LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
LUT School of Energy Systems
LUT Mechanical Engineering

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FACTORS AFFECTING RUNNABILITY OF PRESS FORMING EQUIPMENT

Examiners: Ph.D. Kaj Backfolk
D.Sc. Panu Tanninen

Supervisors: Ph.D. Jari Räsänen
M.Sc. Mari Hiltunen

ABSTRACT

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Keywords: press forming, maintenance, converting, paperboard, tray

The growth of the food packaging industry has raised more interest in bio-based fibre packing. The use of petroleum based packages is unfriendly to the environment while bio-based is a sustainable option for food packing. In this Master Thesis the aim was to discover how the press forming machineries runnability is affected by parameters of the press and how it also affects formability of paperboard trays.

Familiarisation of the working operation parameters was done with the KAMA ST 75 flat-bed die cutting machine and the VP3-70 mould press. Some small test runs of moulding trays where done to get acquainted to the adjustment parameters of the machines.

Literature study was done on how paperboards physical properties react to the forces applied during press forming. The study of what kind of defects to the paperboard tray might occur during forming process and the causes for these defects. Also how the parameters of the press forming machine affects formability of the tray.

Maintenance procedures was done to the press forming machine to enhance the reliably of production process. Tool alignment measurement was done to determine proper alignment. Laboratory test of the physical properties of the test material was done to find any connection to how the test material performs in press forming. An evaluation criterion was made to evaluate the dimensions and defects of the tray. From the test result a conclusion can be drawn on how the parameters of the press forming process affect the paperboard material.

Based on the results the adjustment the parameters of moulding machines to the mechanical properties of paperboard it is possible to produce high quality fibre passed trays for the food packaging industry.

TIIVISTELMÄ

LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
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VUOKAPRÄSSIN VAIKUTTAVAT TEKIJÄT AJETTAVUUTEEN

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88 sivua, 62 kuvaa, 3 taulukkoa, 9 liitettä

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TkT Panu Tanninen

Ohjaajat: FT Jari Räsänen
DI Mari Hiltunen

Hakusanat: press forming, maintenance, converting, paperboard, tray

Pakkausten kysynnän kasvu elintarviketeollisuudessa on herättänyt kiinnostuksen korvata öljypohjaiset pakkaukset biopohjaisilla kuitupakkauksilla. Biopohjainen pakkaus on ympäristöystävällinen ja kestävän kehityksen mukainen vaihtoehto korvaamaan öljypohjaiset pakkaukset elintarvikkeiden pakkaamisessa. Tässä diplomityössä oli tavoitteena selvittää prässäyskoneen parametrien vaikutus ajattavuuteen ja kuitupakkauksen muotoutuvuuteen.

Työssä perehdyttiin koneiden säätöparametreihin KAMA ST 75 stanssi- ja VP3-70 vuokakoneella. Pieniä testiajoja ajettiin, jotta pääsisi tutustumaan koneiden säätöparametreihin.

Kirjallisuustutkimuksessa selvitettiin kartongin fysikaalisten ominaisuuksien vaikutusta vuokaprässäyksessä. Tutkimuksessa käsiteltiin myös prässäyksessä kartonkiin syntyviä vikoja sekä niiden syitä. Lisäksi tutkittiin vuokakoneen säätöparametrien vaikutusta kartongin muotoutuvuuteen.

Vuokakoneelle tehtiin huoltotoimenpiteitä ajettavuuden parantamiseksi ja konerikkojen minimoimiseksi. Vuokakoneen työkaluihin tehtiin kohdistusmittaus, jotta voitiin märittää oikea linjaus prässin työkaluille. Testimateriaalien laboratoriomittauksien avulla pyrittiin löytämään syy kartongin reagoinnille prässäysvoimien vaikutuksen aikana. Arviointikriteerit kehitettiin vuoan epäkohtien ja dimensioiden mittaamiseksi. Testien tuloksista voitiin päätellä vuokakoneen parametrien vaikutus kartonkimateriaalin muotoutuvuuteen. Tulosten perusteella vuokakoneen säätöparametrit tulisi olla säädetty kartongin ominaisuuksien mukaan. Tämä mahdollistaa korkealaatuisten kartonkivuokien valmistamisen elintarvikepakkausteollisuuteen.

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LIST OF ABBREVIATIONS

BT	Bottom side
CD	Cross direction (paper making)
DSC	Differential scanning calorimeter
FBB	Folded boxboard
FF	Form and fill
FFS	Form fill and seal
FS	Fill and seal
HDPE	High-density polyethylene
HFFS	Horizontal form fill and seal
LDPE	Low-density polyethylene
MAP	Modified atmosphere packaging
MD	Machine direction (paper making)
PE	Polyethylene
PET	Polyethylene terephthalate
PP	Polypropylene
RH	Relative humidity
SBS	Solid bleached sulphate
SEM	Scanning electron microscope
SUS	Solid unbleached sulphate
TS	Top side
VFFS	Vertical form fill and seal
WA	Wrap around, form and seal

CONTENTS

APPENDICIES

1 INTRODUCTION

More recently, interest has arisen in the global packaging market due to market analysis of food packaging containers increasing demand. A new market study that foresees the packaging food container made of paper and board is set to rise. Today's present market value at over $53bn is set to rise to $70bn by 2017 with an annual growth of 6%. Study conducted by Smirthers Pira argues that the Chines consumption of paperboard materials will rise by 11 % annual growth and counterbalance the stagnant or slow growth of other nations. In total by the year 2017 the market will consume an additional 7.5 million tons of paper and paperboard foreseen by market analysers (Kable, 2012). The demand in growth in packaging is the driving force for paper and paperboard based packaging solutions.

1.1 Background of the study

New ideas in production of paperboard based packaging materials have been studied by paperboard companies and universities and solution to problems that face the production of paperboard packaging. More attention has been focused in the research of moulding paperboard. Studies conducted in moulding of paperboard shows that by adjusting the parameters of moulding machines to the mechanical properties of paperboard it is possible to produce high quality packages for the consumer (Vishtal, 2015). The improvement on paperboard packaging is essential to the success of the paperboard market so that it can compete with plastics and other forms of packaging materials.

Paperboard companies producing raw materials for the customer should have material know how of how their product acts when it is handled by the customer that makes the end product. This way the paperboard companies can also focus on customer relations by improving their product properties for the customer. Also when there are complaints from the customer that the raw material is not forming in the way it was designed the paperboard companies can do their own troubleshooting analysis and try and solve the problem. In addition to product development, new materials need to be tested to be adequate for customer needs. Research and development can open new markets.

1.2 Objective of the thesis

The first objective of this research is to study the factors that affect press forming equipment. The study will consist of test patterns of the different adjustments that can be done to the press forming machine and how those adjust affect the shape of the tray.

The secondary objective will be the testing of different grades paperboards and to find the best machine and paperboard parameters to produce quality trays. Furthermore, two different mixtures of petroleum based polypropylene (PP) was coated to the surface of the paperboard to see what effect these polymers will have on shaping of the tray. The reason for testing these polymers (PP) mentioned is the possible future use of bio- polypropylene as a substitute for petroleum based PP. Bio and petroleum based PP have similar melting points and might react the same under press forming forces. Bio based PP is a greener alternative for future packaging. Another reason is that some households not having room for a large conventional oven but a microwave oven is smaller and faster to use than the conventional oven. In the future, the share of ready-made meals will increase due to fast passed society and urbanisation.

1.3 Structure of the study

The structure of this thesis work was first focused on literature study on press forming equipment in areas of operating the machinery and maintenance. Literature study will also include how the physical properties of paperboard and how it is affected by pressing process. Familiarization of how the press and flatbed die-cutting machinery works is also one stage. Before the test phase there was some preliminary tests on how the press reacts to different adjustments. Test phase will include test material that is selected from Stora Enso Oyj’s product portfolio. These materials where run through the tray forming process. Test runs are used to try to find the optimum machine settings for each material. Laboratory test where done to find the physical properties of the paperboard. Quality of the trays is judged by evaluation criteria and these criteria where compared to the laboratory results to see if there is any connection. The comparison of unstacked and stacked tray dimensions where also studied to see if there is an effect on the shape. Figure 1 below shows the layout structure of the thesis.

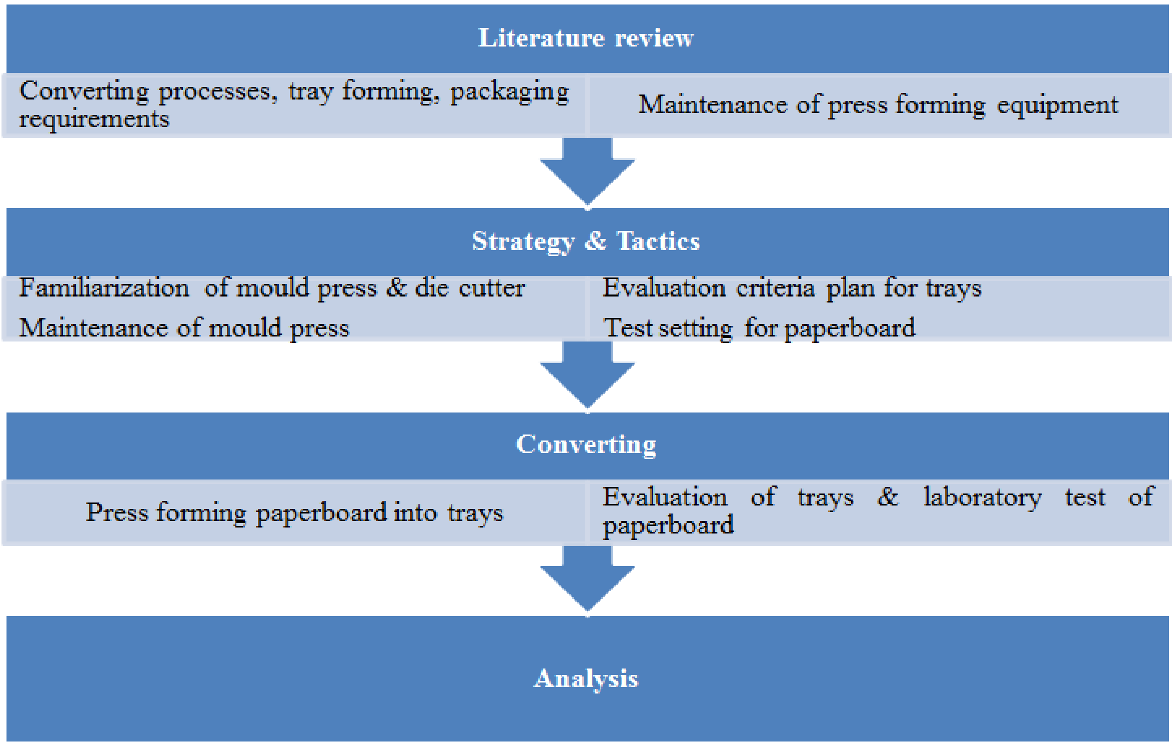


Figure 1. Structure of study.

1.4 Requirements of paperboard packaging

The package has many obstacles to overcome if it is to be a successful. As a package its task is to protect the contents that are held inside from outside contaminants or forces. The package is part of a delivery system of goods to the consumer and so that the consumer will get the goods undamaged. The content of the package can be anything from food to electronics but in this thesis the focus is on foodstuff. From the brand owner's point of view the package is also there to entice the consumer to buy the product. Package shape and design can be a brand symbol that the consumer is familiar with and makes the package stand out from others. This can affect the consumers buying habit.

Consumers expect the package to be easily recognized product, easy to locate, easy to use, safe and be enticing to the eye in the way of appearance (Iggesund Holmen Group, 2016). For the package to meet all required functions must also take into consideration the cost effectiveness of the package. The cost must be related to the packages value, image and end-use (Emblem, 2012). Therefore each package is designed differently and properties can vary with the end use for example to protect fragile electronics or to keep foodstuff fresh.

The process of paper converting is stepwise. The process consists of taking raw material in this case a paper or paperboard roll and converting it by different machinery to get the desired outcome. These converting processes one can create different shapes for the market. The product examples are paper cups, folding boxboards, liquid packages and trays that will be discussed in this thesis.

Paper cups are one of the most regularly used containers for foodstuffs. Cups are used for frozen desserts, dairy, dry goods, ready meals and one most familiar the coffee cup. Board machine produces the cup stock board. From there the raw material is sent for example to extrusion coating where the paperboard will get a coating of plastic one side or both sides depending for what the cup will be used for. Most commonly is used polyethylene (PE) coating that is acceptable for coffee and other Hot and cold drinks. Polyethylene terephthalate (PET) that is used for oven and microwaveable packages for example ready meals. Figure 2 below shows the basic structure of 2 sided PE coated board.

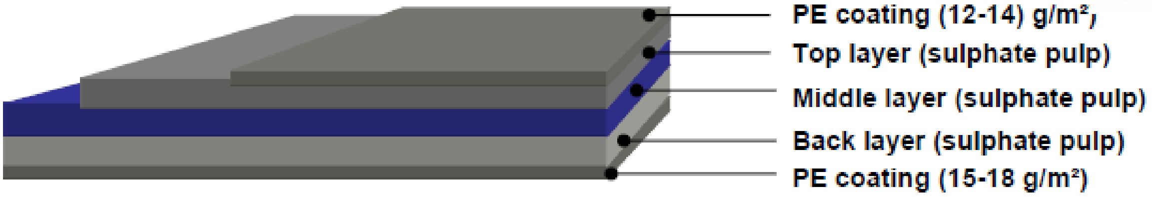


Figure 2. Cupforma Classic 2PE (Sarin, 2012).

To begin the process of cup forming the raw material is first printed on, some printing methods suchlike flexo, offset rotogravure or digital. The next step after printing is die-cutting. The methods used commonly are rotation or flatbed. After the desired printed logo is printed and blank is made the material is ready to be formed into a cup shape.

Forming process starts with the blank paperboard being heated at the sidewall heating section to provide a leak resistant seal. After side wall heating the blank is wrapped around the mandrel and is held in place by vacuum and the seam clamp presses down to make the seal complete. Figure 3 below shows the principle how the moulding is wrapped around the mandrel and seam clamp presses down.

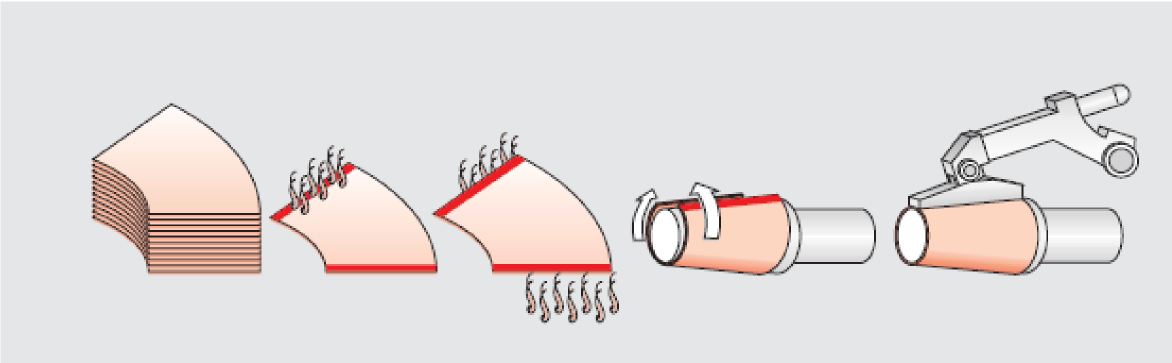


Figure 3. Blank shaping (Hörauf, 2015).

At the same time the bottom paper roll is fed into the bottom punching section and the bottom part of the cup is formed and then will be mated with the cup and heat provides the seal. Figure 4 shows the bottom punching and mating.

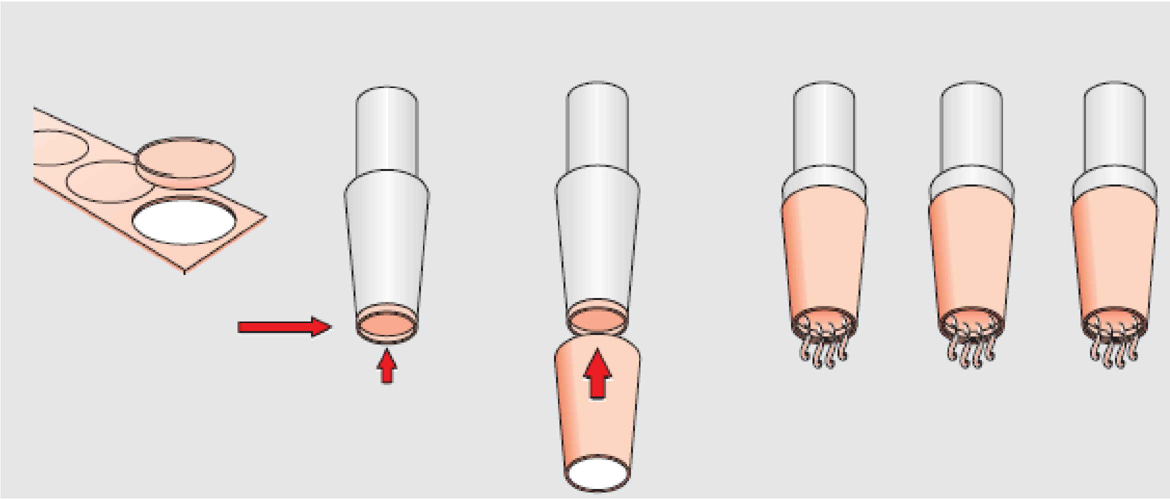


Figure 4. Bottom punching (Hörauf, 2015).

The third step is to bend and make the seal for the bottom using a cup bottom forming tool. Figure 4 show how the cup forming tool works by expanding the tools pieces, pressing and rotating to seal the bottom to the cup wall.

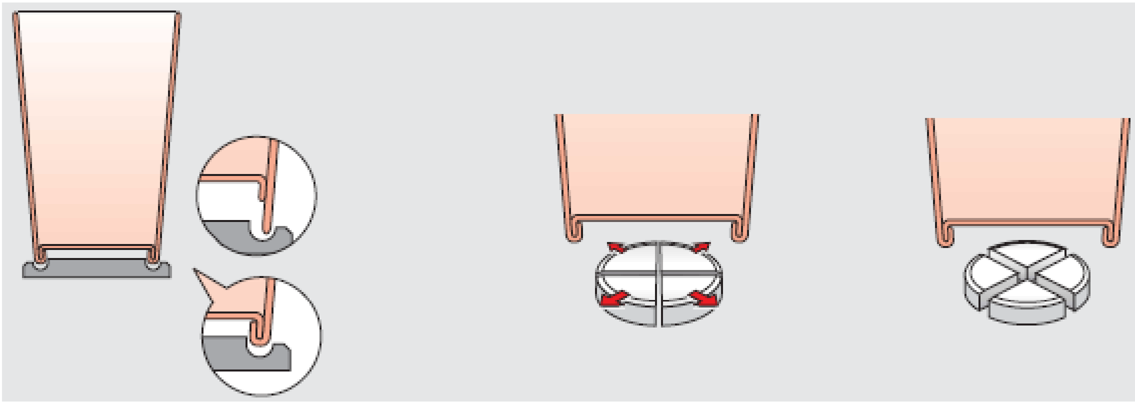


Figure 5. Bottom tool (Hörauf, 2015).

Last section is to make the in-curl for the top rim of the cup to provide the cup rigidity. In-curl section can be a three step process that partially curls the edge of the cup at each section. For higher the calibre of board the more steps are needed for in-curling. There is a mineral oil that is applied to the rim to provide less friction as the in-curling process takes place. Figure 6 shows how the in-curling is done.

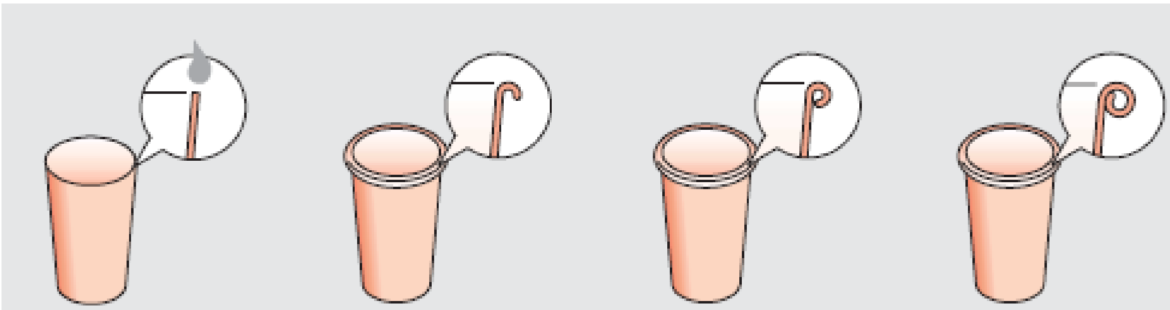


Figure 6. In-curling process (Hörauf, 2015).

Other techniques are used to form cups for example different heating processes; flame and ultrasound and there are different types of ways to mate the bottom to the cup and different raw edge protection techniques that was not mentioned. Whatever the technique the common thing that all processes have is to meet the demands of a high quality cups that are; have no leakages, high hygienic level, good performance in handling, nice appearance and is recyclable (Sarin, 2012).

Folded boxboard, (FBB) is a type of packaging material made from paperboard that is used as containers for various types of consumer goods. Folded boxboard starts as a sheet of paperboard and will be cut and creased for forming into a desired shape. Criteria's set for paperboard that is used for FBB is that it is easily folded, permits good scorability, creasing and groovability and has variable surface properties which affect the printing requirements (Urmanbetova, 2001) FBB is used for products such as; pharmaceutical, foodstuff, cosmetics and cigarette packaging. FBB paperboard is made of several layers to meet the high printing surface quality and bulk demanded set by the customer. Furthermore, the demand for purity is high for the paperboard so that the product is not affected in ways of odour or taste.

The stages of manufacturing FBB starts from packaging design where the packaging is designed around the product to meets desired look, what will be the package shape and where the graphics are located and what type of graphics will the package include. Figure 7 shows a basic folding carton blank design.

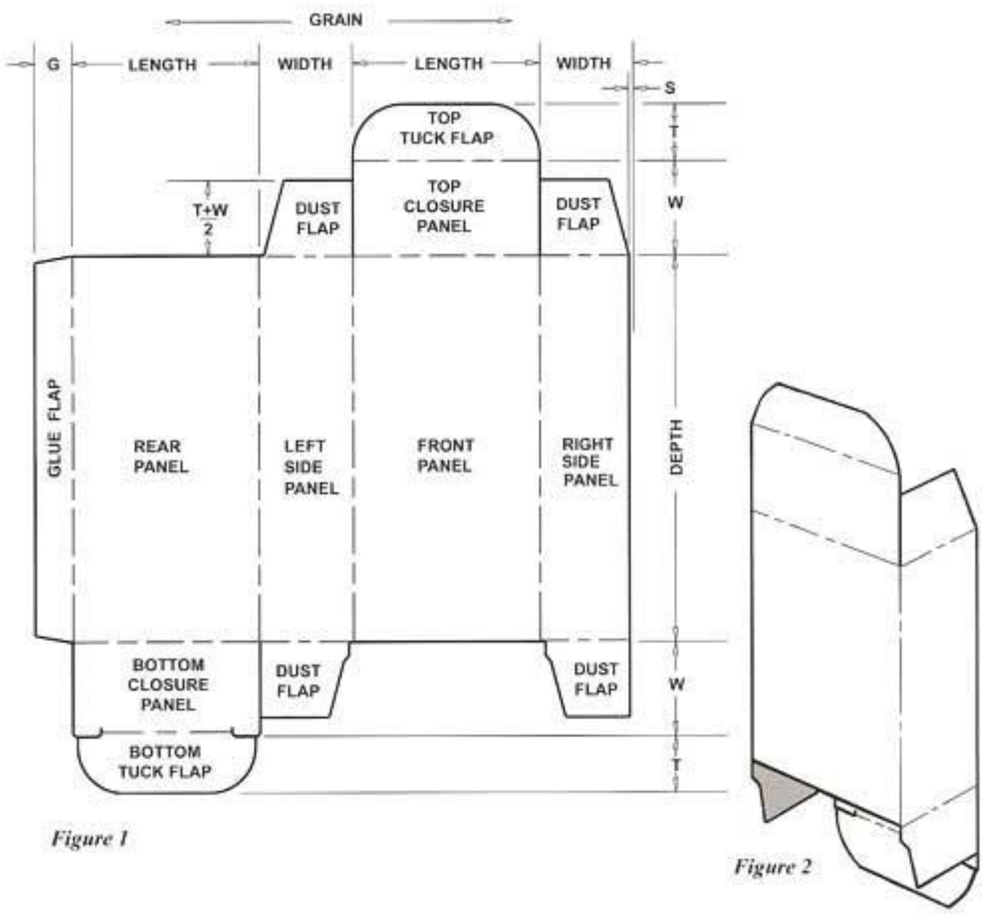


Figure 7. Basic folding carton (Paperboard Packaging Council, 2014).

