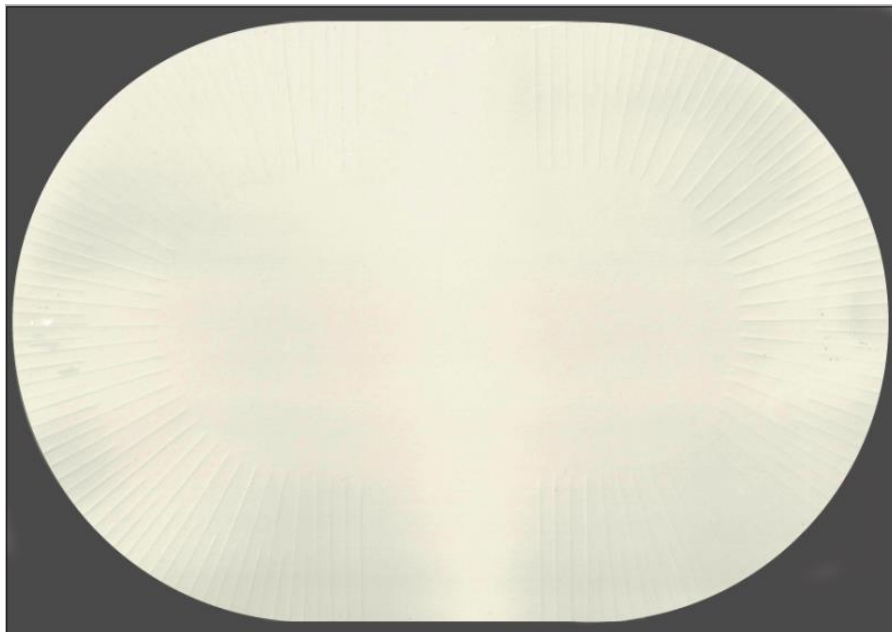


Figure 21. Blank geometry.

2.4 Die configuration

During the test all the test pieces were placed into the mould, paperboard facing the female cavity followed by plastic film under it. In addition to these a normal printing paper was used as a protective layer to protect the male mould from possible damage in case of the film melts. The LUT adjustable packaging line was used for the test which is located at the Laboratory of Packaging Technology. The packaging lines' main product is pressed paperboard trays. It's used in die-cutting and press-forming of sample boards for research purposes as well. The machine also has a real-time quality monitoring feature. Material order in the mould is presented in figure 22.

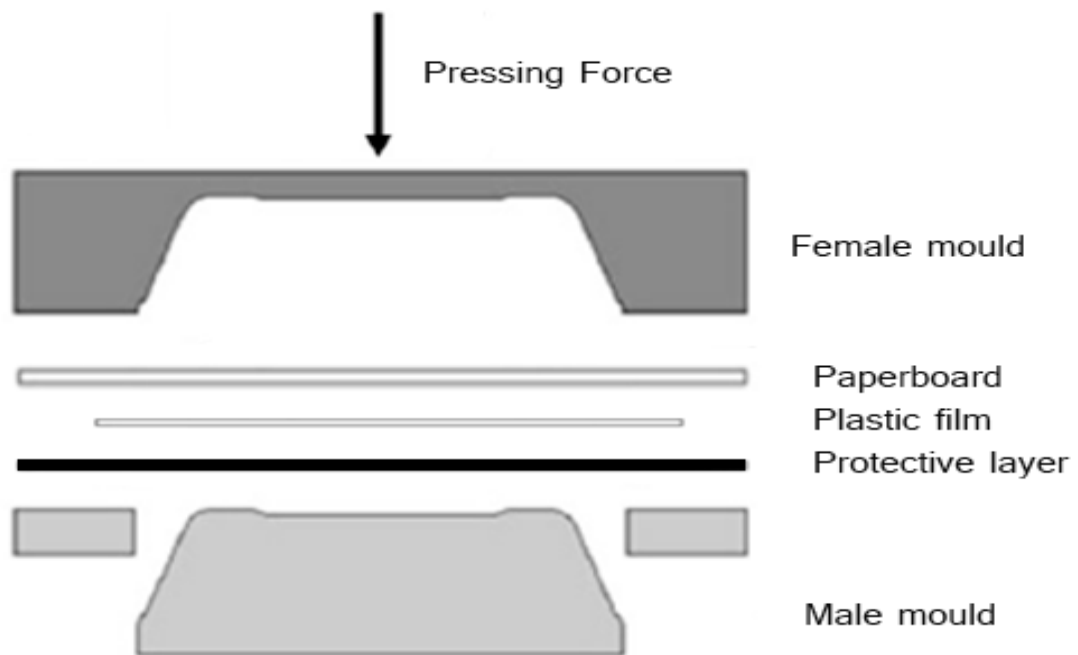


Figure 22. Tray-forming configuration inside the mould. (Tanninen et al, 2014.)

The moulding process has a certain process flow, insertion of the paperboard with the film together, is done manually and the machine claps the paperboard at the edges around the tray. The phases of tray pressing process are presented in figure 23.

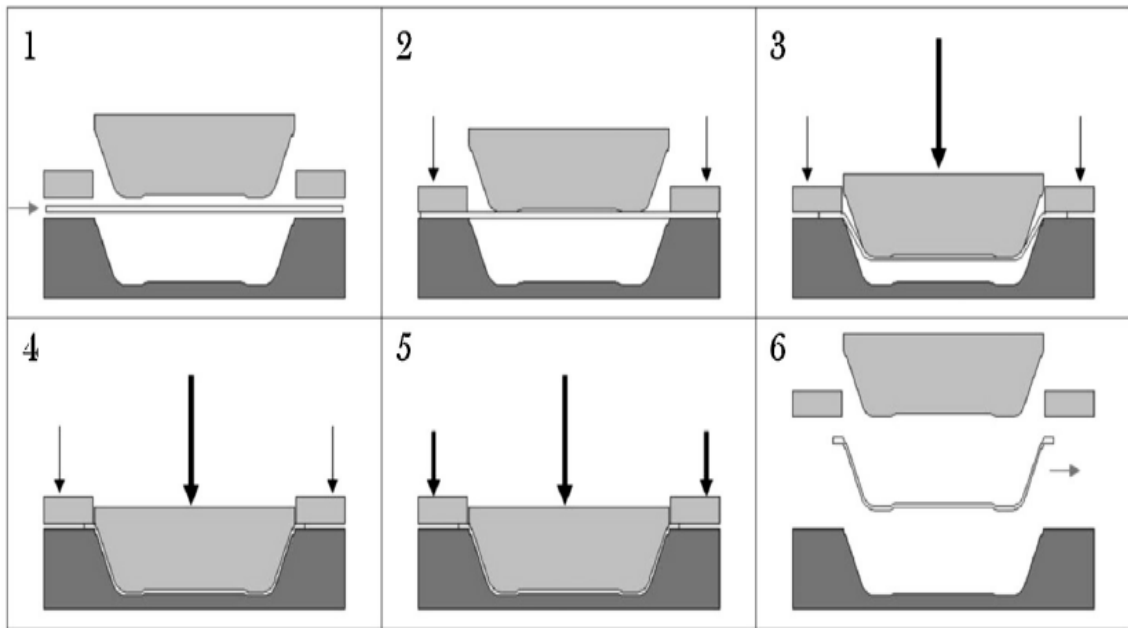


Figure 23. Paperboard tray forming cycle. (Tanninen et al, 2014.)

Phase 1: The blank board is positioned in between the moulds.

Phase 2: The blank holding force tightens the blank between the rim and the female tool.

Phase 3: The male tool presses the blank into the mould cavity in the female tool. Folding of the tray corners is controlled with blank holding force.

Phase 4: The male tool is held at the bottom end of the stroke for a set time.

Phase 5: The flange of the tray is flattened by the rim tool.

Phase 6: The formed tray is removed, and new blank can be fed into the tray press.

2.5 Process parameters

In this test only the female tool was heated at different temperature ranges, while the male tool was kept at room temperature. Both the Performa Natura PE and Trayforma Natura paperboards were tested with two different skin film types. The adhesion of the film with the board was analysed after press forming. Four different combinations of film against paperboard were analysed in six different temperature ranges by keeping the pressing speed, pressing time and force constant. The used machine parameters are given in table 5.

Table 5. Machine parameters.

Pressing dwell time	Rim tool holding force	Pressing force	Female mould temperature	Male mould temperature
2 sec	1.16 kN	100 kN	100 ⁰ c -180 ⁰ c	room temperature

The analysis was done by observing and evaluating the bonding and adhesion of test pieces. Samples were compared to each other on the basis of material adhesion to determine which of the two film materials better adhere to the paperboard better. After a visual evaluation of press formed test pieces, the samples were graded on 0-5 scale according to their level of adhesion. The adhesion scale is given in table 6

Table 6. Sample piece adhesion grading scale.

Grade	Description
5	Excellent bonding
4	Very good bonding
3	Good bonding
2	Poor bonding
1	Very poor bonding
0	No bonding at all

3 RESULTS AND ANALYSIS

3.1 Results of laboratory test

Adhesion quality grading and evaluation results for all test combinations are presented in table 7.

Table 7. Adhesion and bonding test results.