The blanks are pre-cut and creased by a die-cutter then the blanks are placed into the feeder of the folding and gluing. The automated machine transforms the blank into finished form for example a box. Folder and gluer machine uses specially positioned rotary hooks and other tools to fold the box panels to the set positions while the gluing section applies adhesive glue to pre-set positions on the blank (BOBST, 2015) After adhesive dosage is applied the carton is folded and closed and then compressed and ready for filling. Figure 8 shows basics of folding carton production process.

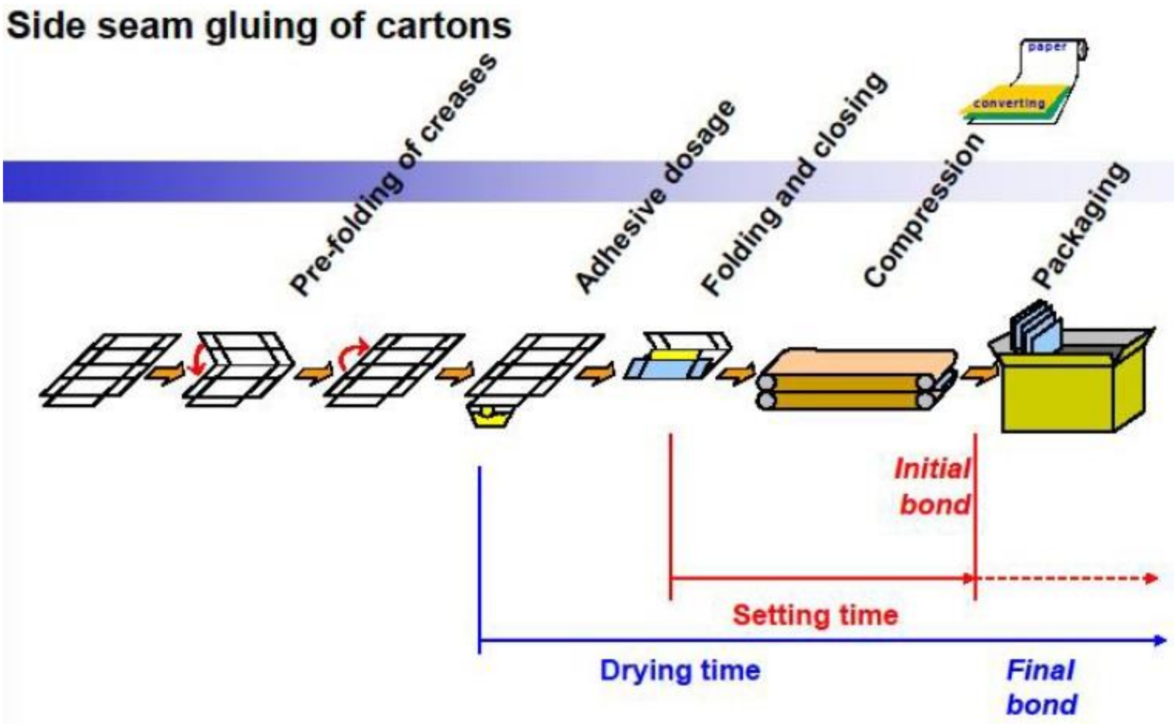


Figure 8. Folding carton production process (Kirwan, 2005).

Other operations that can be performed in the process are embossing. This process can be done simultaneously with the cutting and creasing section. The objective is to press a 2 or 3 dimensional embossing onto the paperboard.

Hot foil stamping is another process which is done to the folding box by pressing a metallic or hologram decoration to the surface of the paperboard.

Windowing is done to paperboard packages so that the consumer can see the contents that are inside the package. Windows are made from PET or other plastic films and are applied to the surface with adhesive (Kirwan, 2005).

Liquid packaging board is a type of paperboard used to contain liquids and to keep the contents of the package uncontaminated, lasting fresh and to maintain natural taste of the liquid product. Paperboard also provides a solid structure and a good printable surface for the container. There are two different basic shapes liquid packaging board come in; gable-top and brick design. There are other shapes but these two are most common used. Some other designs that have been developed are; pyramid, pouch, wedge (standing pouch design), prism and round shape (Kirwan, 2005).

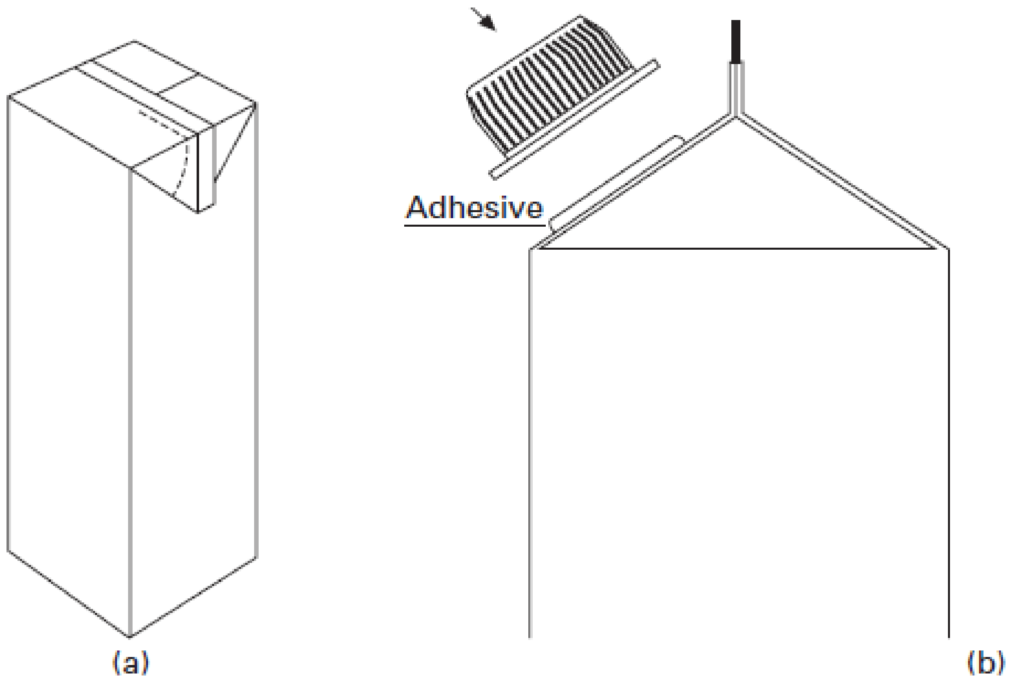


Figure 9. Brick type design (a) & gable-top design (b) (Emblem, 2012).

The liquid board blank is a similar process as folding boxboard, where the paperboard is printed on and then the blank is cut and creased to a certain shape and ready for folding and gluing. The main difference is between the two are the type of internal sizing that is applied during stock preparation stage (Kirwan, 2005). The liquid brick package is designed so that the surface and edges are not exposed to the liquid content so there is no absorption or leakage of the liquid into the raw edge or leakage outside of the container. Basic construction of the barrier layer used in liquid paperboard container can vary, simple package uses a 2 sided polymer coating lined paperboard and some layering goes up to 6 different layers that can have aluminium layer used as a high barrier. Figure 10 shows some examples of different layering materials used in liquid packaging.

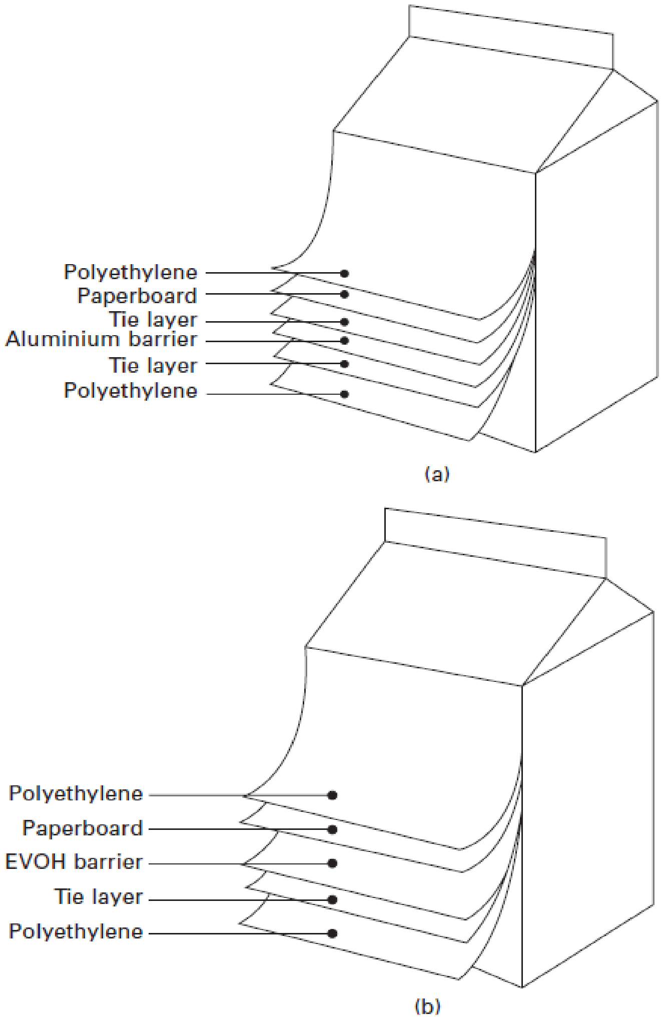


Figure 10. Different layering of liquid packaging paperboard (Emblem, 2012).

Fibre based liquid packaging filling lines are used to form and fill the liquid containers. The list below are shows some examples of different types of fillings lines used.

- FF (form and fill)
- FFS (form fill and seal)
- VFFS (vertical form fill and seal)
- HFFS (horizontal form fill and seal)
- FS (fill and seal)
- WA (wrap around, form and seal)

The flexible packaging material comes in forms of reels or ready-made blanks. Filling machines can perform all the steps from raw-material into filled and finished end product. The operation of packaging the product into a container and the package is formed as part of the machines operation procedure. When the container is filled with foodstuff the package is immediately sealed and the most common type of sealing is heat sealing. VFFS machines are used for liquid packaging such as milk, juices and soups as for HFFS machines are used for packaging dry or solid goods such as peanuts, cakes and cookies. The VFFS machine process steps are; film is wrapped around a real and formed over a collar to create a bag shapes. Through a feed tube the material is fed into the package and the packing material is crimped by heat sealing to form a solid seal. Figure 11 shows basic operation of VFFS type machine (Emblem, 2012).

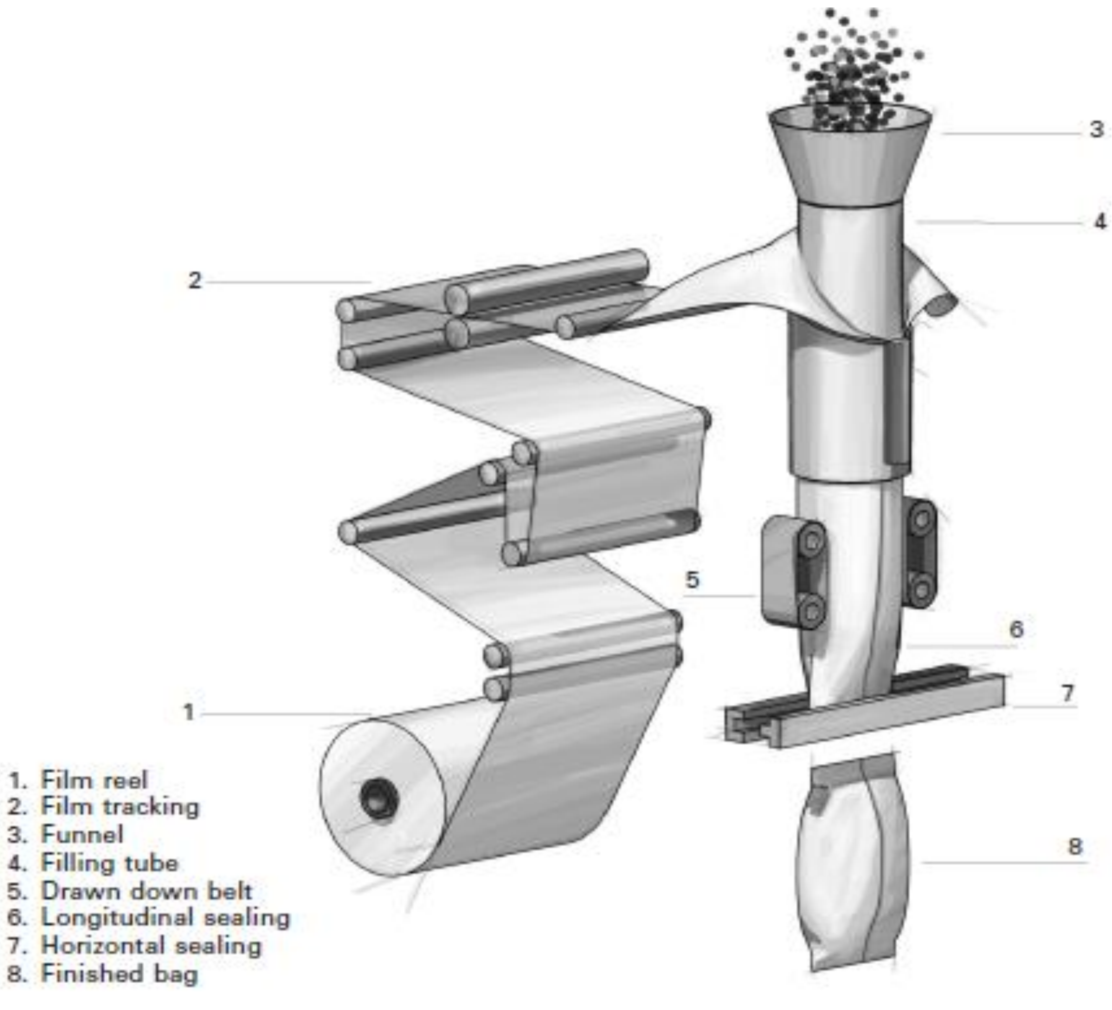


Figure 11. Basic operation of VFFS (Emblem, 2012).

Sealing the package is a crucial process of the line so that the content held inside will not be contaminated. Adhesive sealing is used for heat sensitive materials like chocolate packaging production. Adhesive sealing allows greater speeds in the filling line. Heat seals are stronger than cold seals and the advantage is it is relatively easy to pull open. The three most common styles of seals are bead, fin and overlap, seen in figure 12 below (Emblem, 2012).

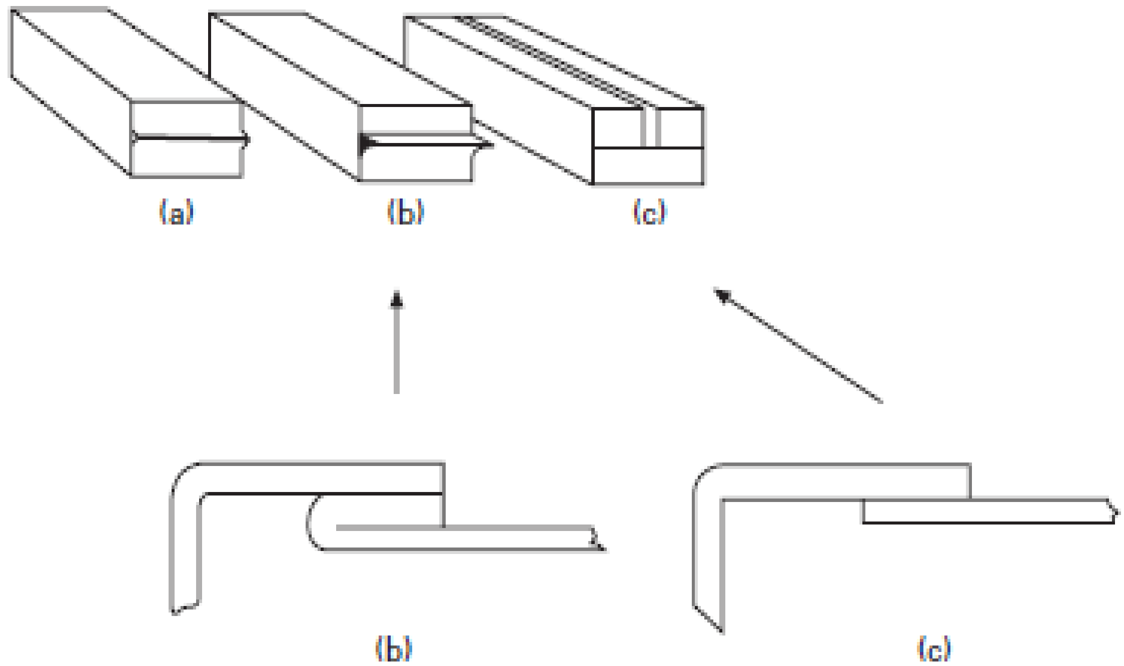


Figure 12. Common type of seals (a) bead, (b) bead, (c) lap (Emblem, 2012).

There are many different types of packaging lines for different products. Still they all serve the same purpose to package the goods and to protect. There is a need to have a cost effective machine that produces quality packaging for the market.

1.5 Tray forming

Press forming is a highly demanding process that forms paperboard into 3 dimensional shapes such as plates and trays. The forming process afflicts high stresses on the paperboard when it is formed. Forming paperboard into trays starts with a creased and cut blanks. Then the blanks are pressed into trays and the process can be compared to deep drawing of metals. Heated forming tools temperatures range from 160–230 °C. Heating temperature of tools depends on the paperboard properties and the type of polymer coating used. Usually the plastic coating sets the limit of the mould temperature. The basic rule to finding the right temperature is to have the tools as hot as possible without scorching the paperboard or sticking of the polymer to the moulding tools. Paperboard pressing have three main criteria's to adjust; pressure from the tools, dwell time of paperboard in mould and sufficient heat that is transferred from the moulding tools. The main physical properties that are required from the paperboard are high elongation, high tear strength, hygiene, low odour and taste and good adhesion of the plastic coating (Iggesund Holmen Group, 2016). Figure 13 shows the stress points and where they affect the paperboard during press forming.

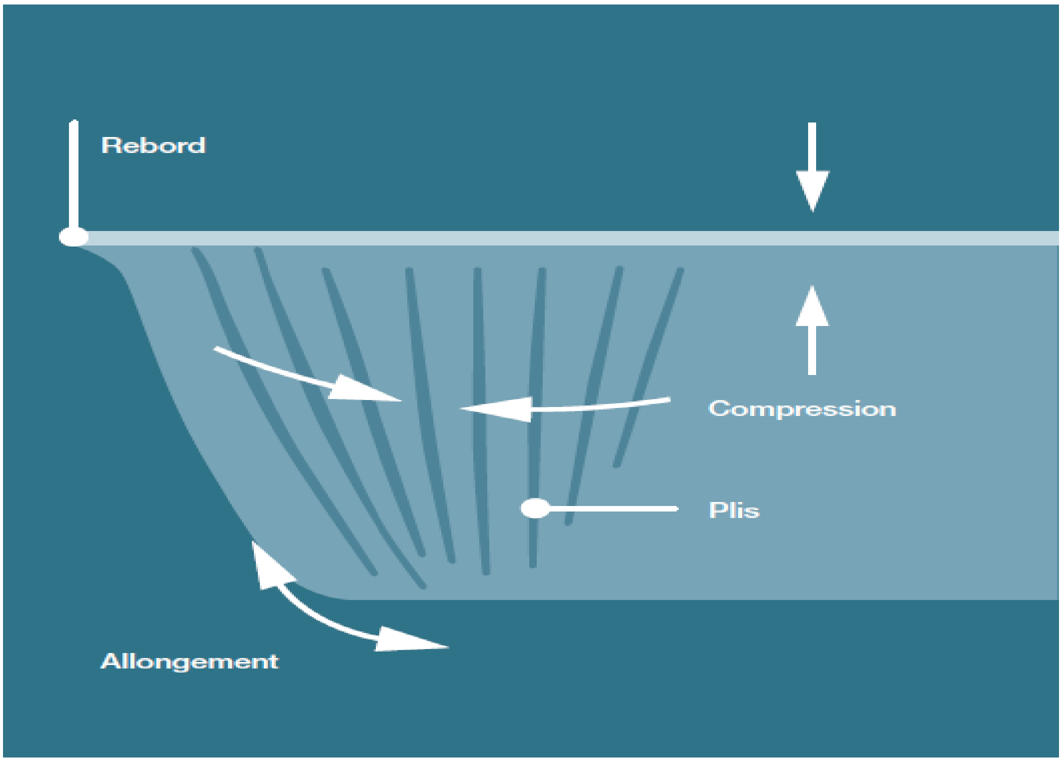


Figure 13. Press forming forces and the areas that are affected (Iggesund Holmen Group, 2016).

There are many challenging areas when press forming paperboard based trays. The deeper the paperboard is drawn the more likely there will be tears in the corners. Corner areas are difficult because of paperboard poor elongation as compared to plastics. The elongation is not as much a serious issue with polymers than fibre based webs.

The process of tray forming is straight forward. The paperboard blank is fed in between the pre-heated female and male moulding tools. The male tool starts its downward press action with first contact to the paperboard blank is the outer flange of the male tool that holds down the blank to the female rim tool with pre-set amount of force. Then the male tool starts to press the blank into the female mould cavity and the forming of the blank and creasing of the corners is performed. The male tool is set for a dwell time a pre-set time that the tool is held at the bottom usually from 0.5 to 1.0 seconds at this stage the plastic coating of the blank softens and the creases and corners of the tray are sealed together and the flange of the tray is flattened and formed (Leminen et al., 2013). After the dwell time is over the male tool begins to rise to its starting position and the ejector tool that is located in the middle of the female tool pushes the formed tray out of the female mould and into a conveyer belt and a new tray blank is fed to start the process all over again. Figure 14 shows the Press forming of tray blanks into trays.

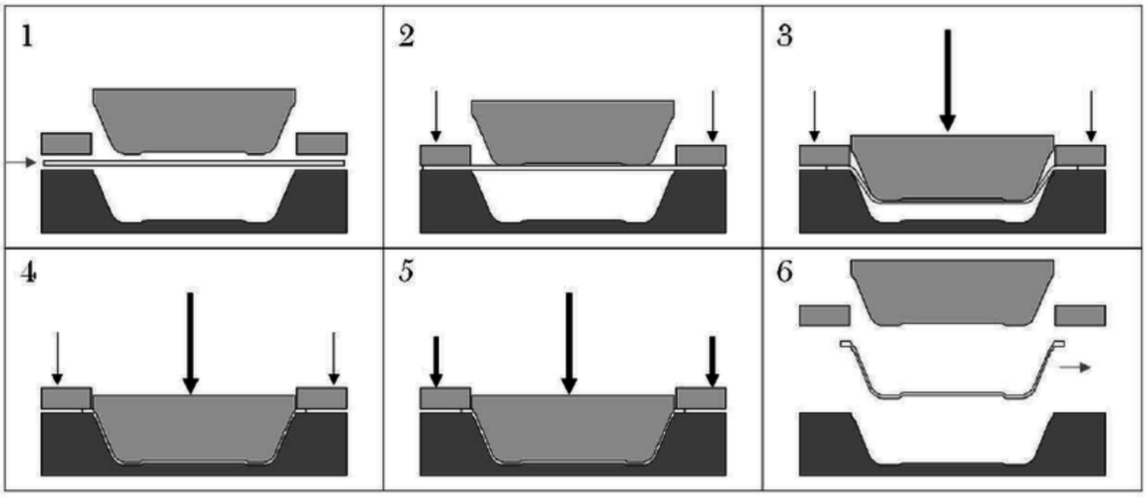


Figure 14. Press forming of trays (Leminen et al., 2013).

1.5.1. Effect of cutting and creases on tray forming

Cutting and creasing paperboard tray blanks is an important processes for forming a quality tray. Creasing rules is the tool used to make creases. The tools have thin strips of smooth rounded metal edges that press the blank against a matrix that has an identical groove that fits the crease rule. As a guideline the groove width is commonly 1.5 times the thickness of the paperboard and plus the width of the creasing rule (Kirwan, 2005). Figure 15 shows the dimensions of the crease rule and matrix.

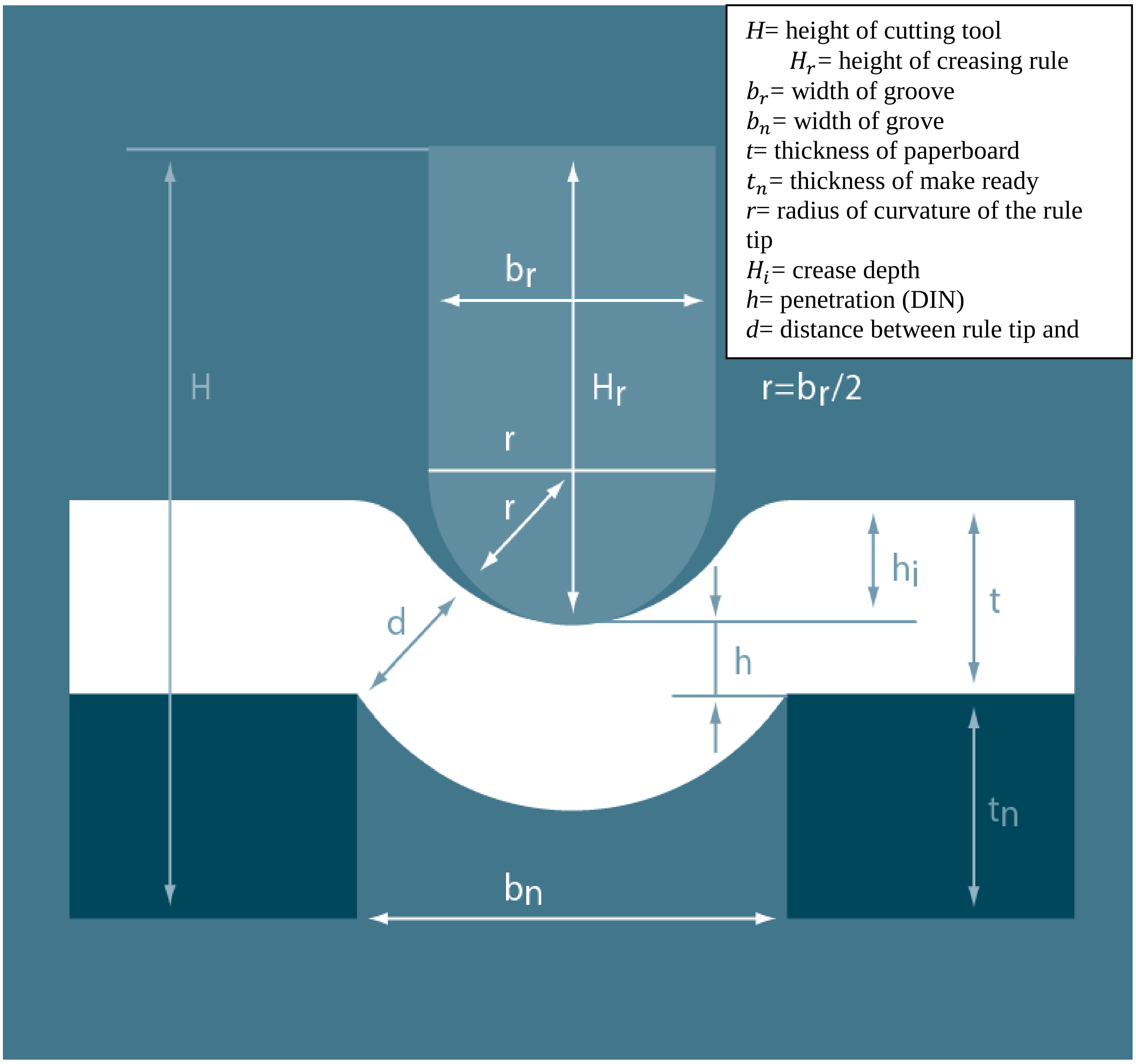


Figure 15. Dimensions of crease rule and matrix (modified Igesund Holmen Group, 2016).

Properly formed creasing will affect the visual appearance of the tray. The creasing will also have an effect on the trays compression strength and affect the seal-ability of the flange. This can be seen especially in the case of modified atmosphere packaging where the gas can leak out of the creases if they are poorly formed. Heat and dwell time will affect the structure of the crease even if the crease is properly made. Creases during press forming are a way to shape and control the shape of the tray blank during press forming. The polymer coating will then fold into the creases to create an air tight seal at the top of the tray (Tanninen, et al., 2015). Figure 16 shows how the creases are folded during press forming.

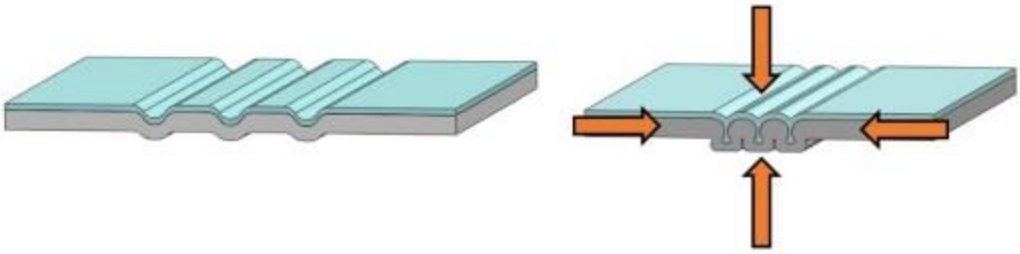


Figure 16. Crease folding during press forming (Tanninen et al., 2015).

When paperboard is subjected to the die cutting and creasing there is a permanent deformation of the paperboard. Paperboard will endure tensile strains in forms of elongation, compression and sheer strains within the paperboard parallel with the surface. The paperboard will endure the greatest strains on the surface and the riverside of the substrate (Lindell, 2012). Figure 17 shows the tensile forces that are applied to paperboard during creasing.

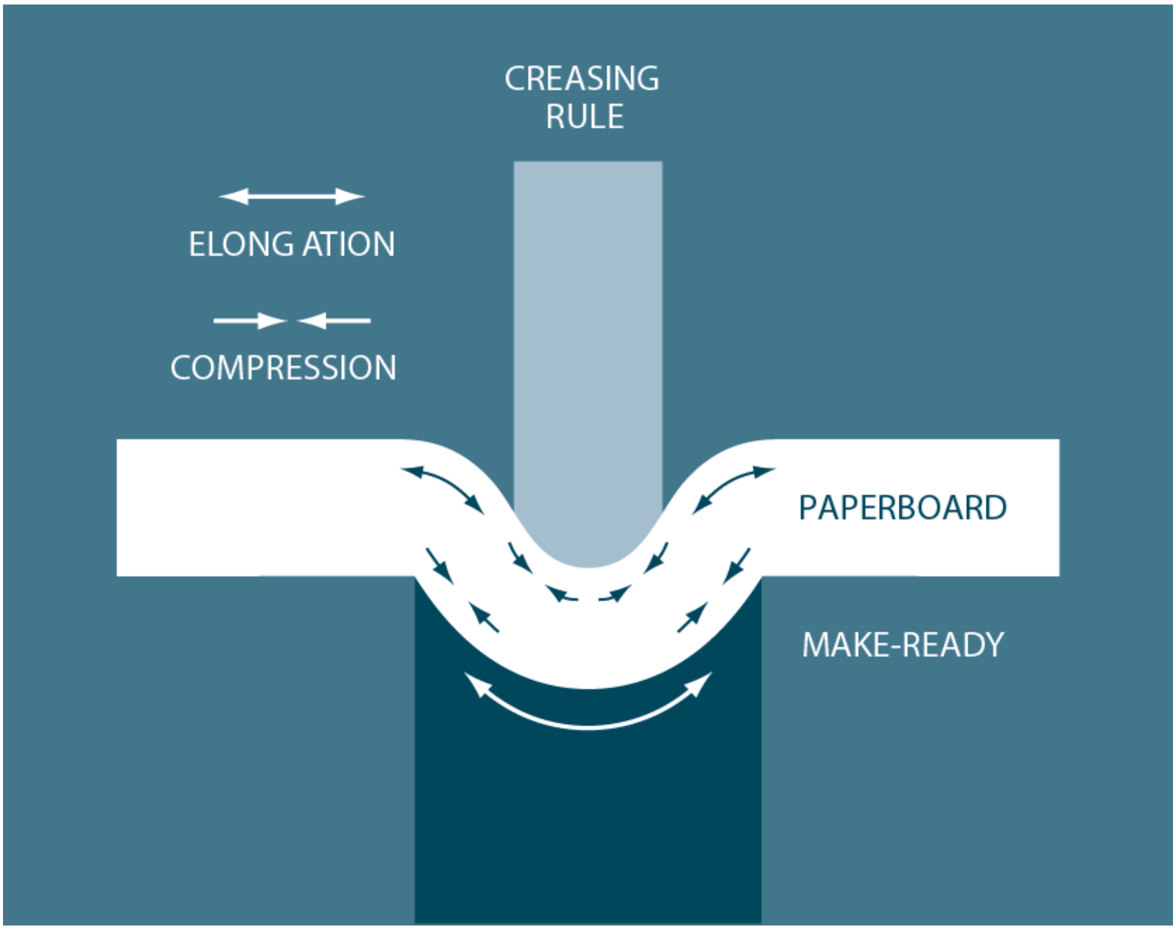


Figure 17. Tensile strains during creasing (Iggesund Holmen Group, 2016).

A proper fold is when the board delaminates in the area of the crease and the objective is that it will form many undamaged layers only in the area of the crease while leaving the rest of the paperboard intact. Therefore to achieve a good crease the settings of the die-cutter must be set to face the paperboard properties. The thicker paperboard requires a wider rule and grove than thin paperboard. Thicker paperboard is more easily creased because thicker paperboard withstands the stresses more easily (Kuusipalo, 2008).

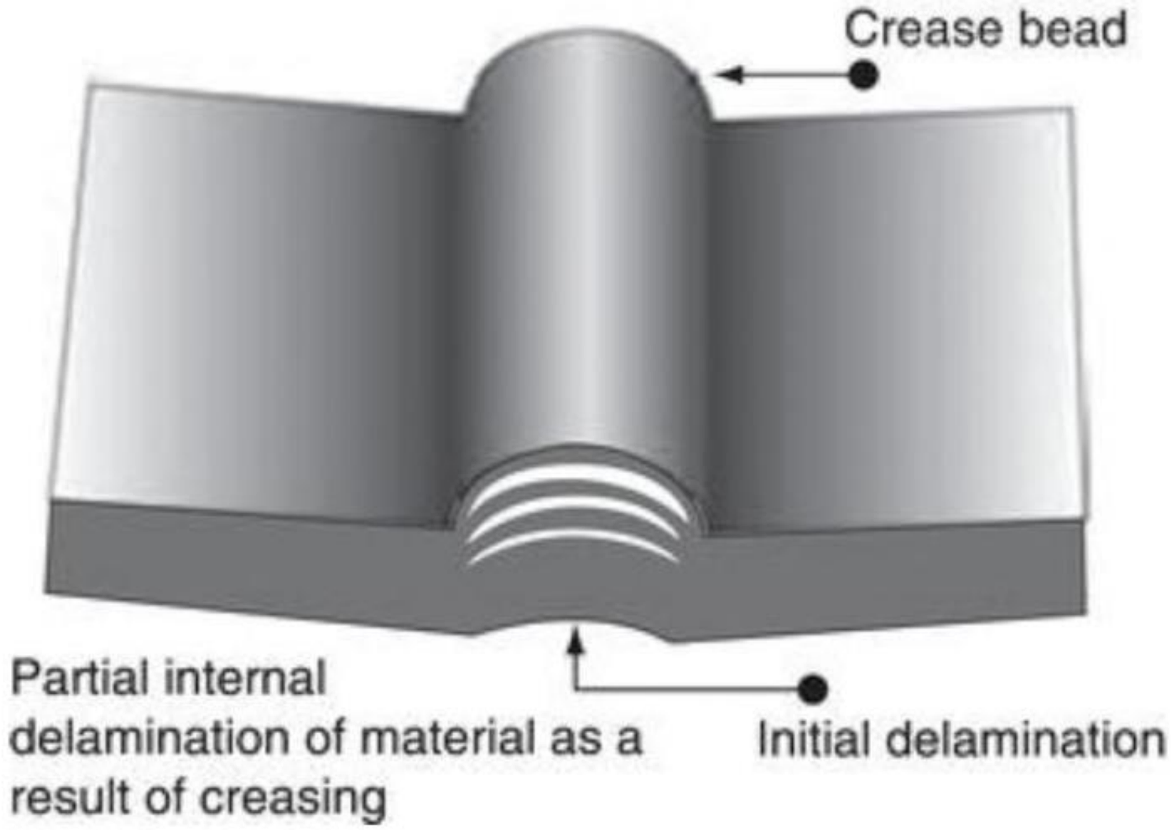


Figure 18. Delamination of creasing (Lindell, 2012).

Preparing the paperboard blanks is an important part of press forming process to achieve a good quality tray. The two main basic operations to ensure a desired shape of tray is preparation of the blank and right settings for the press forming machine. Below figure 19 shows good creasing area.

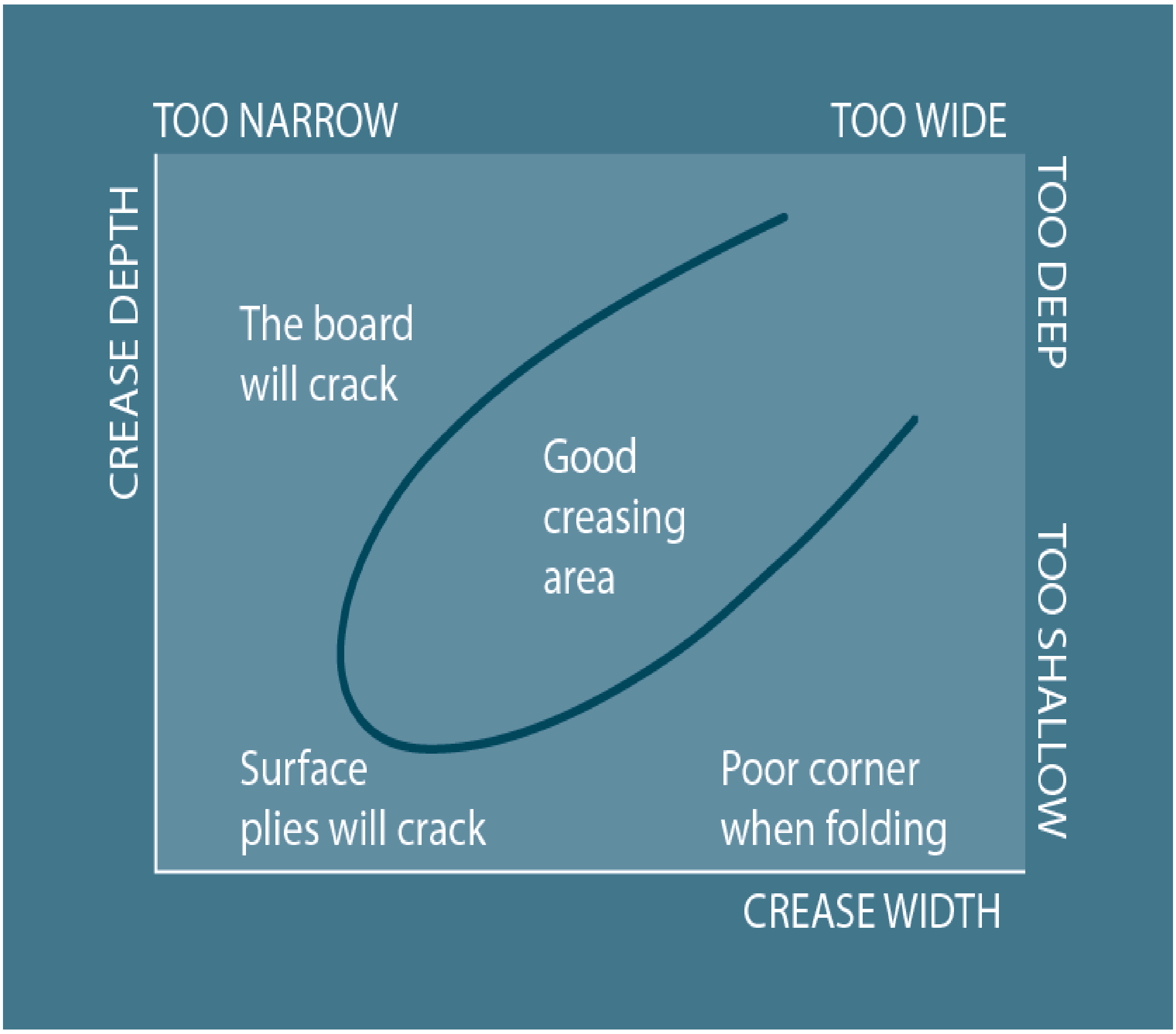


Figure 19. Problem areas creasing (Iggesund Holmen Group, 2016).

1.6 Maintenance of press forming equipment

The definition of maintenance is a collection of administrative, technical and managerial work during the life cycle of a machine. The goal is to retain it in, restore it to a state of performance so the machine functions flawlessly. The procedure is explained in standard (SFS-EN 13306). Maintenance efficiency is an important aspect of the efficiency of the machine and the output quantity. Therefore this means that the operator running the machinery is able to prepare a maintenance schedule and be able to perform the strategy. Dependability of the machine will become more reliable when proper maintenance is performed and the equipment will perform as intended and without any failure. When technical failure occurs maintainability is the way to repair the machine to proper operation condition (KnowPap, n.d.).

Maintenance of press forming machine is an important part of producing quality trays and should not be neglected. Maintenance ensures that all mechanical systems and operations are in working order at all times. In packaging machinery maintenance can also be seen as ability to keep the machines in optimum operating order and to ensure optimum production and quality outcome. This means non-interrupted production without any unscheduled downtime of the production line. The preventive maintenance will save money and time in the long run. Therefore a good way to do preventive maintenance is to have a check list. The check list consists of going through main components of the press forming machinery. Example of the general areas that should be checked is shown below for proper maintenance of press forming machinery.

- Pneumatic equipment
- Lubrication equipment
- Electrical equipment
- General press equipment
    - Safety(guards and covers)
    - Switches and buttons
- Condition of moulds
- Cleanliness of machinery and production area

Proper operating procedures of the press forming machinery will reduce the amount of maintenance and down time. If the machinery is not used in the way it is intended parts may break or even worse. Also if maintenance is neglected this may result in poor quality of the product and also will put the machinery at a greater chance of mechanical failure. Therefore to ensure proper runnability of press forming equipment one must keep machinery in excellent working condition to produce quality trays this also will save time and money.

1.7 Paperboard properties and the effect on moulding

Weight of paperboard is an important factor that has an effect on the properties of the paperboard and is measured in g/m^2. Reducing the weight of paperboard will affect in ways of stiffness and strength which will affect the mould ability of paperboard. From weight and thickness one can calculate the bulk and density of the paperboard. Density is measured in kg/m^3 as for bulk it is measured in cm^3/g. (KnowPap, n.d.) Thickness is an important parameter for the production of trays. The closer the thickness is to the set mould clearance of the press forming machine the better quality trays will be formed. If mould clearance is not set to the thickness the formation of creasing shape will suffer and also wrinkles will form outside of the crease area. (Leminen et al., 2013.)

Tensile strength of paperboard is the greatest force acted in the direction of the surface that the material can withstand. Best tensile strength can be accomplished with straight fibres that have good spring properties. A single fibre will judge the maximum strength of the paperboard. Paperboard tensile strength lower when moisture content is too high, this occurs when water molecules replace the fibre bonds thus lowering the tensile strength. (Särkkinen, 2010.) Good tensile strength contributes to better moulding of the paperboard in press forming equipment.

In the press forming process friction is born in-between the surfaces of the paperboard and metal and plastic coating and metal. The surface friction is affected by heat, moisture, speed of die and surface roughness. The effect of heat on paperboard is minimal but the effect of heated polymer and metal surfaces friction increases due to the fact that polymers when heated tend to soften. If the tools are heated too much will polymer starts to stick to the surface of the die of the press forming machine. (Tanninen, 2015)

Moisture content is an important factor in moulding as the moisture effects the properties of paperboard. Paperboard is hygroscopic material and will try to reach the moisture content of the surrounding environment. When moisture is absorbed into the fibres of the paperboard the fibres will become more flexible and less stiff. Humidity up to certain level will improve mould ability of the paperboard. Too much moisture of the paperboard will weaken the hydrogen bonds of the fibres and result is weakening of the strength properties. The worst case this high humidity might result in is tearing of the tray in press forming. As tensile strength diminishes there is an increase in elongation when moisture content is higher. When moisture of paperboard is low and the moisture content start to rise at the same time the tensile strength will rise to a certain point when moisture levels get too high and have a weakening effect on the paperboard (KnowPap, n.d.). Previous studies have shown that paperboard moisture level between 7-9.4% or relative humidity (RH) level of 60 -75% will give the best results (Särkkinen, 2010). Moisture content is one of the most important factors that must be acknowledged in tray forming process. Paperboard is too dry and stiff it will tear and if it is too moist and soft it will tear also under press forming. Figure 20 shows how moisture affects the stiffness of paperboard.