Temp [°C]	Performa Natura PE		Trayforma Natura	
	MULTIFOL SV100	MULTIFOL GVA 90	MULTIFOL SV100	MULTIFOL GVA 90
100	1	1	0	0
110	2	2	0	1
120	3	2	1	1
130	3	2	2	2
150	4	3	3	3
160	5	3	3	4

Based on these results, better adhesion property is recorded at higher temperature ranges for both plastic film types. In both cases there was good bonding at temperature between 150°C -160°C. Example of the test pieces is presented in figure 24.

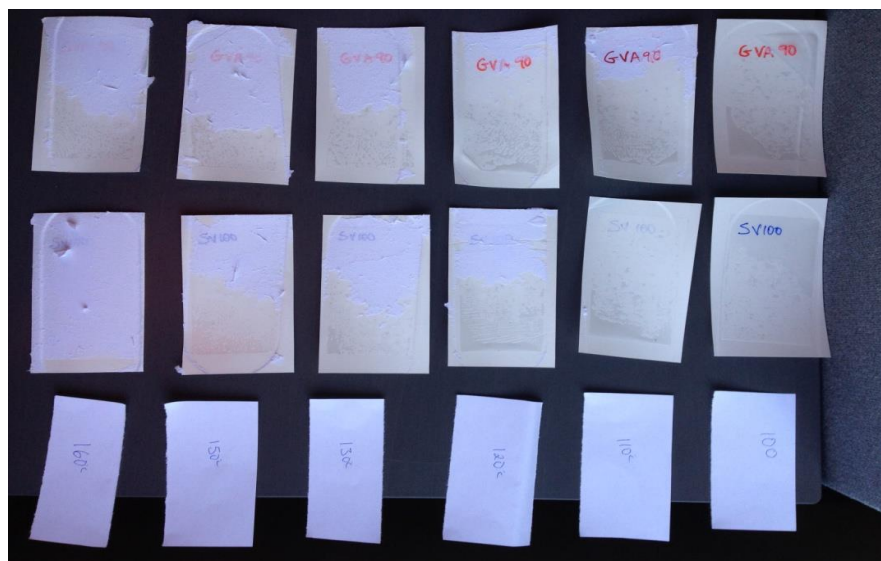


Figure 24. Examples of test pieces.

3.2 Adhesion properties

Based on the test and analysis made the MULTIFOL GVA 90 film has better adhesion behaviour at around 160°C and above to the Trayforma Natura paperboard. MULTIFOL SV 90 film adheres well to the Performa Natura PE paperboard. The contrast between the films for both paperboard types is presented in figure 25 and 26.

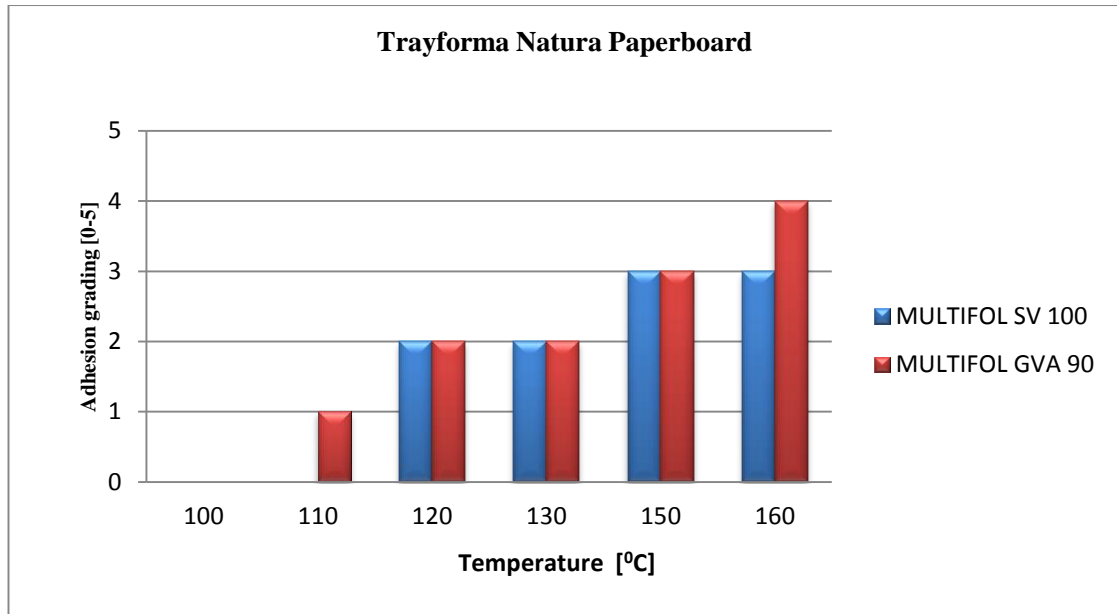


Figure 25. Adhesion comparison of films at different temperature.