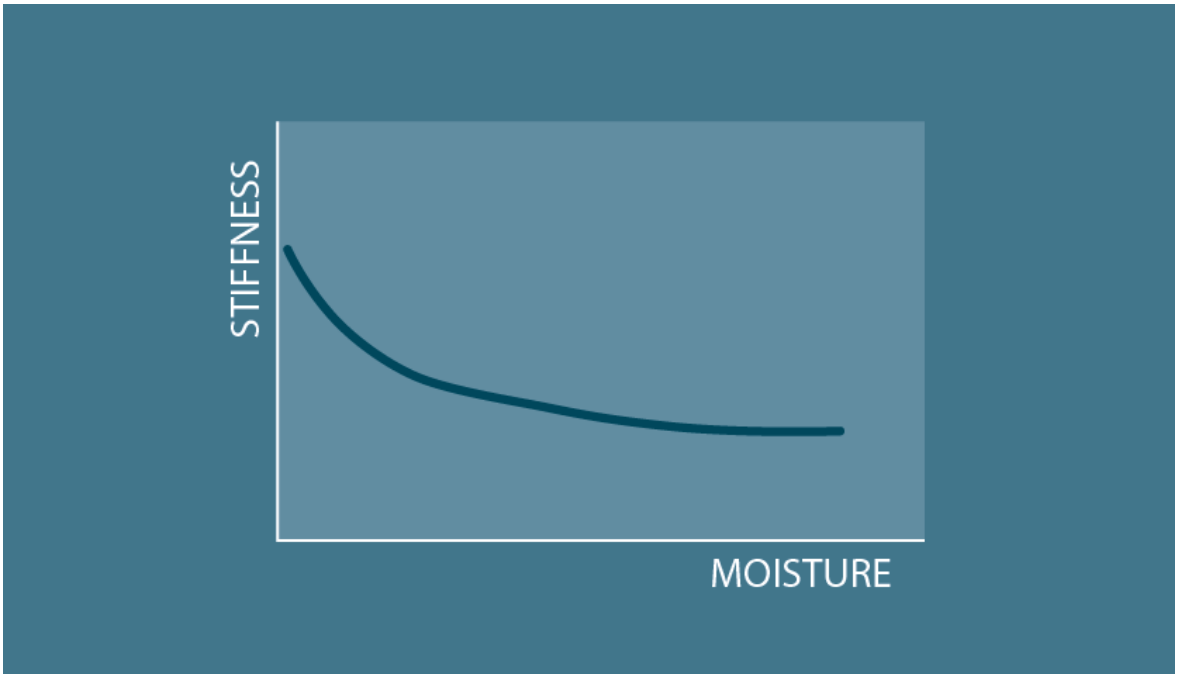


Figure 20. Effect of moisture on paperboard stiffness (Iggesund Holmen Group, 2016)

1.7.1. Tray forming defects

Food packaging companies that use pressed paperboard as containers want to use high speed and automated filling lines. That is why the pressed paperboard must meet the quality criteria's. All possible defects in the paperboard container will cause production and economical losses for the company.

Dimension of trays can vary as result of press forming. This can be caused by incorrect setting of the press forming machine or defects in the material. The cause's dimensional defects are spring back and defection. Spring back and deflection are caused by the materials elastic recovery to return toward to its former shape. Spring back has an effect on the trays side walls where the angle will change when the load of the die is released. The way to control spring back and deflection is proper moisture content of paperboard and heating of die tools. (Vishtal & Retulainen, 2012.) The benefits of air-conditioned machine hall will keep the paperboard from drying. If the air is too dry in the machine hall there is an increase in static friction that may cause problems for the production line. A stable and constant atmosphere has more pleasant working conditions for the workers.

Quality creases are essential for the tray to be used as food container. The creases function is to mould the tray into its desired shape. The creases may also present a problem if they are poorly formed. Defective creases may cause the package to leak and foodstuff can be spoiled for example in modified atmosphere packaging (MAP). In order to achieve a good seal on a filling machine the creases in the corners and flange must be even. Heat will make the polymer softer and seal the corner area together. Blank holding force controls the folding of corners. Previous results states (Leminen et al., 2013) that the mould clearance of the male and female mould affects operation of creases in the corners but does not affect the flange because the rim tool flattens the flange against the female mould.

Pinholes are small holes about 10μm in size that may be present in the polymer coating of paperboard. These small holes have an effect on the leakage of the paperboard and these small holes may reduce the shelf life of the packaged product (Tanninen, et al., 2015). In press forming trays pinholes usually occur in the die cutting of blanks, especially in the crease area. When pinholes occur in die cutting process it is usually due to the die tool is adjusted to move too deep and therefore it is pressing too hard into the paperboard.

Cracks and fractures may occur when the press forming machine applies too much force to the paperboard and the properties of the paperboard cannot withstand these forces. Fractures usually occur in the corners areas of the tray where the most elongation is present. When forces exceed the paperboards strength properties the fibre bonds fail and the fibres can tear apart. (Vishtal, 2015.)

Wrinkles are types of folds that occur outside of the crease area. Incorrect blank holding force is one of the main causes for wrinkles and improper creasing design of the tray blank. Different types of fibre layers are one factor that causes wrinkles because different types of fibre layers react differently to the forces applied when press forming. (Vishtal & Retulainen, 2012.)

Blistering is where the polymer coating of the paperboard separates from the substrate due the heating of the moisture and releasing of steam. When heat is applied to the paperboard the moisture tries to escape in form of steam and this may causes the blisters in the substrate. Polymer sticking to the mould occurs when the temperature of the dies exceed the softening point of the polymer coating and will stick to the moulds. This might affect the increased friction of the moulding process and will damage the surface of the coating surface and pinholes may occur. (Tanninen, 2015.)

1.8 Paperboard packaging for foodstuffs

Paperboard has advantages over other materials used for food packaging such as, glass, metals and plastics. Paperboard competitive edge is environment friendliness and it is abundant and easy harvest resource of raw material. Paperboard is bio-based and environmentally more favourable in ways of recyclability, light weight and biodegradability. The paperboard package is more presenting due to its excellent printability. Printing can be done directly to the surface of the package and can display the packages information and nutritional value of the content to the consumer. Paperboard can be easily combined with other materials to improve its properties by using for example waxes, polymers and oils. When press moulding paperboard trays polymers play an important role in improving the characteristics of the tray to improve its gas and wet barrier properties. (Han, 2014.)

1.8.1. Common polymers used in trays

Polymers are necessary for food trays because they form barrier properties for the packages. Without polymer layer the package could not have a proper barrier. List below shows the advantages that polymers have in packaging.

- Chemical and oil resistance
- Gas water barrier properties (water, steam)
- Sealing
- Thermal properties (heat, ovenable, microwave)
- Easily moulded
- Can be enhanced by colorants, fillers and active agents
- Odour, teats and aroma
- Adds rigidity to the package

Polyethylene (PE) is one of the most used polymers and is a synthetic resin. The polymerization of PE is where monomers combine to make a chain of molecules called a polymer. PE is a member of the polyolefin family and fall into categories of Low-density (LDPE) or high-density (HDPE) that are usually used in foodstuff packaging (Encyclopaedia Britannica Inc., 2016).

Polypropylene (PP) is commonly accessible in two forms PP homopolymer and PP copolymer. They both are used in foodstuff packaging. PP has a medium melting temperature, low transition temperature and low density. PP is used in packages where toughness, light weight, flexibility and heat resistance is needed. PP as PE is at first gaseous compounds that are produced by cracking process in oil refining (Encyclopaedia Britannica Inc., 2016).

Polyethylene terephthalate (PET) is a durable, ridged synthetic fibre that is used for tray applications that require high heat resistance. PET material is used extensively in bottled product because it is highly transparent, light, and tough and is cost effective.

1.8.2. Types of trays

Basic food containers used for food stuffs can vary from paper plates, trays and disposable cups where food stuff is not present for a long period of time. The paperboard is usually coated with PE or waxes too keep the foodstuff from absorbing into the substrate. (Robertson, 2006)

Microwave trays polymer coating are semi-transparent or wholly transparent because of the microwave radiation will be absorbed by the material (Emblem, 2012). Non-transparent polymer coating might cause sagging or other problems because it will absorb microwaves. Transparent materials do not react in the microwave and the heat will be transferred into the foodstuff. Commonly used polymers with paperboard are PP and PET due to their heat resistant characteristics. (Robertson, 2006.)

Dual-oven trays are foodstuff packages that can withstand heat of excess of 260°C. These trays are usually coated with PET. Trays are usually heat sealed to protect the food inside and the trays can be frozen to keep a longer shelf life.

Modified atmosphere packages are containers that have excellent seal ability and barrier to keep foodstuff fresh. The package works by replacing oxygen including air with ozone, carbon dioxide or nitrogen. Nitrogen is used to disperse other gases. Oxygen is removed because organisms need it to survive (Ministry for Primary Industries, 2009). MAP packages need to be perfectly formed to specification because any defect can cause leakage that will spoil foodstuff inside.

Moulded pulp trays are made by different process than press forming but have some similarities. The raw material is pulp which can be virgin fibre or recycled paper or board. The pulp slurry is sucked up into moulds from a slurry tank then the suction mould presses against the transferring mould and then the tray is sent to drying section. From there the tray or plate is dropped into a conveyer belt to be inspected and packaged for shipping. Moulded pulp trays can be used from variety of applications from disposable plates, egg packaging or electronics packages.

2 METHODS

The test procedures set-up, execution and evaluation were done at Stora Enso Oyj research and development centre located in Imatra. Machinery used at the packaging laboratory at the R&D centre includes a press forming machine and a flatbed die-cutter that were used to form the test trays. The material was obtained from Stora Enso Oyj mills. The polymer coating was done by Borealis Beloit extrusion and laminating pilot line. All the test samples of paperboard where stored in a humidity controlled cabinet where the RH is 75% and temperature 23°C

2.1. Test board materials

The test paperboard material that was used in press forming is listed below in table 1.

Table 1: Test materials

Test Code	Structure of substrate & Grammage g/m^2	Top polymer coating & Grammage g/m^2	Layer structure
Material 1	Three layer board top SBS, bottom SUS, 253	PP1-30	Polymer on SUS surface
Material 2	Three layer board top SBS, bottom SUS, 253	PP1-30	Polymer on SBS surface
Material 3	Three layer board top SBS, bottom SUS, 253	PP1-15 + PP2-15	Polymer on SUS surface
Material 4	Three layer board top SBS, bottom SUS, 253	PP1-15 + PP2-15	Polymer on SBS surface
Material 5	Three layer SBS 190	PP1-15 + PP2-15	Layer of PE coated in between two SBS 190
Material 6	One layer SBS 90 + Three layer SBS 190	PP1-15 + PP2-15	Layer of PE coated in between SBS 90 & SBS 190

*SBS solid bleached sulphate *SUS Solid unbleached sulphate

2.2. Borealis Beloit extrusion and laminating pilot line

The polymer coating for the test materials was done at Borealis at their coating and laminating pilot line. Figure 21 below shows information about the pilot line.

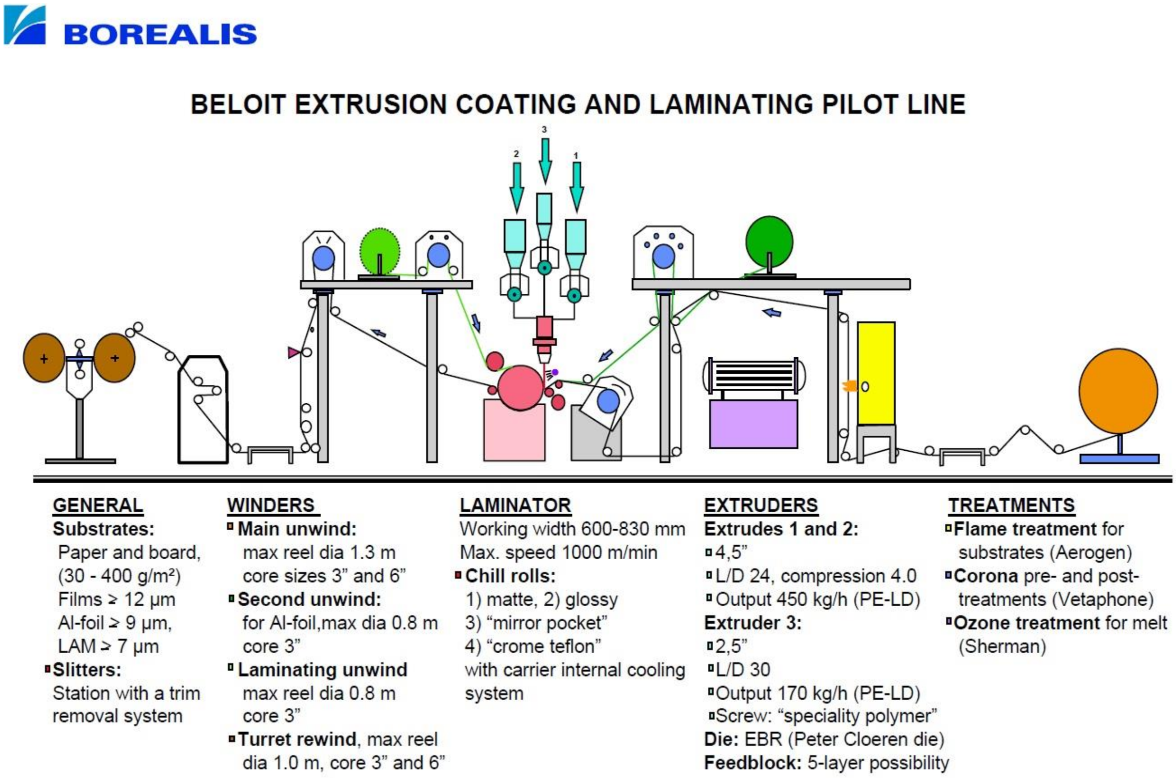


Figure 21. Coating and laminating pilot line.

2.3. Preparation of tray blanks

The die cutter KAMA TS-74 is an automatic flat-bed die cutter that was used in this thesis for the cutting and creasing of the blank test materials. The top tool has the cutting plate where the cutting blades and the creasing tools are located. The bottom tool has the counter plate with a groove patter that aligns up with the top. The paperboard is placed in stacks onto the feed table where it is transferred singularly and continuously to the creasing and cutting faze. The ready cut and creased paperboard stack to the delivery plat form. After the desired amount of blanks is produced the machine is stopped and the operator has to manually strip the excess paperboard away. The die cutting machines speed and pressing force can be adjusted. Figure 22 shows the KAMA TS-74 flatbed die cutter.

Figure 22. KAMA TS-74 flatbed die cutter.

Paperboard sheets arrived in size of 690mm x 550mm and where creased and cut by the KAMA TS-74 flatbed die cutter. The sheet where placed on to the feed table and a test run was performed and visual inspection of the quality of the creases was made. Visual observation of the crease depth, uniformity and quality was performed. The die-cutter tools can be adjusted left to right to get the perfect groove. Possible visual defects include cracking of the paperboard and polymer and too shallow depth of the crease. The cut tray blank also must detach easily enough from the sheet. After visual inspection and quality is assured the tray blank was subjected to pinhole testing. The penetration test with blue dye solution was used to detect any pinholes. If pinholes where detected the die-cutter would be adjusted accordingly, this means that pressing force was reduced slightly and visual and pinhole test where performed over until the tray blank quality was sufficient. An example of pinhole can be seen in appendix 2. Figure 23 shows to top and bottom die tools and their crease pattern.

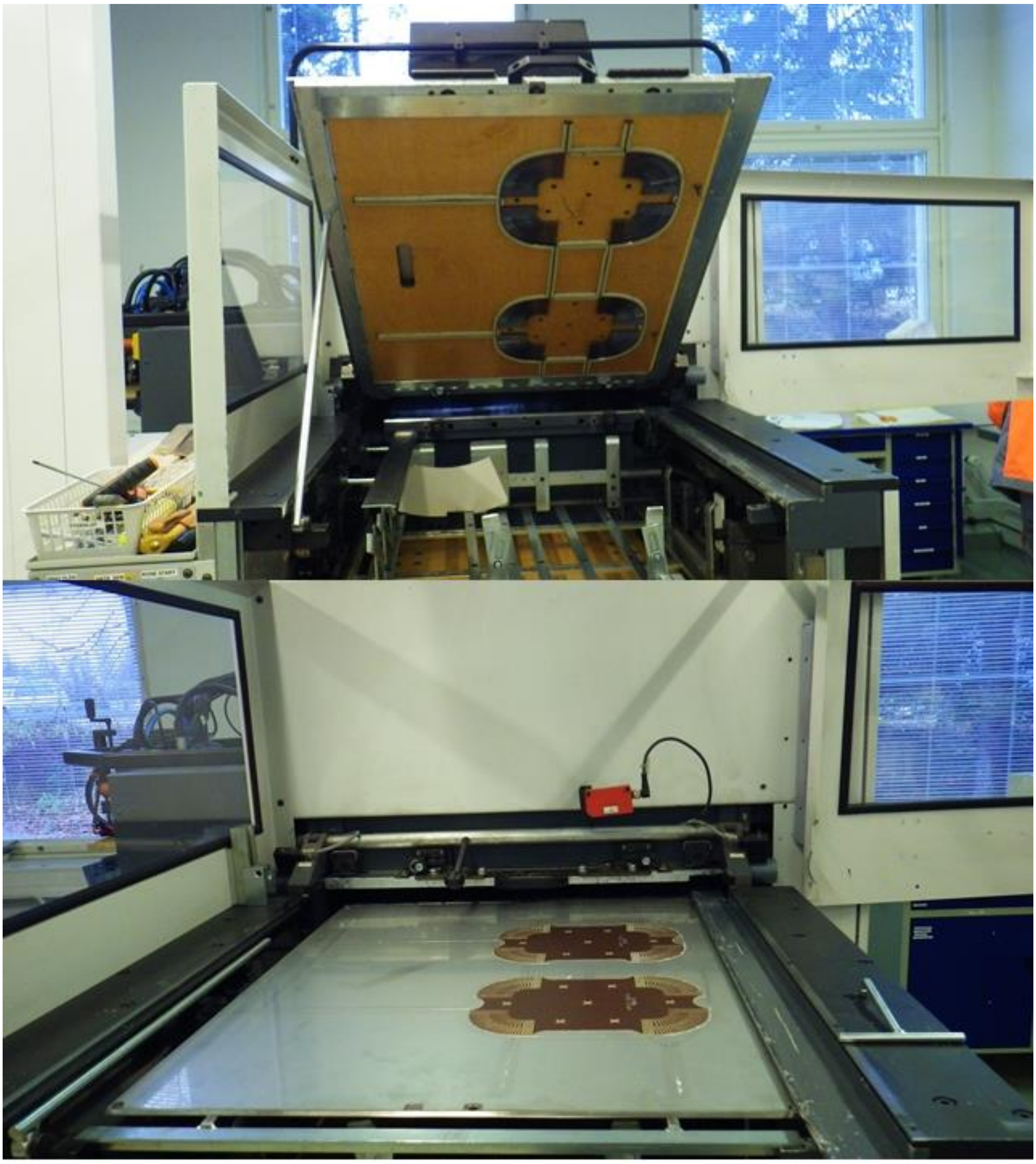


Figure 23. Top and bottom die-tool.

Figure 24 below shows the crease patter done by the die-cutting tool to tray blank and shows a trays moulded corner compared to the tray blank creases.

Figure 24. Tray blank creases.

2.4. Operation of mould press VP3-70

Mould press VP3-70 is a single tool press forming machine designed for paper/paperboard and coated paper/paperboard. The forming tools are on about 45 degree angle and the tools are changeable for different tray shapes. In this thesis the simple geometry tray mould was used to form the test trays. The press machine allows for adjustment of heat for upper and lower tools and cooling of upper tool. Speed of the machine can be adjusted to how many trays per minute are produced. Ply-holder pressure can be adjusted by increasing the air pressure. The pressing force can be adjusted with circular metal shims that are placed on the shaft above the male mould tool. List below shows the processing material data.

- Dimensions blank size
    - Max: 450mm x 400mm or Ø 400mm
    - Min: 100mm x 100mm or Ø 100mm
- Thickness: 0.4 – 2.0mm
- Weight: 250 – 600 g/m^2
- Moisture content min: approx. 7 – 10%
- Mould depth max: 70mm
- Max: Speed 40 strokes per minute
- Min: speed 5 strokes per minute

Figure 25. Mould press VP3-70.

Operating the press forming machine safety is important. The operator must know the safety aspects of the machine so no injury can occur. There is risk of pinching of fingers between moving parts and burns if heated moulds are touched. Safe guards must not be by-passed or alter to avoid injury to staff. Getting acquainted and good training for the operator of the press machine is the key for a safe work atmosphere.

Starting the production of the machine the operator should check that the machines surrounding are clean and the press machine is in operating condition, nothing is broken and maintenance is performed on a timely schedule. List below shows the normal start up procedure.

- Open air valve check air pressure is at 6 bar
- Turn on main power switch to position 1
- Adjust heating to test material specification temperature and push heating button
    - Heating light will go from red to green
    - Wait until heating light turns off on top left corner
- Push reset button

- Fill blank storage with pre-cut and creased blanks
- Place a blank manually on female mould so there is no metal to metal contact
- To start production press start button
- To stop machine press stop

Adjusting the mechanical work parameters of the press machine is done by step by step by changing the degree settings. Each degree setting shows the starting or stopping point of each action the machine performs. Figure 26 shows the principle idea of how the press mould cycle works.

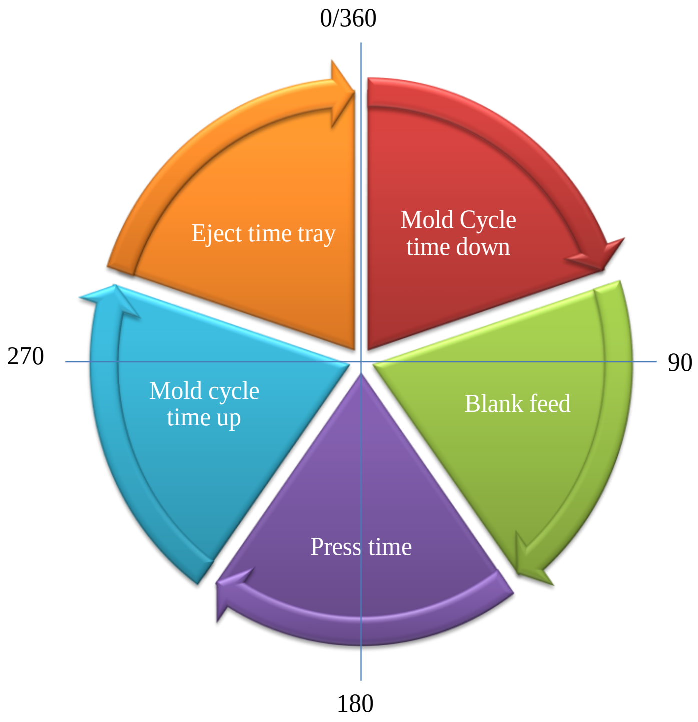


Figure 26. Press mould cycle.

Speed adjustments are how many strokes per minuets the press performs and the range can be adjusted from 5-40 but the max speed 40 was difficult to set due to the feeding of blanks could not keep up with the mould speed. The speed of the blanks fed into the moulds is adjust by hertz the higher the number the faster the speed the blank is fed. If the blank is not settling properly into the female mould and is flown out it is usually that the speed is too high and must be adjusted properly until the blank is settles properly on top of the female mould.

Ply-holder pressure is adjusted on the right hand side of the machine where the air pressure is turned on. The ply-hold pressure settings is amount is measured bars. This air pressure is sent to two actuators located on the side of the male tool that press down, the actual force applied to the ply-holder cannot be measured due to that fact that the machine does not have sensor that measures the force in that location.

The male and female mould clearance adjustment is done manually and there are no accurate clearance values that can be set and therefore the clearance is adjusted by trial runs of trays and observing the outcome. Every new paperboard test material the mould clearance should be adjusted. The adjustment procedure first starts by placing a blank on to the non-heated female mould. Then the manual turning hand-wheel is placed into position and the break is released, this will release the male mould on a downward cycle when in top position. The hand-wheel is turned by the operator to the lowest position and stopped before the male mould starts its upward cycle. The mould clearance is adjusted at the top of the machines ram where there is a shaft. The locking nut is loosed first then the adjusting nut can be loosed or tightened, seen in figure 27 below.