Pressing force and pressing speed are presented as percentages because the actual values of these parameters are tool and press machine dependent and they cannot be applied to other solutions directly. In this study, these values were kept constant almost all the time for all test pieces. The preliminary tests were mainly done by increasing the temperature. Although the sealing films have sealing range at lower temperatures (115-155°C), there was better adhesion and bonding at higher temperature.

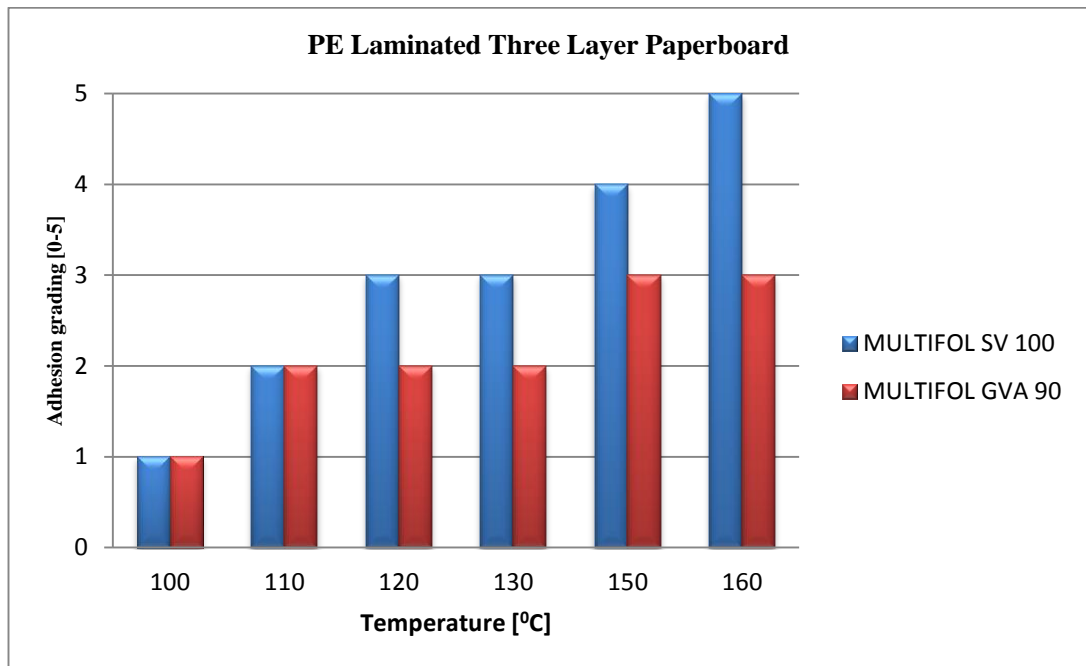


Figure 26. Adhesion comparison of films at different temperature.

3.3 Air bubble formation

Press forming causes defects mainly in the corners of deep drawn trays when the material properties of the paperboard are insufficient to endure forming force and temperature. This results in unevenness and rupturing of the tray corners. One of the main challenges discovered in this test was air bubble formation. Air bubble is formed due to the gap between the film and the paperboard. As temperature was raised there was a slight decrease in the size of the air bubbles, but avoiding them for good was not achieved. Air bubble formed during pressing is presented in figure 27 and 28.



Figure 27. Air Bubble formation during pressing of MULTIFOL SV 100 coated paperboard.

Comparing the two skin films, MULTIFOL SV 100 film tends to have more air bubble formation compared to MULTIFOL GVA 90 film due to its hardness. Comparatively MULTIFOL GVA 90 has better adhesion and bonding.



Figure 28. Air bubble formation during pressing of MULTIFOL GVA 90 coated paperboard.

3.4 Influence of heat

Even though increasing the mould temperature increases the adhesion between the paperboard and the film. Heating at higher temperatures could cause the paperboard to start curling and give uneven shape. This can be avoided by using additional materials such as additives that could increase the adhesion property of the materials. Tray deformation takes place when the film is overheated. Overheating causes the plastic to deform or change the particle structure to deform from elastic form into plastic form. During this stage the plastic tends to hold a permanent structure as it cools down causing the paperboard to deform. Possible deformation during heating is presented in figure 29.



Figure 29. Deformed paperboard due to high temperature (160⁰C).

Another observation from the study is lack of adhesion at the tray edges due to low heating which occurred at 150⁰C. This took place for MULTIFOL SV 100 and Performa Natura paperboard combination case as shown in figure 30. The adhesion at the edges was improved when the temperature was raised to 180⁰C. But high temperature caused the tray to deform. This problem can also be either due to uneven heat distribution on the female mould surface or a problem with the film and paperboard combination. This problem can be avoided by adding certain additives that could enhance adhesion properties.



Figure 30. Defects at the edge of tray when coating Performa Natura with MULTIFOL SV 100.

4 DISCUSSION AND CONCLUSIONS

The results from the study show that there are some challenges in coating a paperboard during the moulding process. The main challenges are air bubble formation, corner rupture and adhesion at the edges. Air bubble formation might not be an easy thing to avoid unless a new tool is designed with air sucking chamber on the female side of the mould to suck the air out. This air sucking tool could avoid air bubble formation, and could provide better adhesion between the film and the paperboard. Air bubble formation was getting less and less as the temperature was raised, but raising the temperature had other effects on the paperboard such as rupture and curling.

The adhesion grading was done by observing the bonding of film with the paperboard by observation and feeling the smoothness. This might not give accurate results to determine the optimum temperature in which the two materials adhere best or if there is good bondage between the two materials or not. It's suggested for further work that adhesion testing device could be used to figure out the best bonding state at a certain temperature.

As temperature is one of the main factors in adhesion of two materials it's recommended to heat both the female and male moulds. As heat is applied on both moulds there is a chance of getting uniform heating at lower temperature. And this in other words avoids melting of the film on the mould. Heating both sides of the moulds may not require high temperature heating since there will be good distribution of heat on both sides.

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Appendix 2. Material adhesion test for Performa Natura PE paperboard at various temperatures.



Figure 33. Performa Natura paperboard pressed under 100⁰C of temperature.

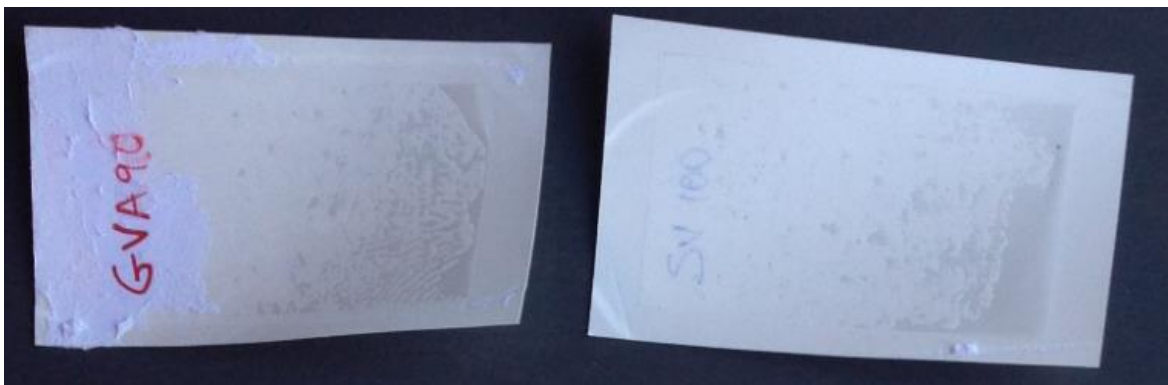


Figure 34. Performa Natura paperboard pressed under 110⁰C of temperature.

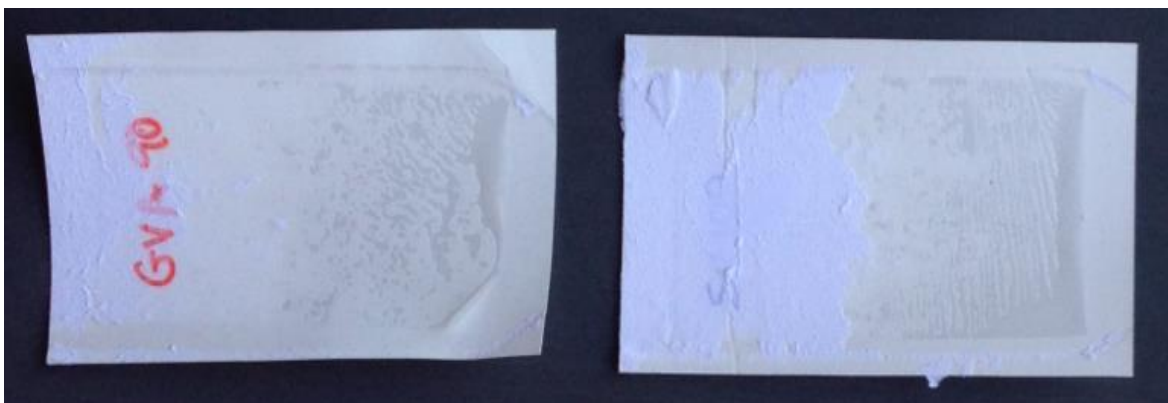


Figure 35. Performa Natura paperboard pressed under 120⁰C of temperature.