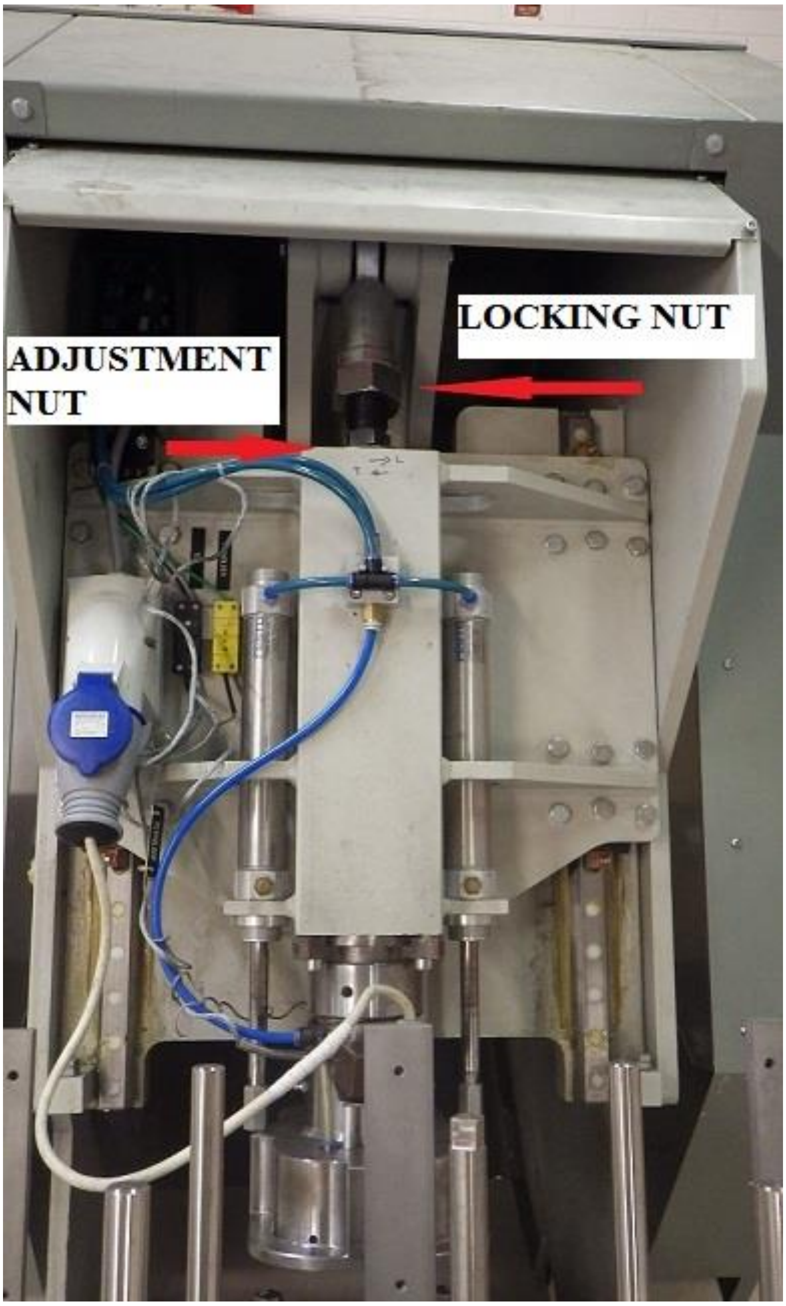


Figure 27. Mould clearance adjustment.

The hand-wheel is rotated so that it is possible to do one cycle, it should be fairly tight to rotate. After the proper clearance is achieved the locking nut is tightened and the male mould is rotated to top position and the break is turned on. Then the trial run begins to see if the mould clearance is correct and the moulds are heated to materials specifications. To achieve best clearance results there should be slight imprints of the hex-screws from the ejector on the bottom of the tray. Figure 28 below you can see a faint imprint of the hex-screw.

Figure 28. Hex-screw imprint on the bottom of tray.

To do the last adjustment and remove the hex-screw imprints from the formed tray the placement of the shims onto the shaft just above the male tool will give the last fine tuning of the mould clearance. The shims restrict downward press of the mould cycle and will adjust the mould clearance. By adding shims the mould clearance will grow and removing shims will have a reverse effect. Placements of the shims are seen in figure 29 below.

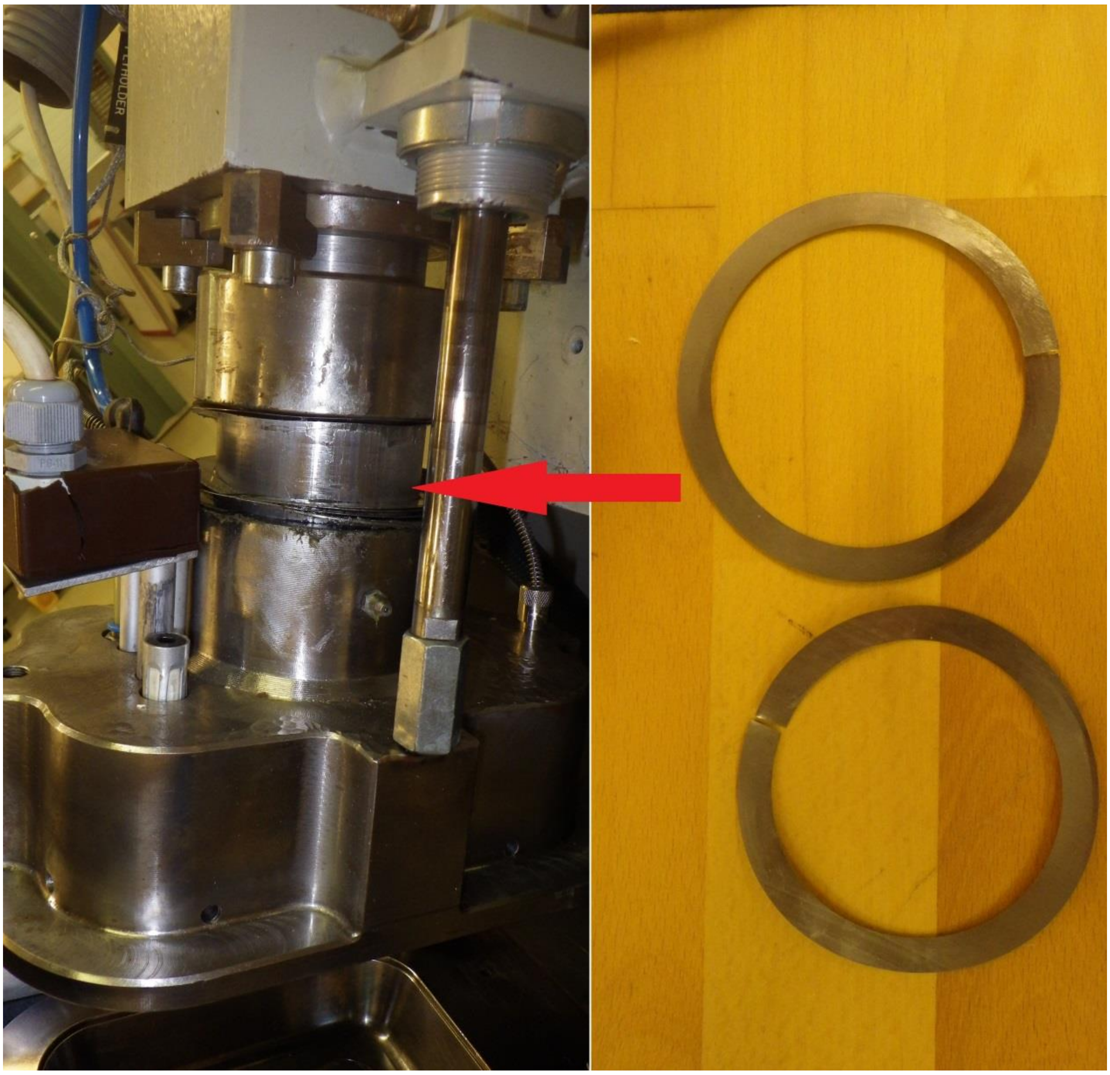


Figure 29. Shim placements.

2.4.1. Maintenance of mould press VP3-70

Daily maintenance of mould press VP3-70 when it is used in high production capacity includes lubrication of nipples that are located on rams linear guide. Neglecting the lubrication of the ram linear guide will wear down the guide rails and will result in mechanical failure of the machine. Mould tools are checked for any debris that might be stuck to the tools and removed accordingly. Daily cleaning of the surrounding of the machine is performed to remove all contaminants.

Weekly maintenance of mould press VP3-70 includes the lubrication of grease nipples that are located on the top of the ram that lubricates the can shaft. Lubrication of chains and sprockets are done weekly and mechanical inspection of chain and belt tension of main drive, feed-through rollers and conveyer belt. The pneumatic system must be checked weekly. Low pressure indicates that the water separator has collected too much debris and insufficient air flow is provided and this can cause infeed problems of tray blanks.

Monthly maintenance of mould press VP3-70 includes the lubrication of grease nipples located at the rear of the machine. Lubrication of gear wheels must be done this requires the removal of protective cover from cam drive. Also the main cam and curve roller are lubricated monthly and mechanical inspection of wear is performed simultaneously. Table 2 shows maintenance lubricant chart.

Table 2: Lubricant maintenance chart.

Time	Location	Lubricant
Daily	Ram shaft guides x2 grease nipples	Multipurpose grease
Weekly	Chains and sprockets Grease nipples bearings x1	EP open gear lubricant Multipurpose grease
Monthly	Gear wheels, main cam and curve roller Cam chat grease nipples x2	EP open gear lubricant Multipurpose grease

Debris from polymers and paperboard will after time grunge the surface of the forming tools. This debris will affect the friction properties of the press forming process. High friction values my attribute to tears in the paperboard tray. Therefore the moulds must be kept clean and debris free. A grinding paste of grit 500 was used to clean and polish the surface of the moulding tools. Grinding paste and a power drill with a polishing wheel made of cloth was used to polish the metal surface.

Debris from sound dampening foam caused problems to the VP3-70 mould press machine. The sound dampening foam after years was brittle and started to flake and fall into the machines components. The debris was first discovered on the conveyer belt and caused no mechanical problems at this point. Noise from the cam shaft belt was discovered when running the press machine and this was caused by the foam debris falling in-between the belt and the gear wheel. This also caused the main electric motor to jump because the tension of the belt grew due to the debris clogging all the gearwheel groves. Figure 30 shows the brittle sound dampening foam that has flaked off the side wall. Figure 31 shows the changing of the main drive belt.

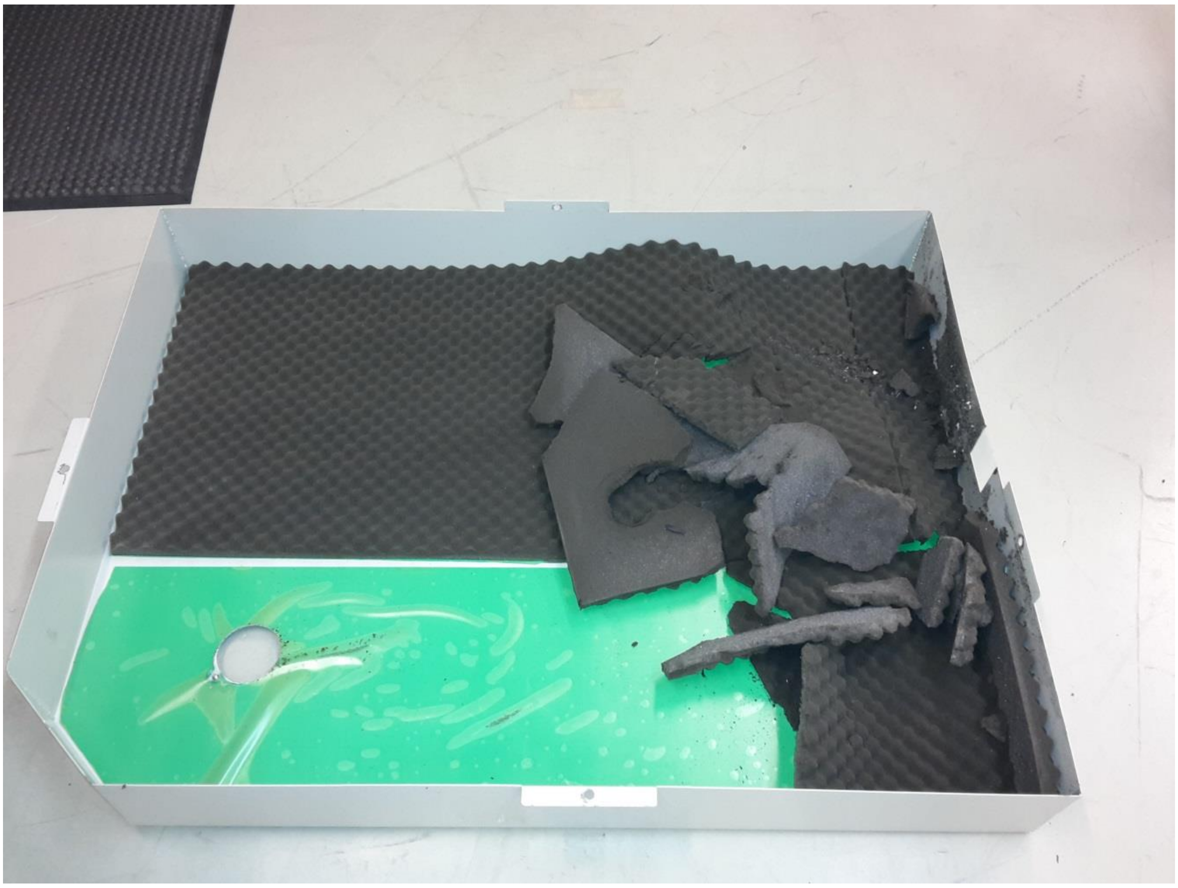


Figure 30. Brittle sound dampening foam.

All the sound dampening foam was removed so it would not cause any more mechanical failures. There was no significant noise increase when the sound dampening foam was removed. New sound dampening foam will be installed to the manufacturer's specifications.

Figure 31. Main drive shaft belt change.

Main drive shaft belt was easily changed by loosening the adjuster bolts on the electric motor and moving the motor forward to loosen the belt tension. Belt was removed and the gearwheel grooves where cleaned and a new belt was installed.

The male tool did not have air pressure added for cooling. The press machines pneumatic system was check and was noticed that the air pressure hose was removed for the cooling of the male tool. This cooling hose was installed back into the machine and made it possible to run longer production times decreasing the chance of sticking to the male tool. Also the air filter was cleaned and the air pressure increased from 5bar to 6bars which is the maximum air pressure of the line.

2.4.2. Mould tool alignment

Mould tool adjustment is important so that the tray shape will be uniform. The top mould is stationary and the bottom mould is adjusted accordingly. Tray blank is placed on the bottom mould and the mould is then set into down position. The bottom moulds locking nut is loosened so that it can move into place. When the adjustment is done the locking nut is then tightened and a test run is done to see if the moulds are aligned. Some indications of incorrect alignment can be seen when one or more tray corners have tears. Another sign that the mould tool alignment is out of place is when the trays are stacked and twisting of the stacks in one direction can be seen. To do fine adjustment a corner is to cut out of a readymade tray and place it in the corner female mould where adjustment is needed and loosen the locking nut. Release the top mould to bottom position in the female mould and tighten the locking nut and redo the test procedure mentioned above to get a properly formed tray. Figure 32 shows a piece of tray corner is cut out to adjust the female mould.

Figure 32. Female mould fine alignment with cut tray corner method.

To check for proper alignment and get a numerical value for alignment a 2mm tin soldering wire is placed in the female mould. The wire is run manually through the press and is flattened by the mould. A measuring calliper is used to measure the thickness of the flattened wire and the results are written down. Figure 33 shows how the tin soldering wire is placed in the mould.

Figure 33. Tin wire placement used for measuring alignment.

2.5. Evaluation criteria for test material and settings for VP3-70

The paperboard blanks are put in the humidity cabinet at RH 75%. Mould clearance of the press forming machine is adjusted to test material 4 at $253 g/m^2$. Mould clearance will only be adjusted with shims if other test material is too thick or thin for the first clearance settings and this modification will be written down. Mould clearance will not be adjusted from the adjust bolt located at the top of the ram. Cooling temperature of the male mould will be set to 25°C. When the male mould temperature exceeds over 25°C air will start to cool the male mould. There are nine different test setting that will be used and they are listed in the tables below. The minimum and maximum temperature setting was chosen from Differential scanning calorimeter (DSC) results that can be seen in section 2.6.1. Blank holding force was chosen low to high pressure. Press stroke setting was chosen to be a medium speed at 17 press strokes per minute. Each paperboard material will be run through each test settings and 100 trays will be made for each setting.

Table 3: Test settings for press forming machine.

Test settings	Set.1.1	Set.1.2	Set.1.3	Set.2.1	Set.2.2	Set.2.3	Set.3.1	Set.3.2	Set.3.3
Female mould temperature °C	140	140	140	160	160	160	180	180	180
Blank holding force (bar)	1	2	3	1	2	3	1	2	3
Press strokes	17	17	17	17	17	17	17	17	17

The criteria's for tray quality will be tested and compared to the laboratory results to see if there is any relation between paperboard material that performed well in laboratory and paperboard material that made quality trays . List below shows the criteria area that will be tested. All trays will be inspected for cracks/tears and wrinkles, if multiple cracks/tears or wrinkles are present in one tray it will account for 1 in the criteria evaluation. Pinholes will be tested from 10 random trays picked from the stack and if multiple pinholes are present in one tray it will also account for 1 in the evaluation criteria.

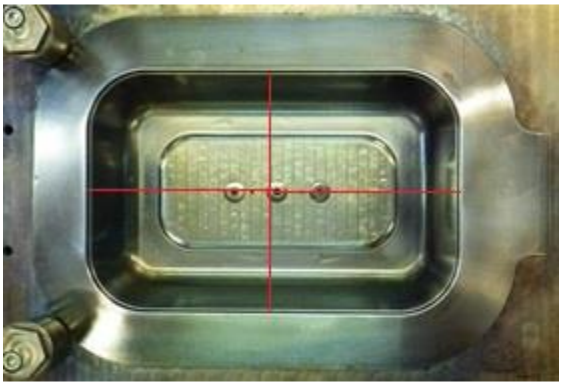
- Dimension of tray versus the dimension of the female mould
- Sum of cracks and tears
- Sum of wrinkles
- Sum of pinholes

- Visual inspection of corners using figure

Twisting of stacks will also be observed because this will show if the mould tool is aligned properly and to see that all the trays are uniform. Figure 34 shows twisted stack this is the result of the tool being out of alignment.

Figure 34. Twisted tray stack indicates improper tool alignment.

Also the dimensions of the staked trays will be compared to the dimensions of the non-staked trays. This test is done to see if there is any effect due to rapid cooling of trays that are non-stacked to slower cooling trays that are stacked. Dimension of female mould is seen below in figure 35.



Length: ~196.34mm

Width: ~126.29mm

Figure 35. Dimension of female mould.

Figure 36 will be used as a guide to visually inspect the corners where 0 = best quality and 3 = worst quality.

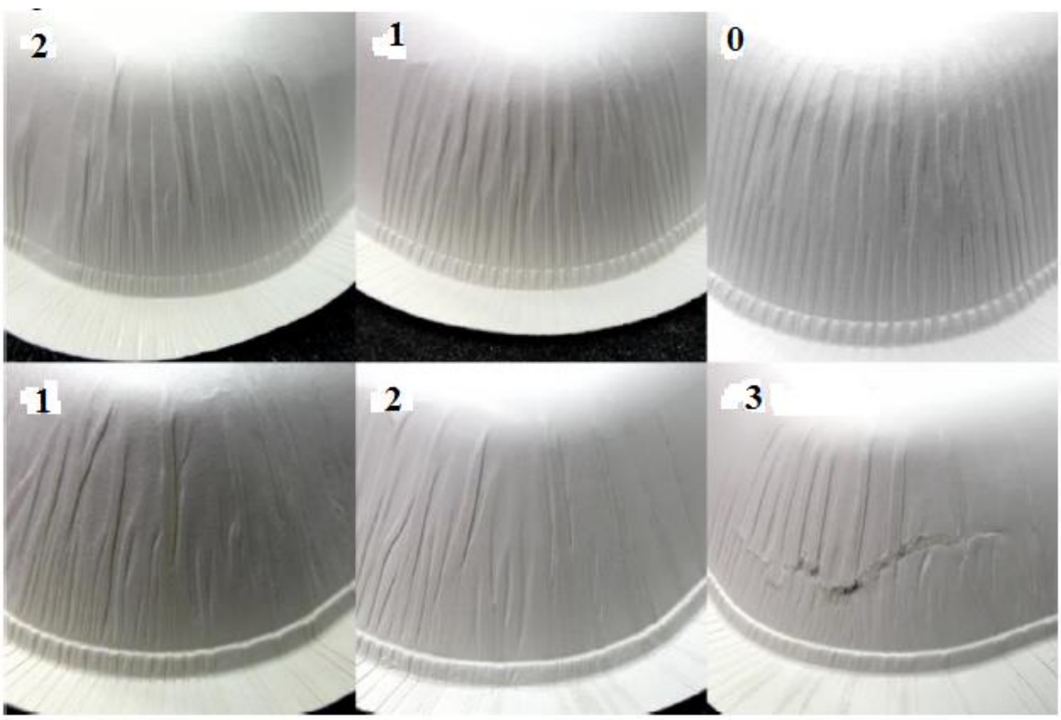


Figure 36. Visual inspection of corners guide figure modified (Leminen et al., 2013).

2.6. Laboratory test of paperboard materials

The test paperboard material samples were sent to the paper laboratory for further testing of their properties. The objective of the test was to find the properties of the test materials and if the results can be used to foresee the affect it has on the press forming process.

Scott bond test is one of the methods to determine the delamination resistance or the internal strength of the test paperboard material. Scott bond test complies with the TAPPI T 569 standard. The test will be completed with the internal bond tester model 1314. Model 1314 measures and determines strength with regard to energy adsorption (Thwing-Albert Instrument Company, 2012).

Tensile strength method will be performed on the test paperboard material to determine the tensile strength, energy absorption, and stiffness. All measurements made are in accordance with TAPPI T 541and ISO 15754. The L&W tensile Tester/Fracture toughness tester was used at the laboratory. The paperboard test material is placed in between two clamps that hold the material securely. Even tension is the applied evenly and the test material is pulled in opposite directions until breakage occurs. Elongation of the paperboard test material is measured to determine the elongation or stretch.

Friction test will be made to the polymer and paperboard surfaces. The test material will be placed against a metal surface closely simulating that of the metal material used in the press forming equipment. The test sample is dragged along a plane surface to get the dynamic friction measurement. This test meets TAPPI T 815 standard.

Scanning electron microscope will be used to determine the thickness of the test materials layers. A cross section cut is performed on the test material and the edge is put under the microscope. These pictures will show the polymer layer thickness and the paperboard material thickness. Figure 37 show layers present in material 1.