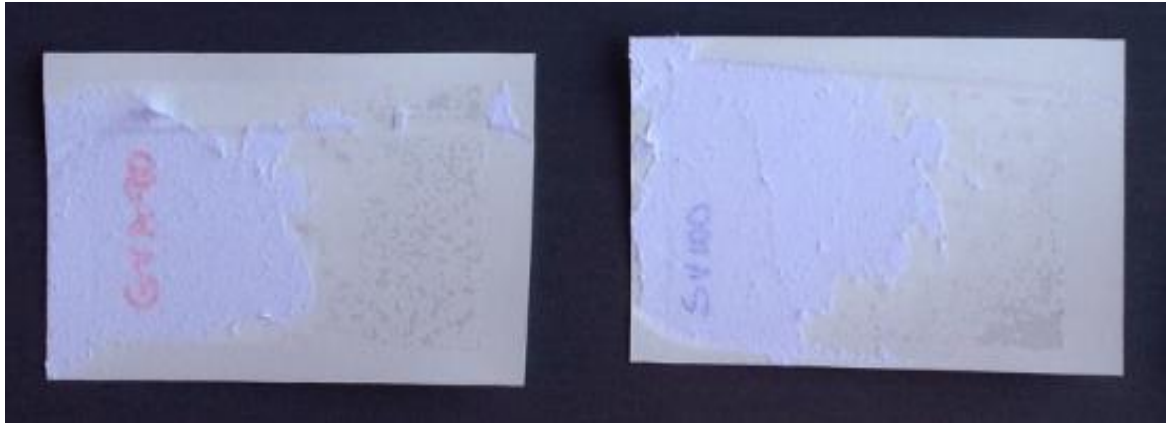


Figure 36. Performa Natura paperboard pressed under 130⁰C of temperature.

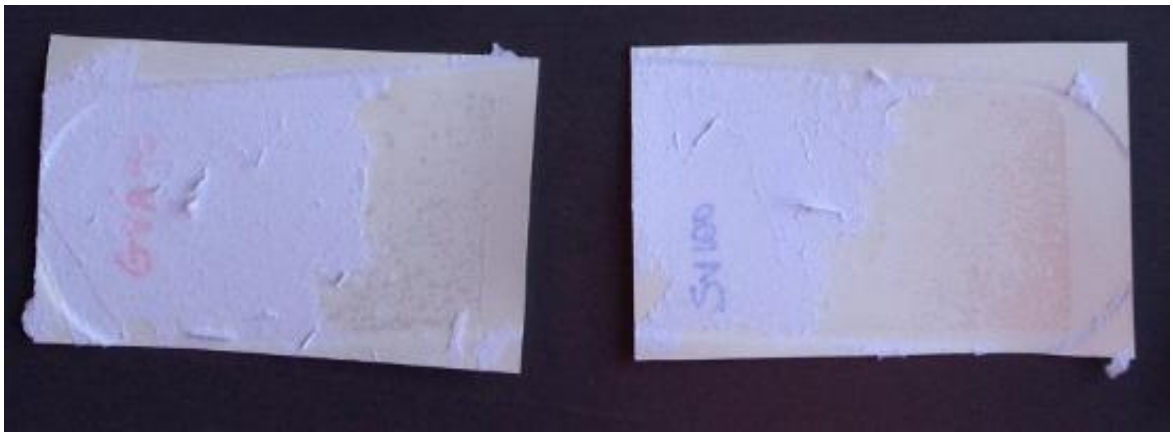


Figure 37. Performa Natura paperboard pressed under 150⁰C of temperature.

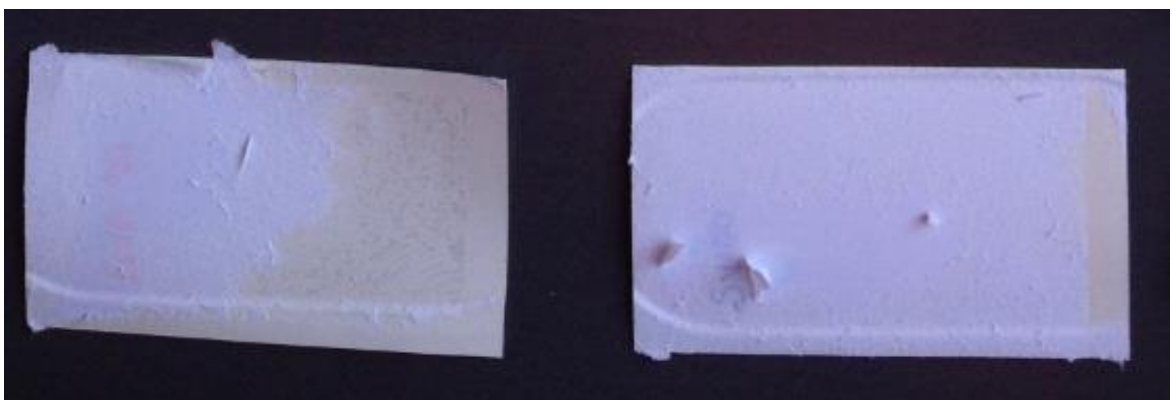


Figure 38. Performa Natura paperboard pressed under 160⁰C of temperature.

Appendix 3. Material adhesion test for Trayforma PE paperboard at various temperatures.

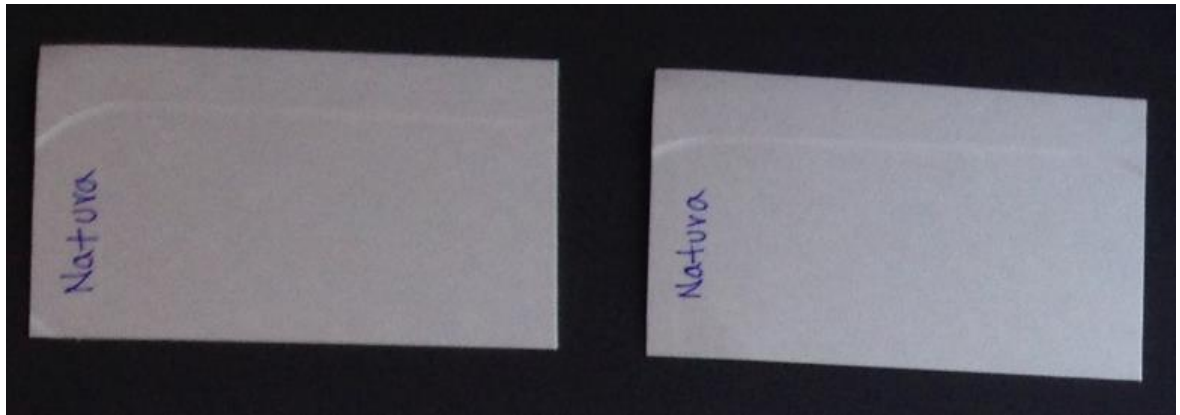


Figure 39. Trayforma Natura paperboard pressed under 110⁰C of temperature.

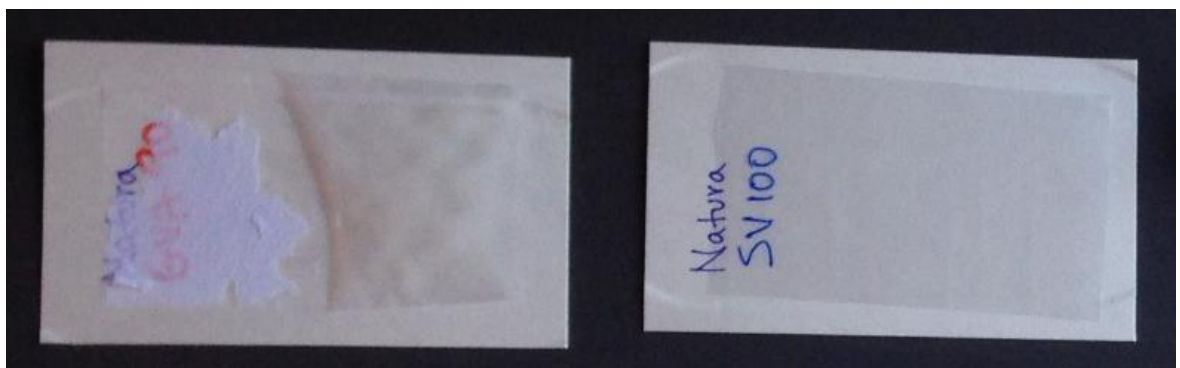


Figure 40. Trayforma Natura paperboard pressed under 120⁰C of temperature.