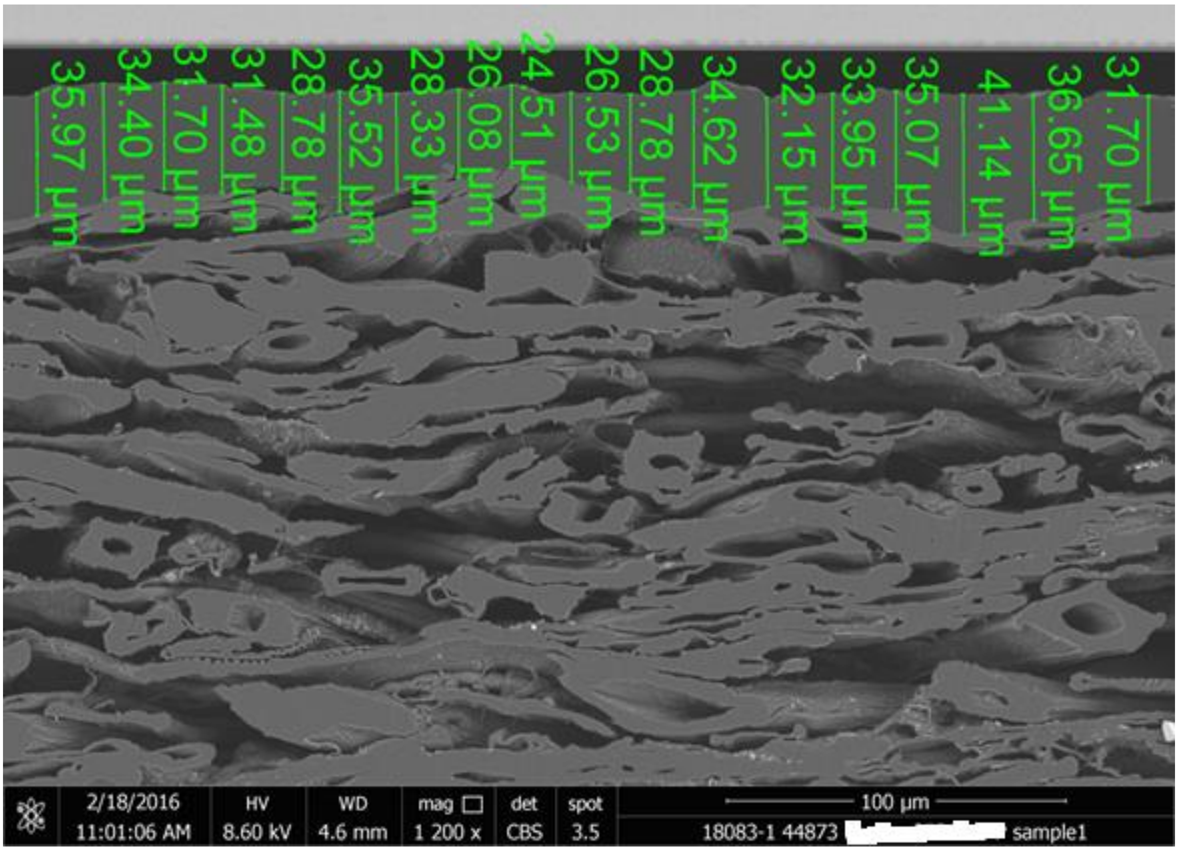


Figure 37. Layer thickness of test material 1.

Differential scanning calorimeter (DSC) was used to test the melting point of the polymers used in the paperboard test materials. DSC has two hot plates that that are used for testing, one of the plates has the sample material and the other is kept empty as a control. Then the two plates are heated at same time and are monitored on how much energy it takes to heat each one. The differences of the heat and energy consumed are recorded by the DSC and the results are displayed on a chart as peaks. From these reading one can predict the max temperature that should be used on the press moulding machine.

Test performed on the paperboard materials were done to see if the materials that performed well in the laboratory would also perform well in press forming. List below of test that was performed on the paperboard materials. All material that where tested had a RH of 50%.

- Scott bond test
- Tensile strength test
- Humidity of paperboard
- Friction test

- DSC
- Scanning electron microscope (SEM) pictures of board and barrier structure

2.6.1. DSC test

Using the DSC testing it is possible to get the polymers melting point and to have a reference temperature that will be used during the press moulding process. The max temperature that is obtained from the DSC can be only used as a reference, this does not mean that if max temperature is exceeded in the press forming process that there will be sticking of polymer to the tools. Figure 38 below shows the max melting point for PP1 polymer coating and figure 39 shows the melting point for PP2. From the DSC figures the maximum test temperature for the female tool will be set at 180°C. Starting temperature for testing will be set at 140°C, medium temperature will be set at 160°C. The melting point from the DSC test is used as a medium temperature reference. Using too low of a temperature will affect the mouldability of the tray negatively. Therefore it is un-feasible to use low temperature settings for press moulding.

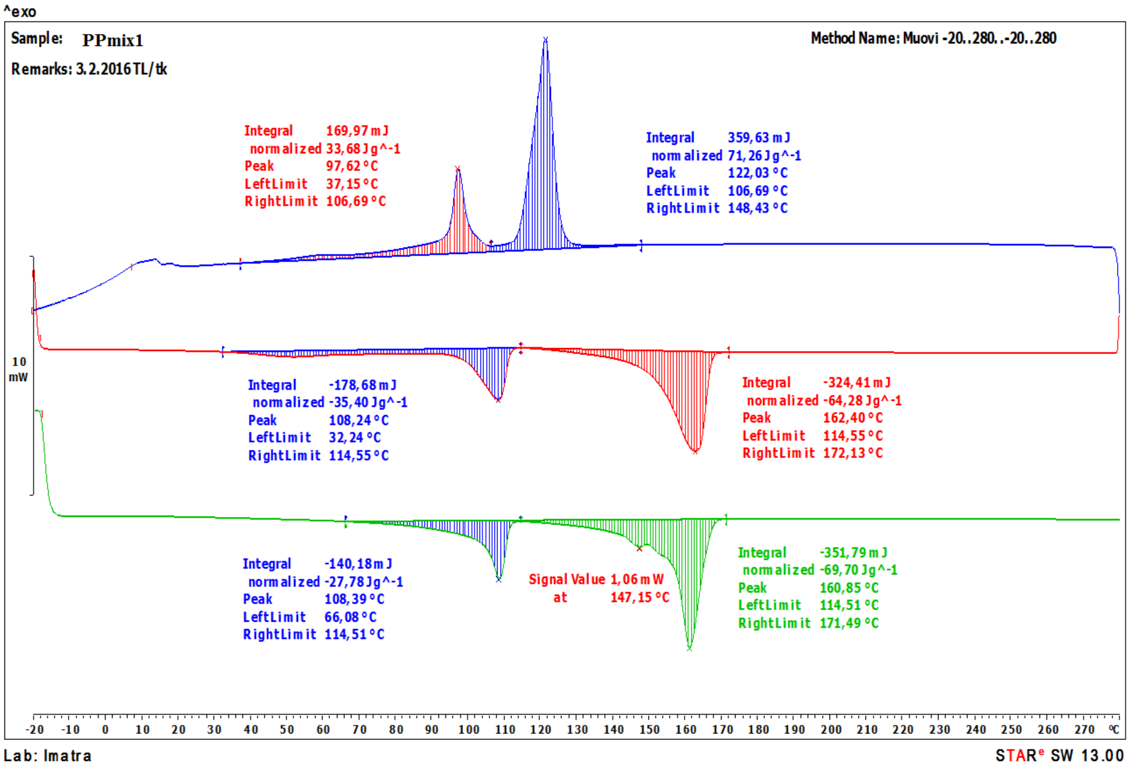


Figure 38. DSC curves PP1.

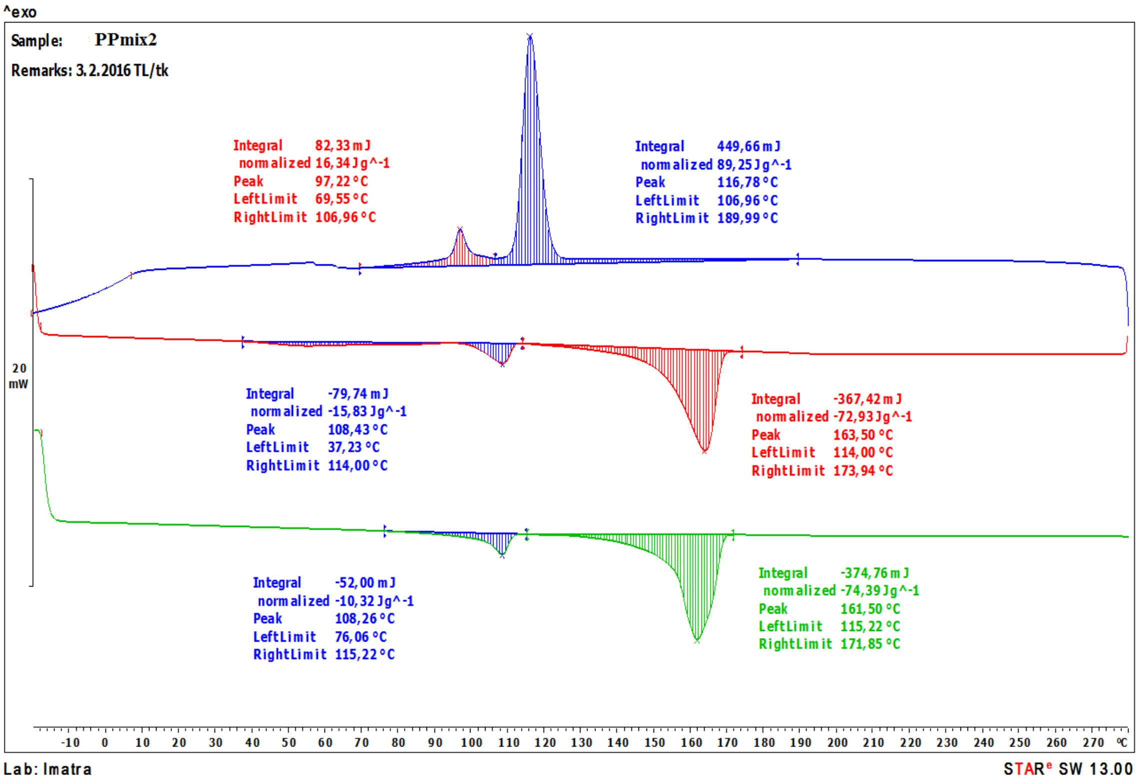


Figure 39. DSC curves PP2.

3 RESULTS

3.1 Maintenance results of tools

The polishing of the female and male tools may have some effect on the moulding process. The polishing may have reduced friction that will help in moulding the paperboard material. Below in figure 40 are the before and after pictures of polishing.

Figure 40. Mould tools before and after polishing.

3.2 Measurements results using tin wire method

Measurement show that the tool is adequately aligned and there are no major deviations. This procedure of measurement is a crude way of measuring alignment but for this press machine it is adequate and more modern press forming machines have created better measuring methods to align their moulds.

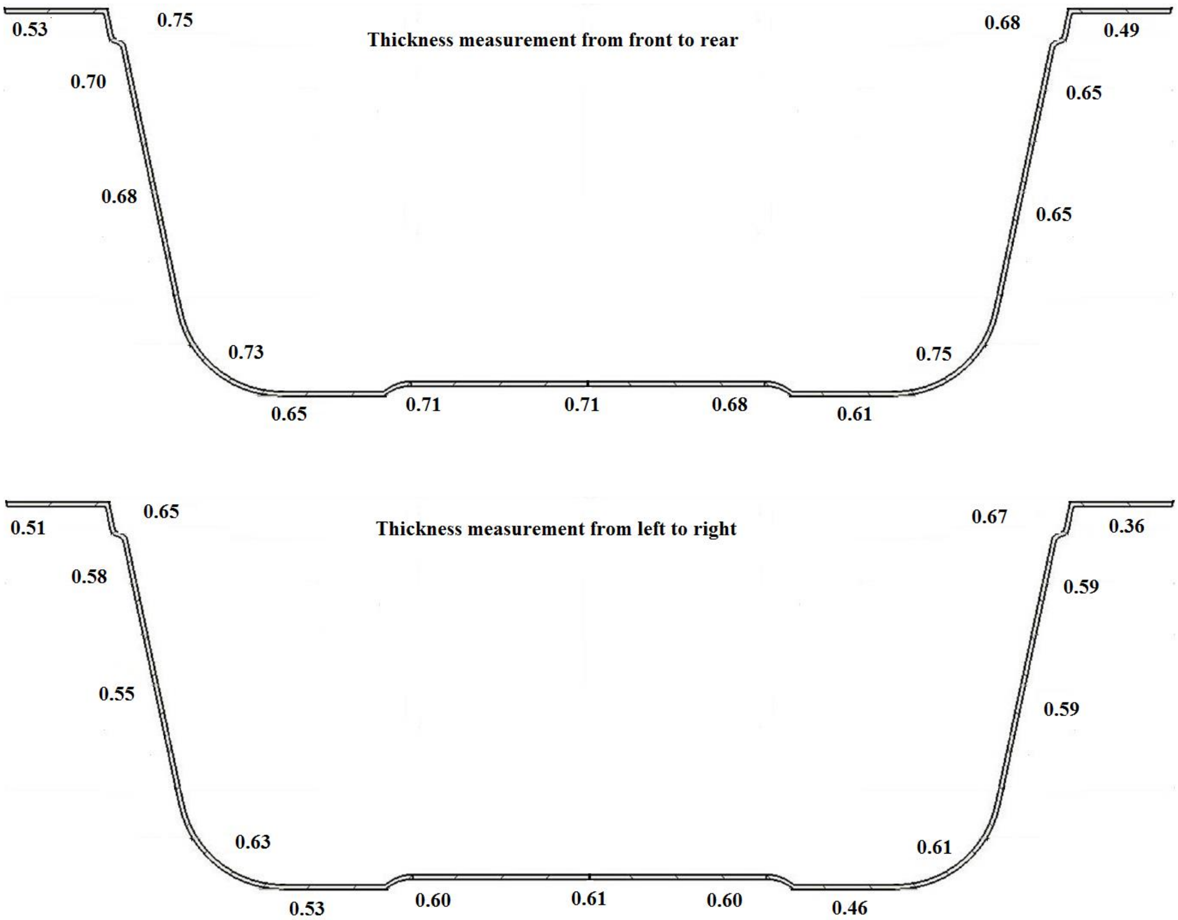


Figure 41. Measurements of mould alignment using tin wire method.

3.3 Laboratory test results

Laboratory test of the paperboard was done to find if the physical properties of each test material. The laboratory results are compared to the test moulding results of the trays. The objective of the comparison is to find if the test materials results have any effect on the moulding process. Laboratory results are displayed in bar graphs.

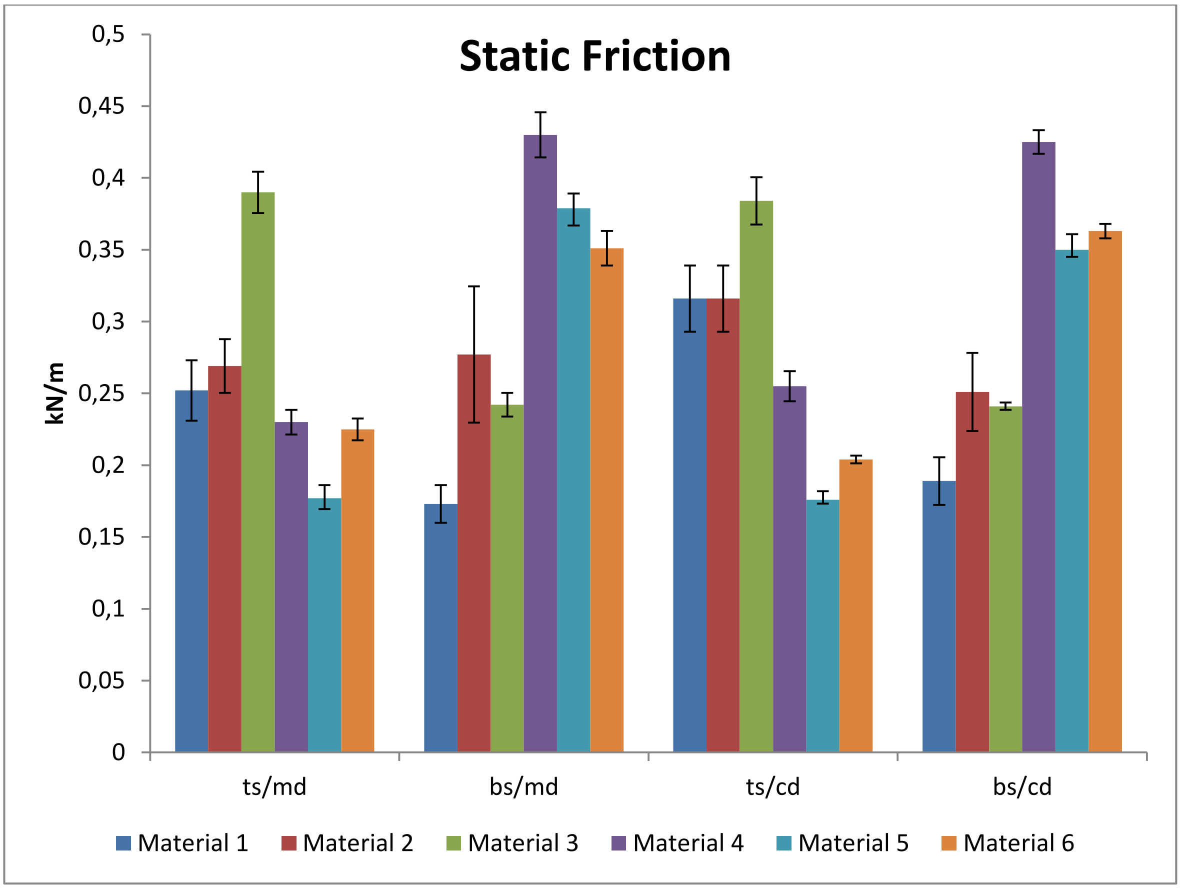


Figure 42. Static friction of test materials.

Static Friction figure 42 shows the static friction of the test materials polymer coating surface and paperboard surface. The polymer surface is marked top side (TS) and the paperboard surface is marked bottom side (BS). Also the measurements are done in machine direction (MD) and cross direction (CD). With this chart you can compare the materials surface friction and how friction acts in MD and CD. Can be seen that some materials have less friction in MD and how other materials have less friction in CD. These same observations can be applied to the kinetic friction chart below in figure 43.

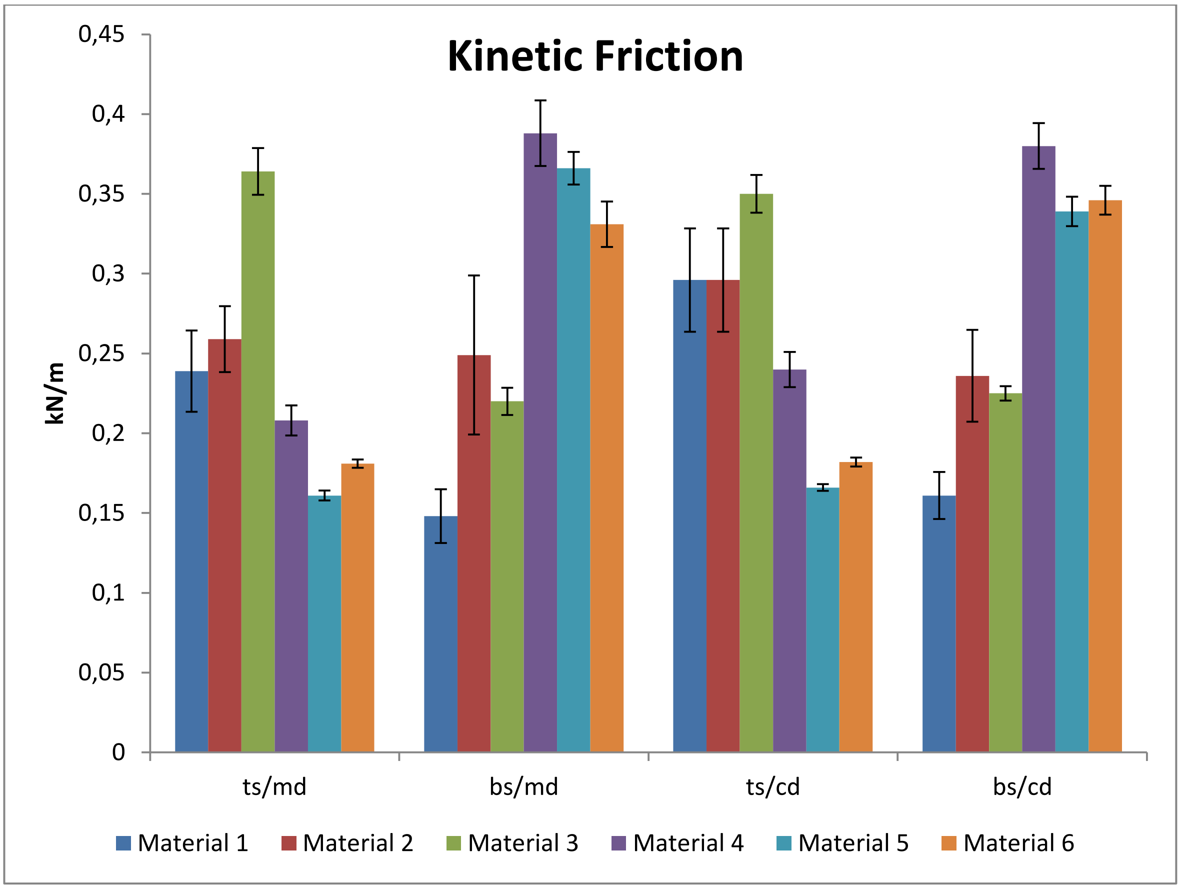


Figure 43. Kinetic friction of test materials.

Kinetic friction is where the surface of the test material is dragged along a metal surface closely resembling the surface of the mould tools. Measurements are done in TS, BS, CD and MD. Kinetic and static friction laboratory results can vary significantly when compared to the mould pressing process (Tanninen, 2015).

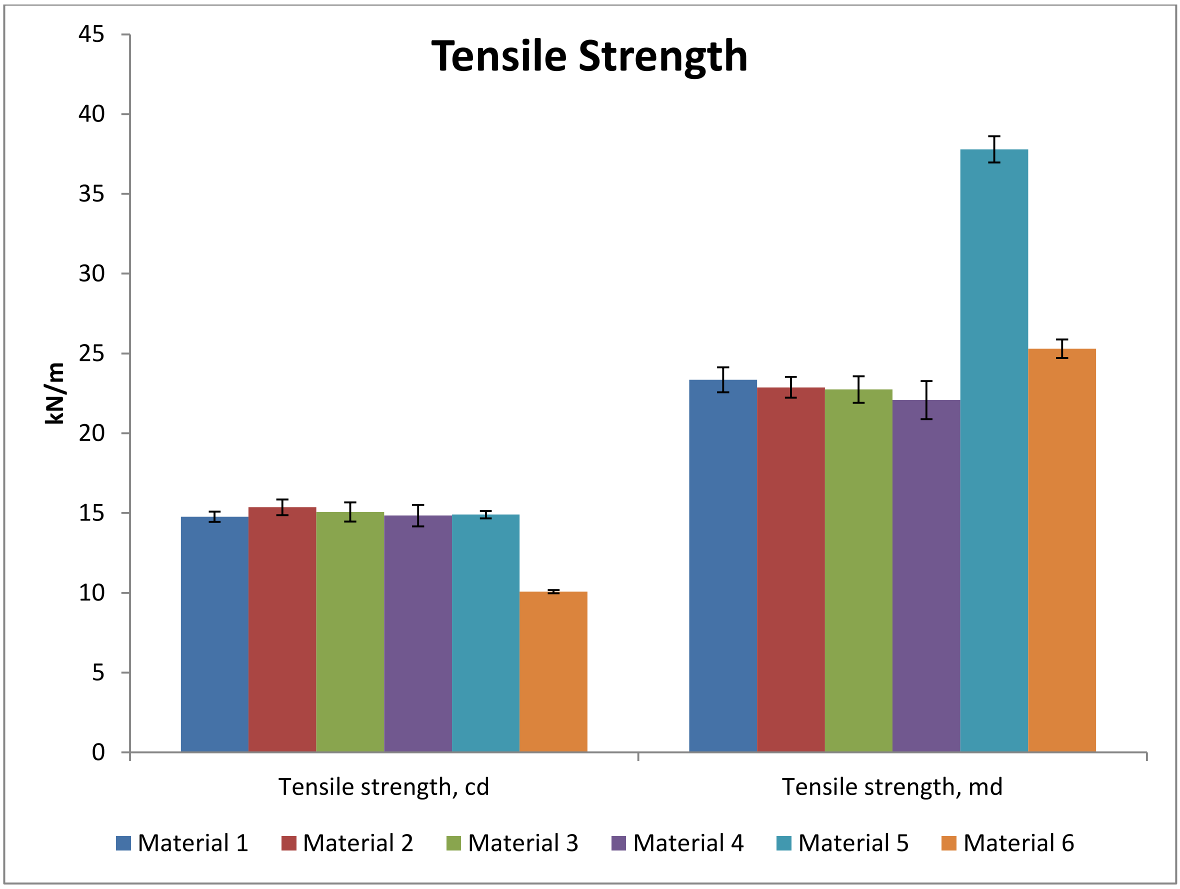


Figure 44. Tensile strength of test materials.