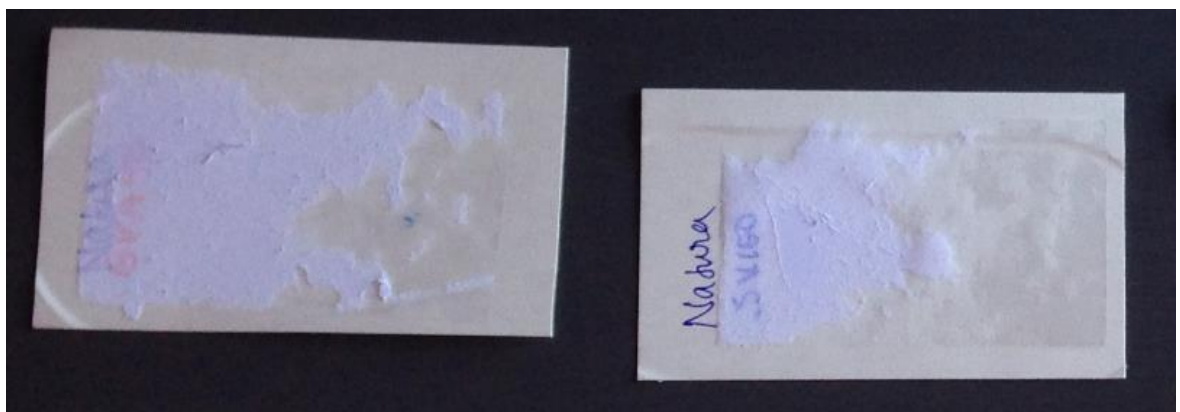


Figure 41. Trayforma Natura paperboard pressed under 130⁰C of temperature.

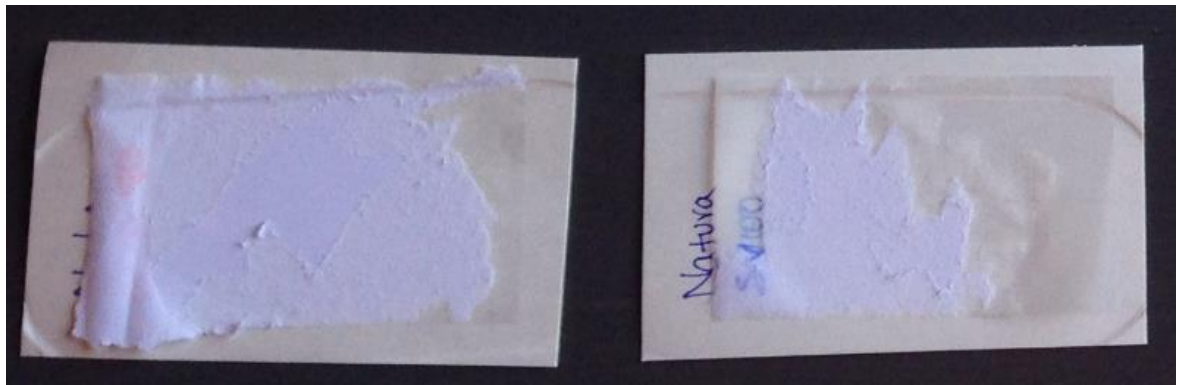


Figure 42. Trayforma Natura paperboard pressed under 150⁰C of temperature.

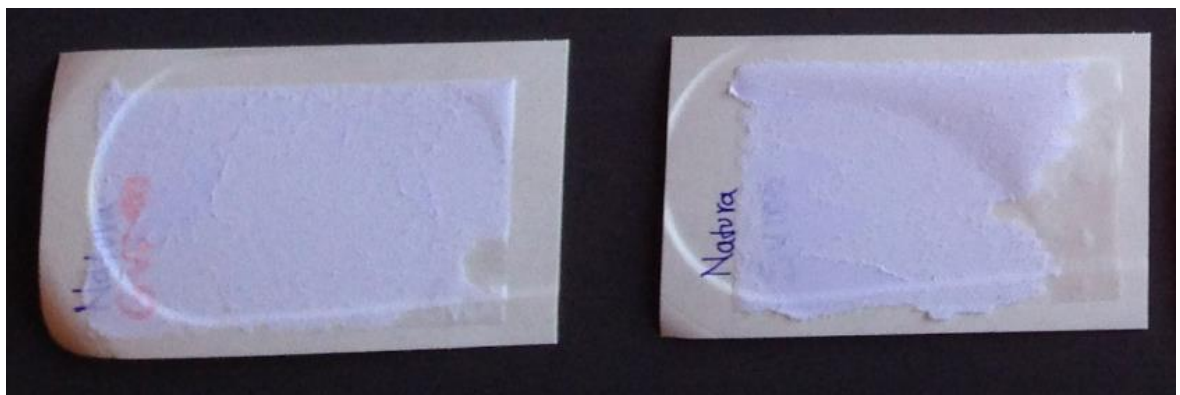


Figure 43. Trayforma Natura paperboard pressed under 160⁰C of temperature.