The chart shows the tensile strength of the test materials and is compared to other test materials in CD and MD direction.

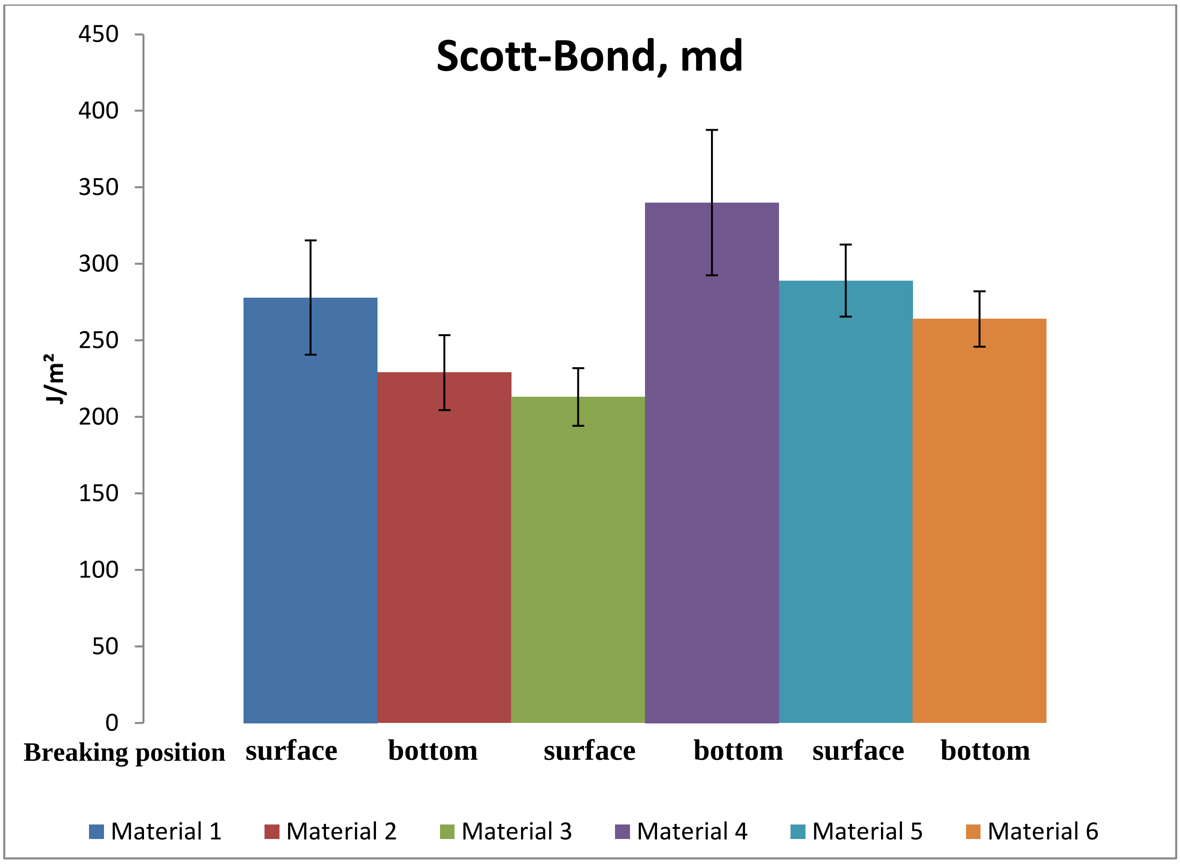


Figure 45. Scott bond of test materials.

Scott bond results show the materials internal bond strength. The chart below shows the breaking position of the paperboard material.

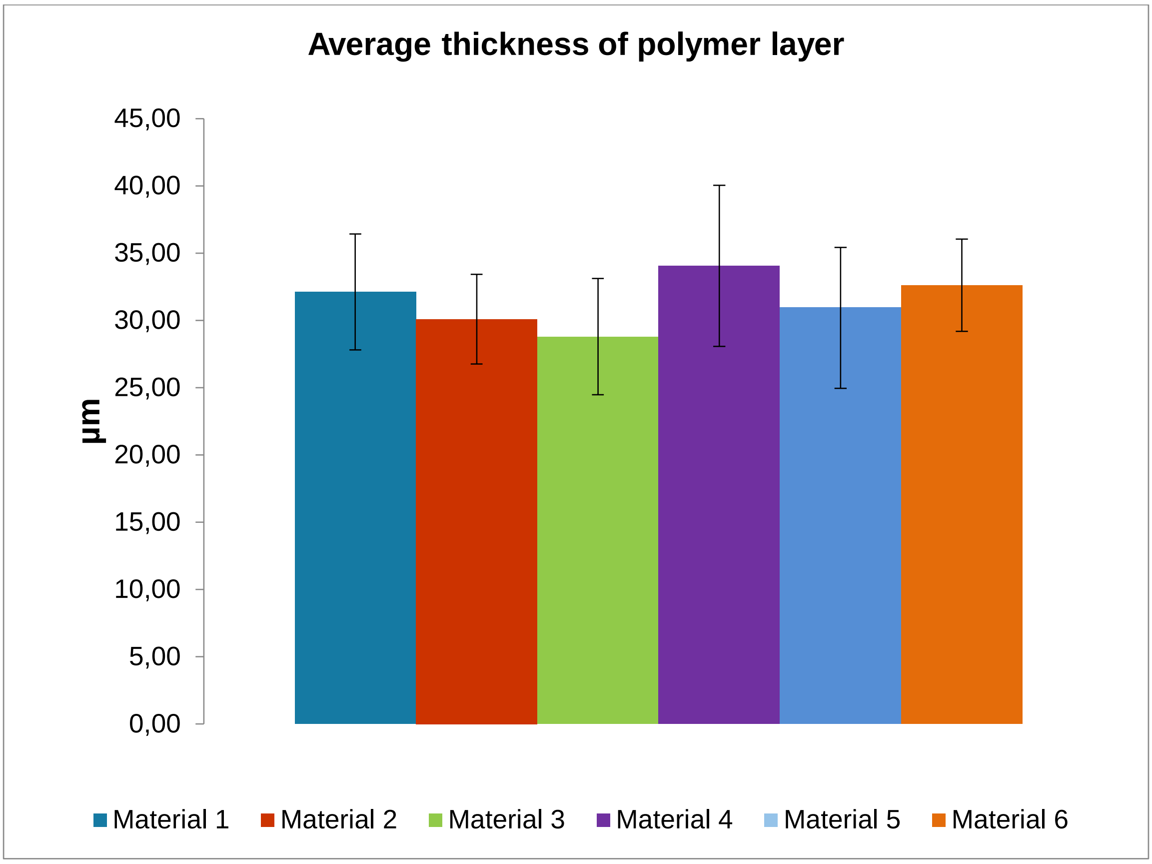


Figure 46. Average thickness polymer coating.

SEM pictures were taken to see the polymer and paperboard structure and thickness of polymer layer used. Figure 46 shows the average thickness of the polymer taken from a small area. Detailed SEM pictures can be seen in the appendix 1.

3.4 Test results of mould pressed material

In the evaluation charts data is collected from the mould pressed trays. The corners, pinholes, wrinkles and cracks are found from the trays and the data is collected. The evaluation criterion is the average of all the defects and the target line is set at 2 for good quality trays. Therefore if the average exceeds the target line the tray is substandard.
The test materials dimensions where measured in length and width. The dimension of the trays was compared to the female moulds dimensions.

In the production of the trays the trays where stacked and the other trays where not stacked. The dimension of stacked and unstacked trays is compared to see if rapid cooling has any effect on the dimensions or shape of the tray.

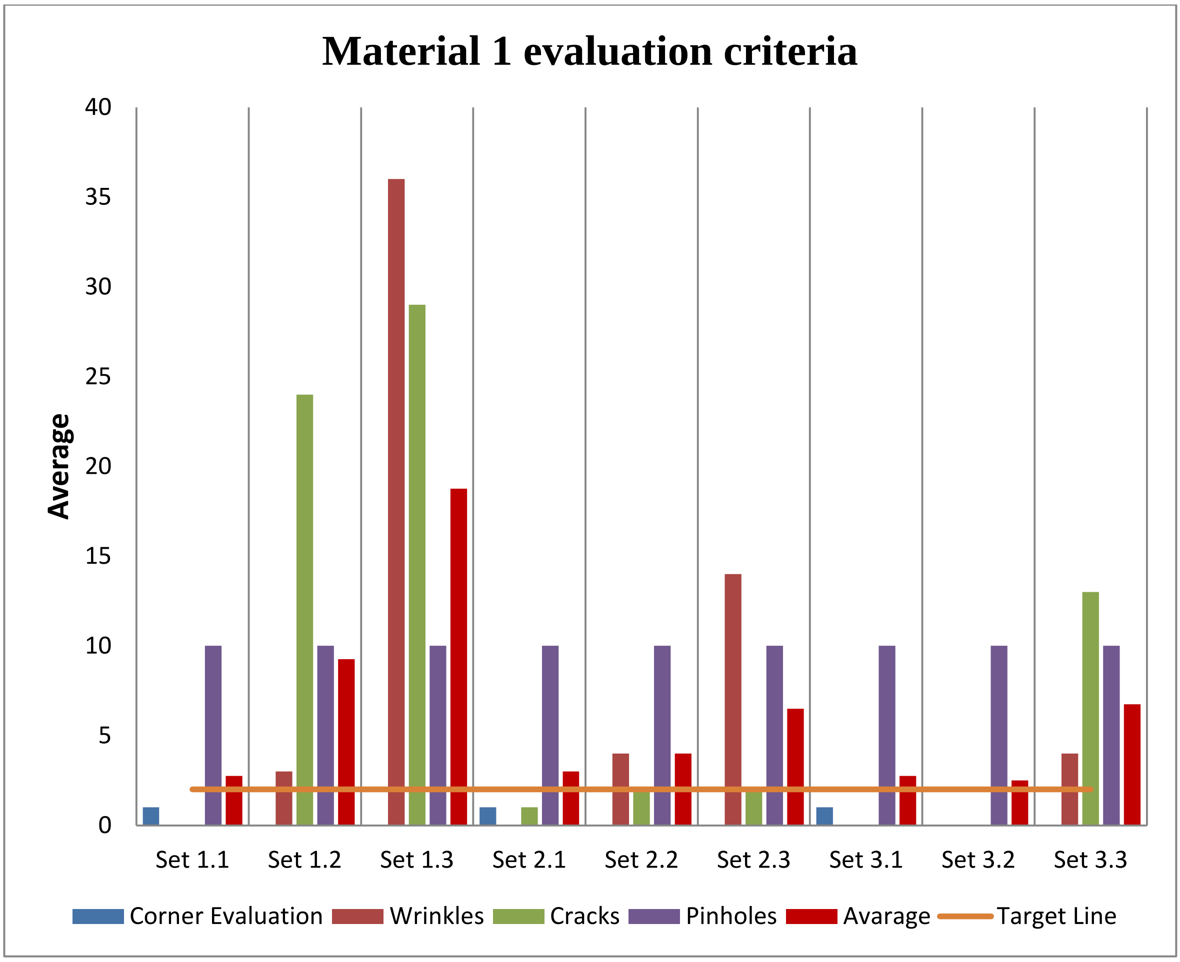


Figure 47. Material 1 evaluation criteria.

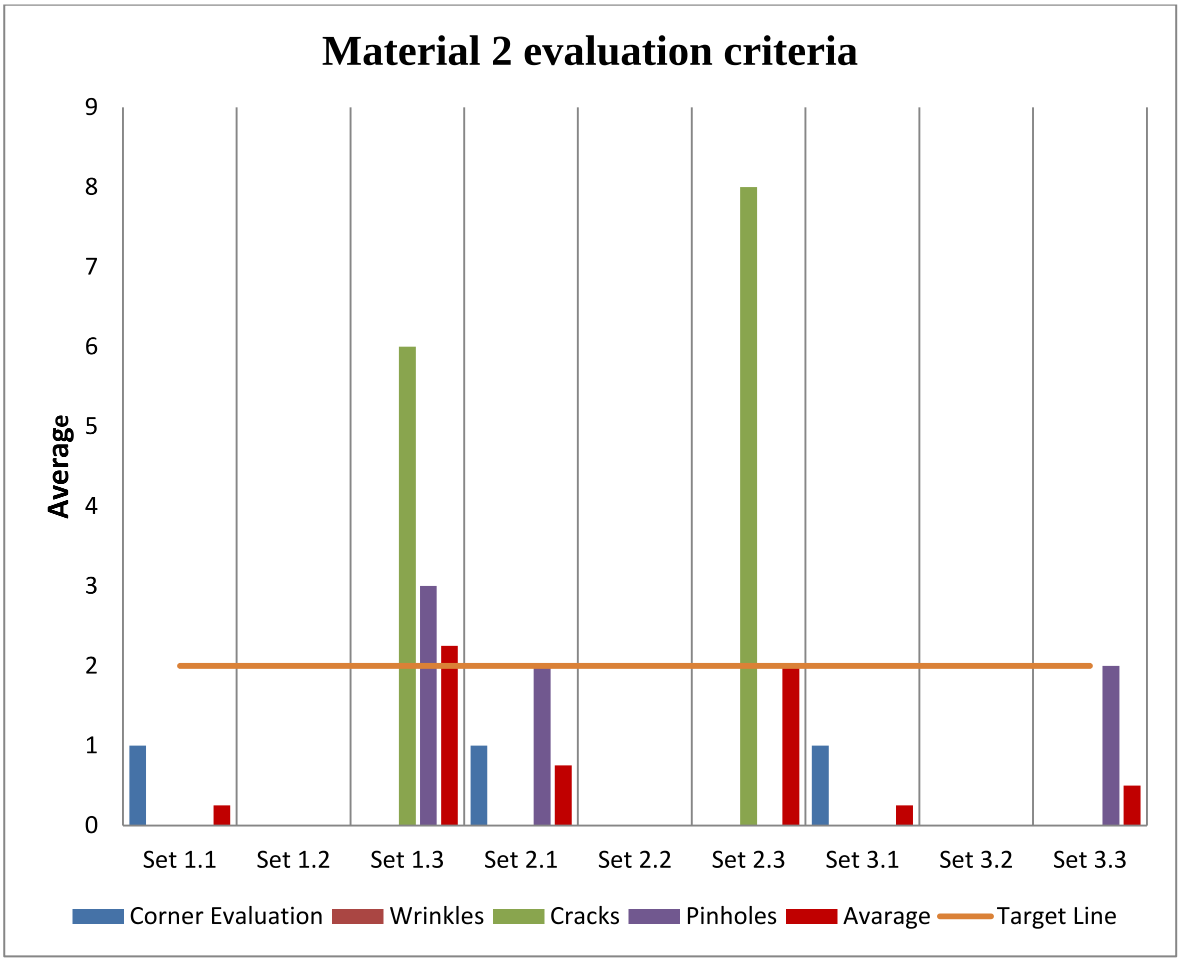


Figure 48. Material 2 evaluation criteria.

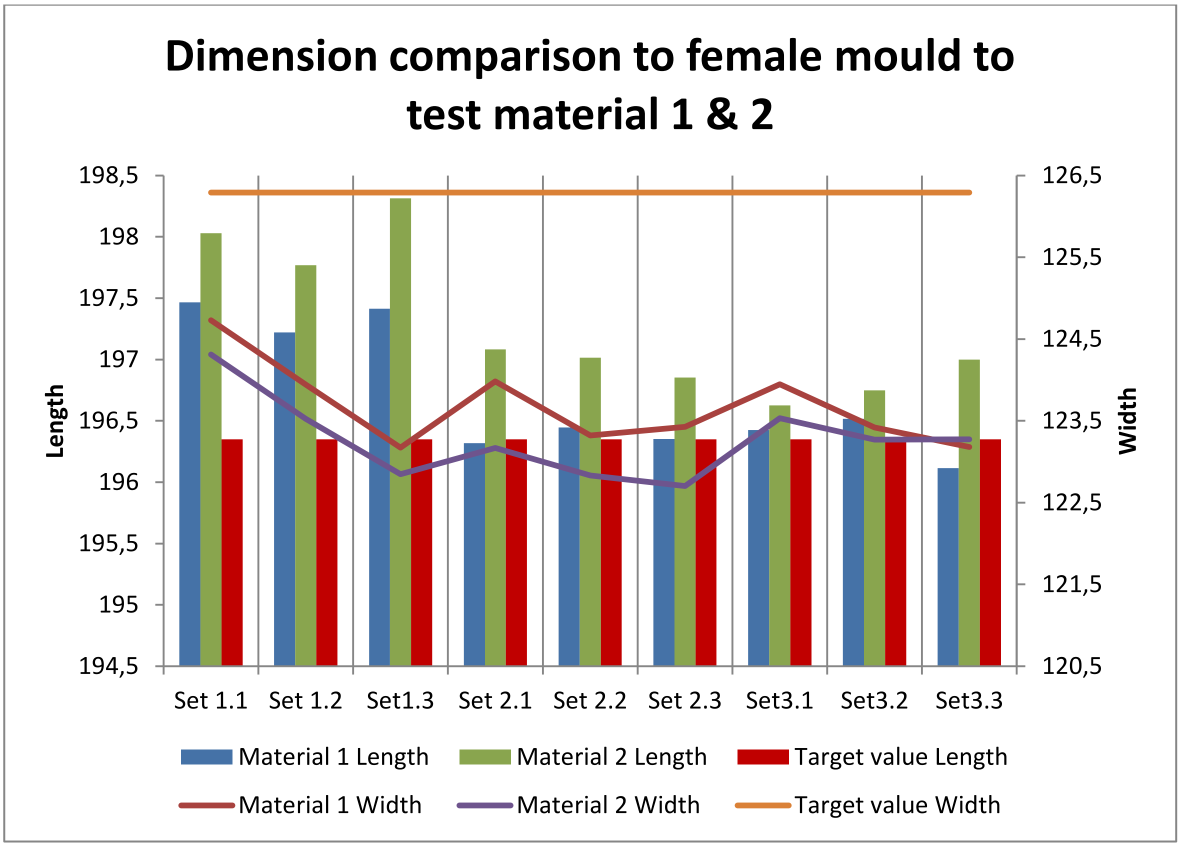


Figure 49. Dimension comparison to female mould to test material 1 & 2.

In this chart is the comparison of the female mould dimension is compared to the dimensions of the tray. Target values are the dimensions of the female mould. Optimal dimension is for the paperboard tray is to get as close as possible value of the female mould.

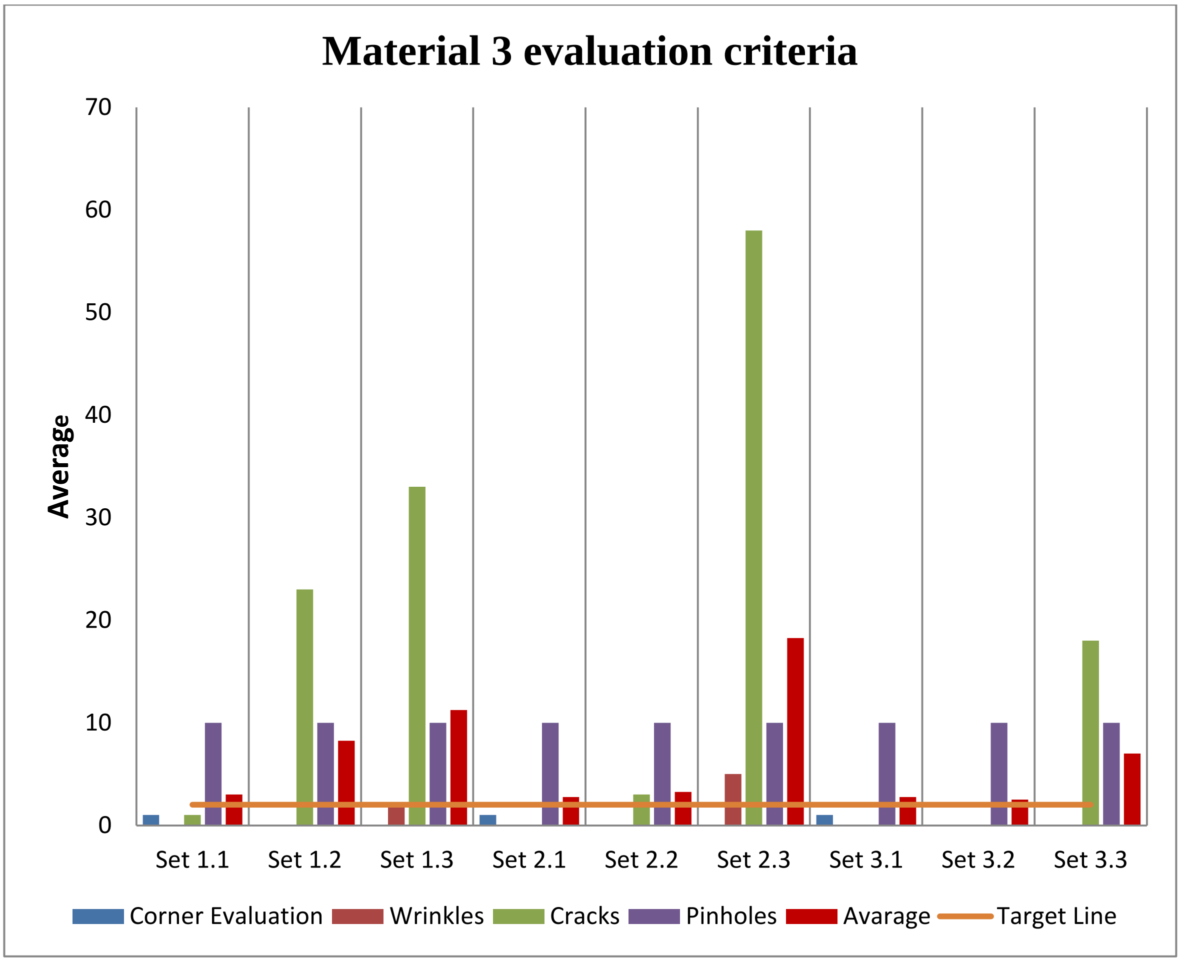


Figure 50. Material 3 evaluation criteria.

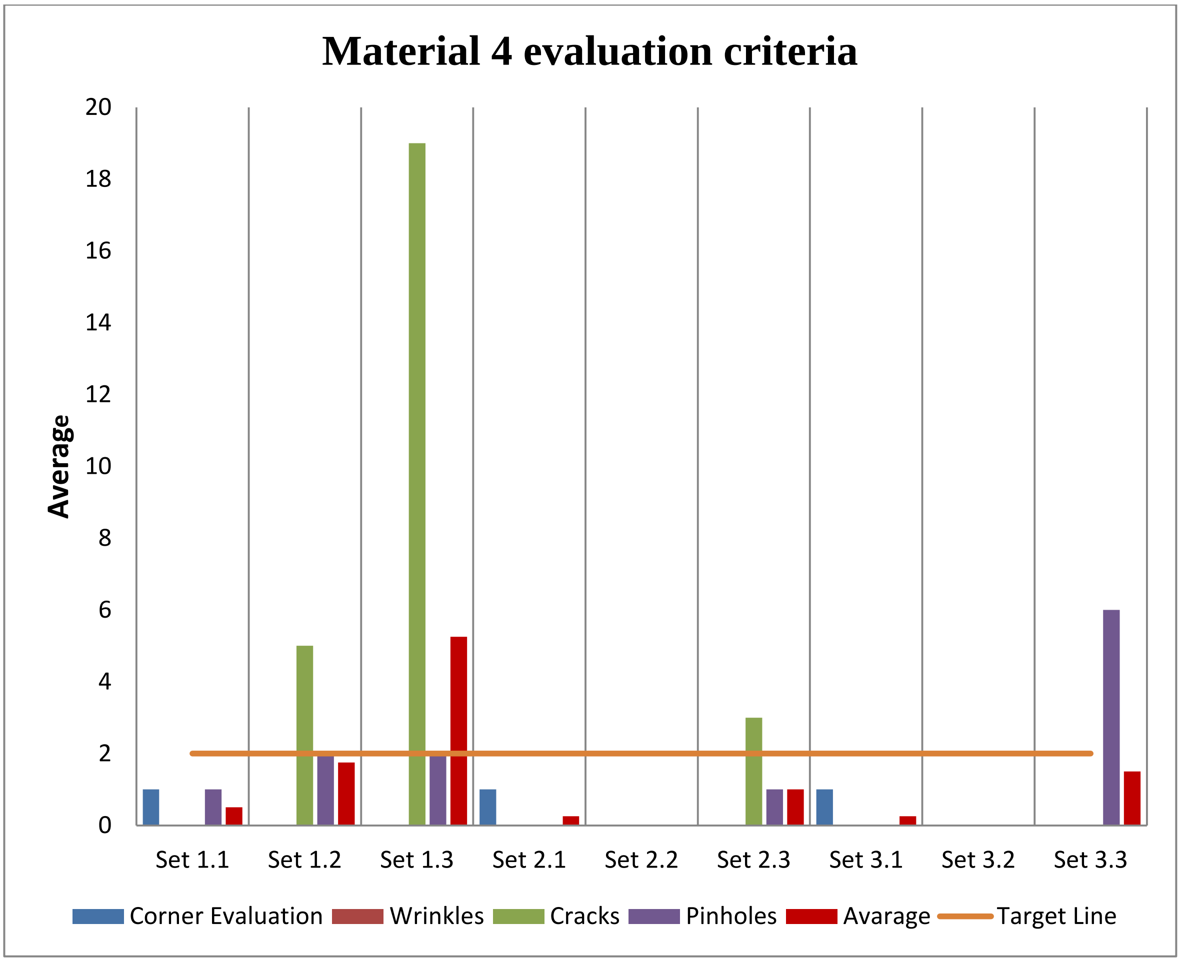


Figure 51. Material 4 evaluation criteria.

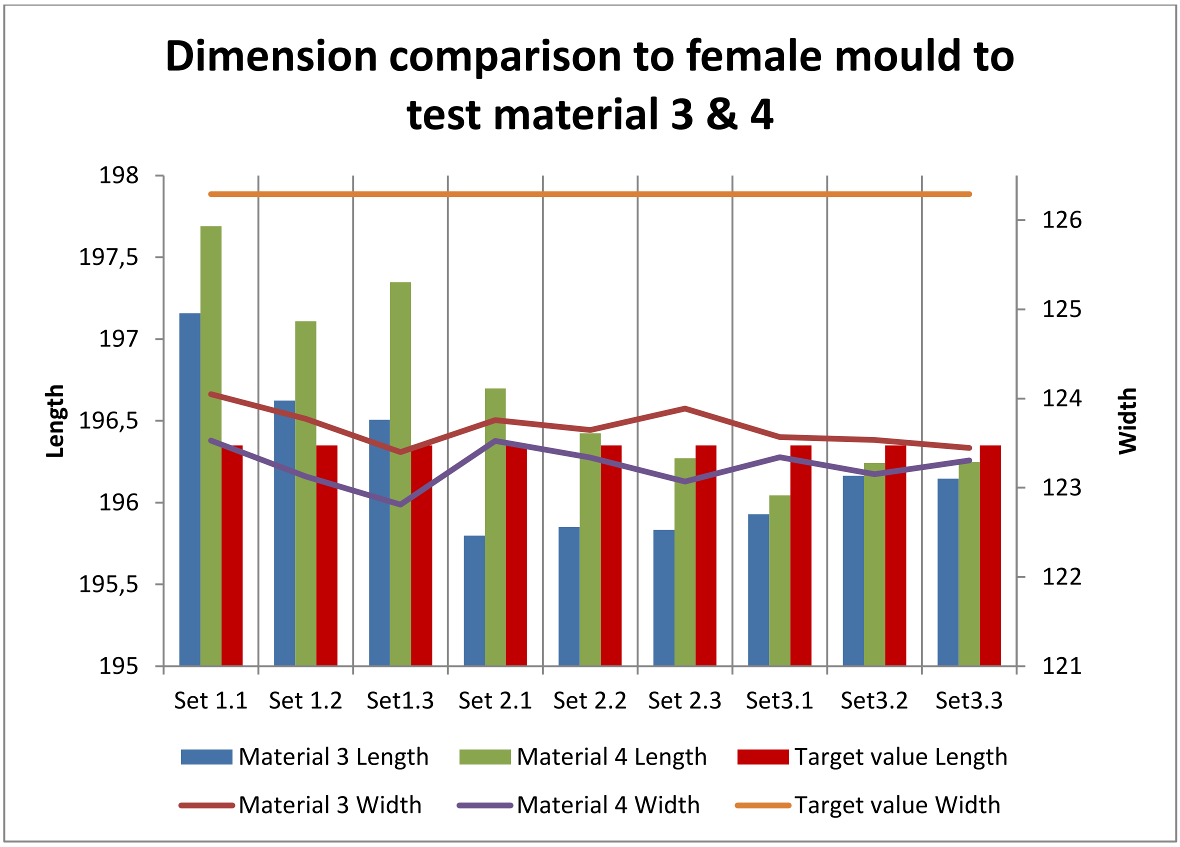


Figure 52. Dimension comparison to female mould to test material 3 & 4.

In this chart is the comparison of the female mould to test material 3 and test material 4.

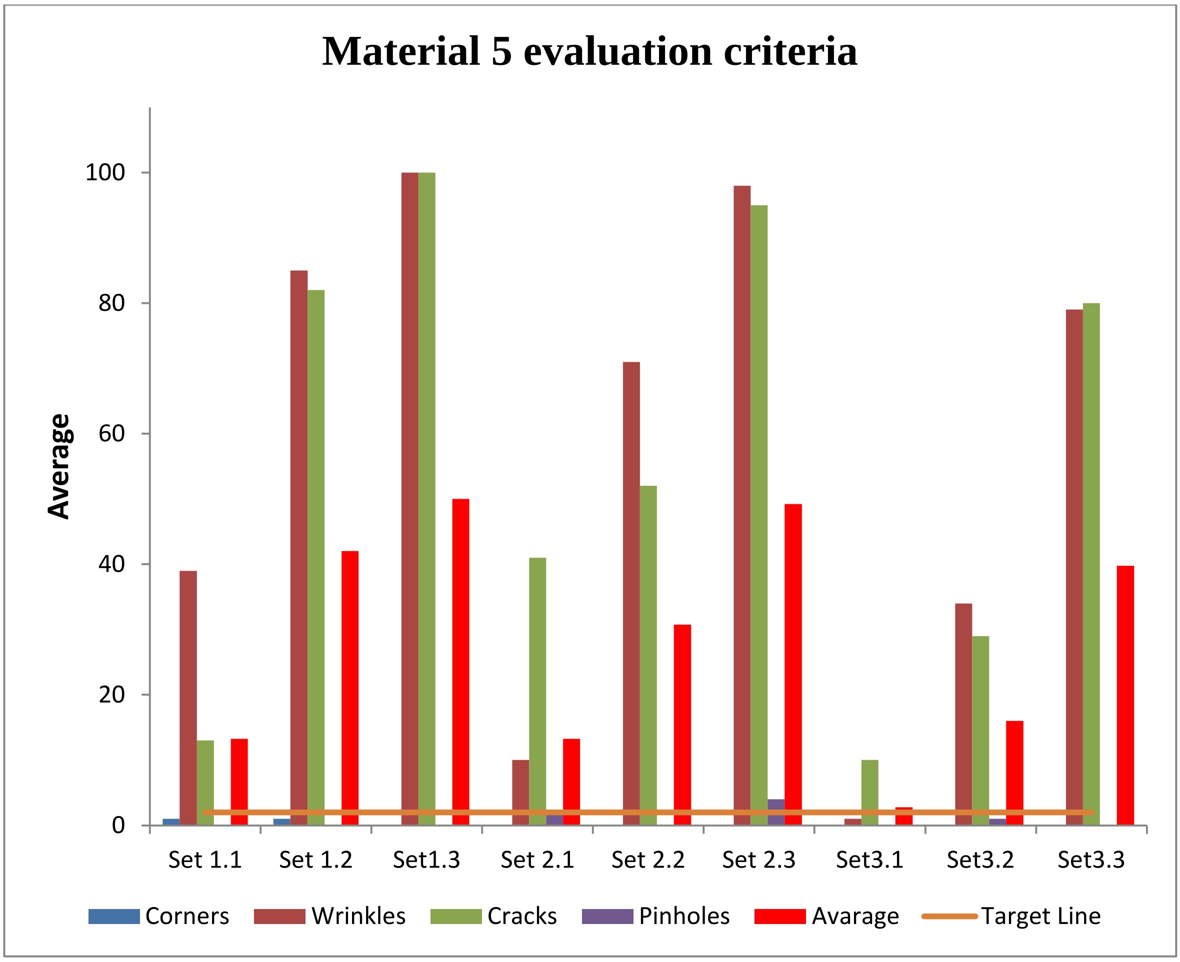


Figure 53. Material 5 evaluation criteria.

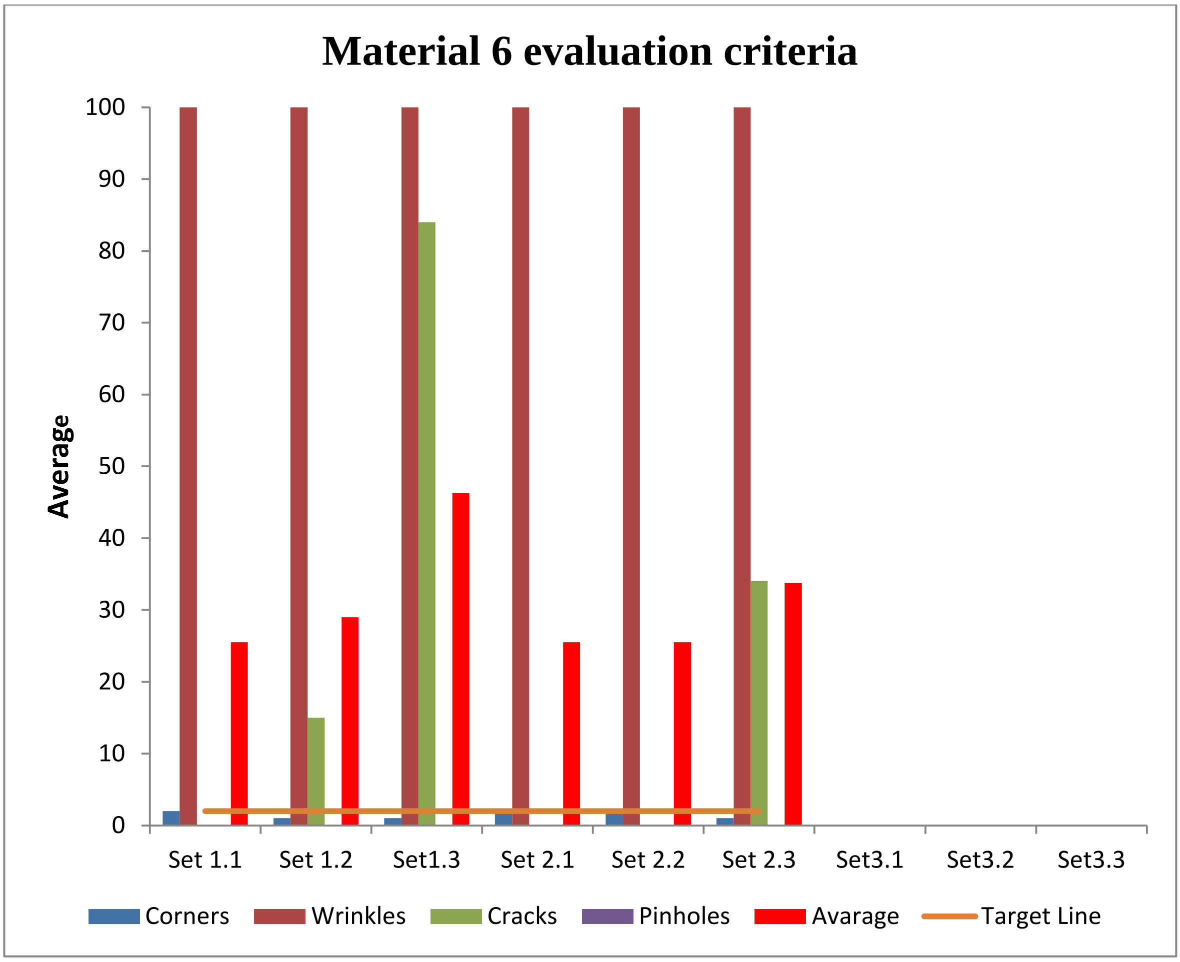


Figure 54. Material evaluation criteria.

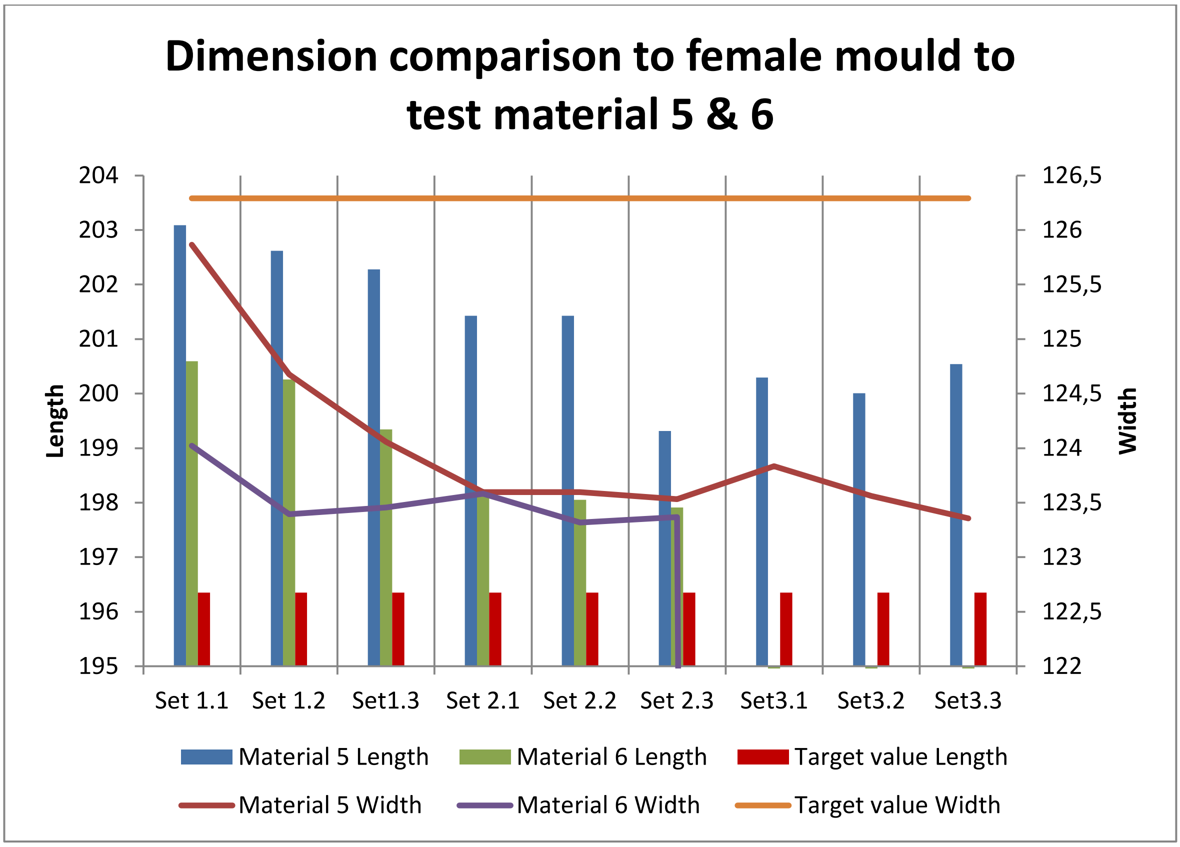


Figure 55. Dimension comparison to female mould to test material 5 & 6.

In this chart is the comparison of the female mould to test material 5 and test material 6.

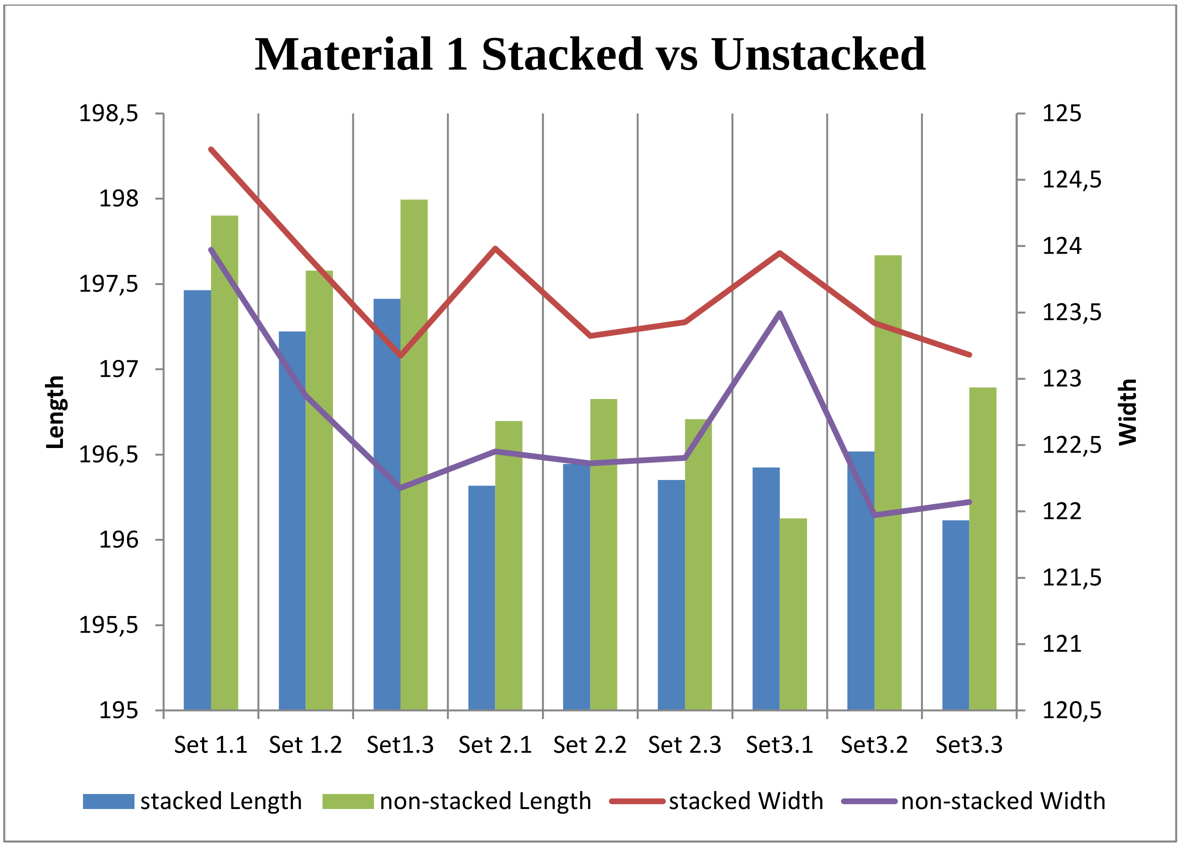


Figure 56. Stacked versus unstacked material 1.

The method used in the stacked versus unstacked charts was that 100 trays where run through the press forming machine. Out of those 100 trays 90 trays where stacked and left to cool. The last 10 trays where put on a table individually and left to cool. After both test material phases where cooled the length and dimension of the trays where measured and compared to each other.

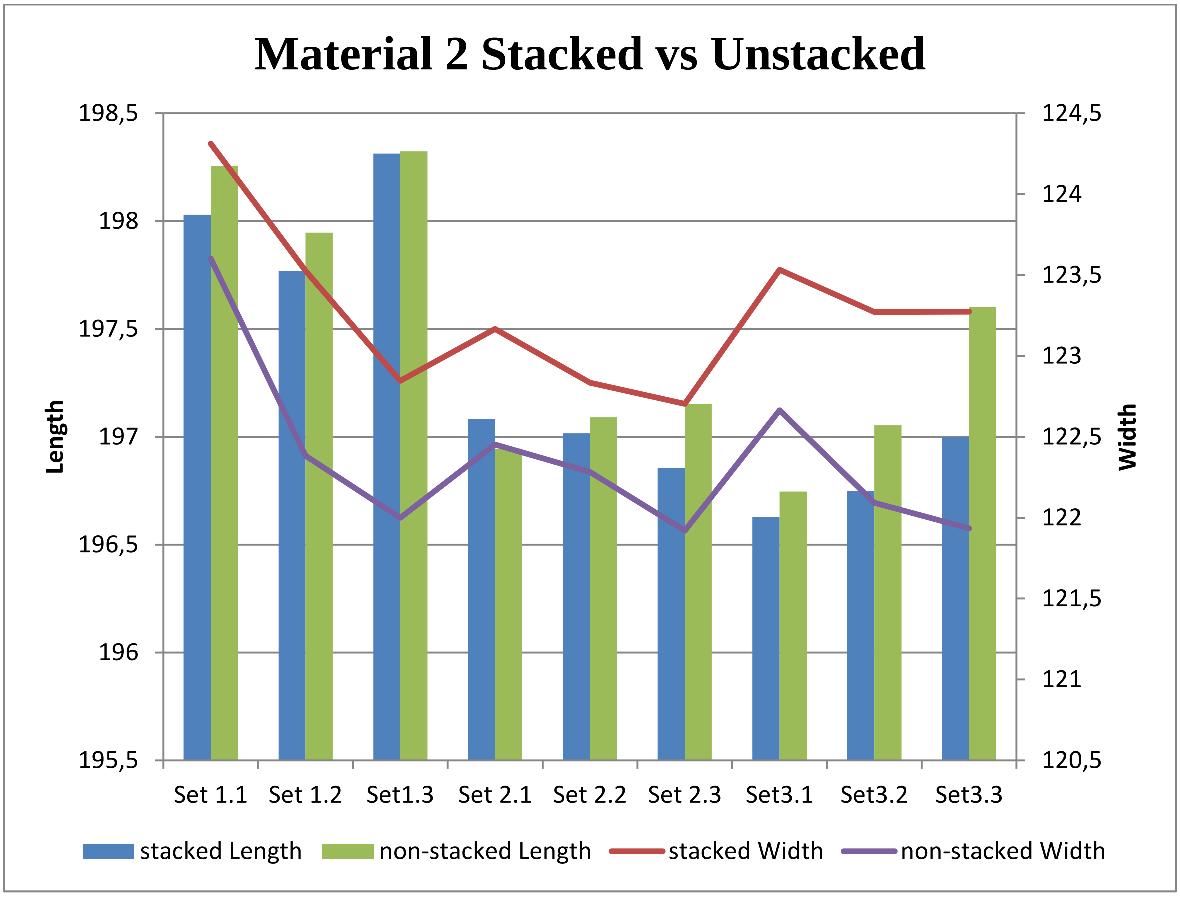


Figure 57. Stacked versus unstacked material 2.

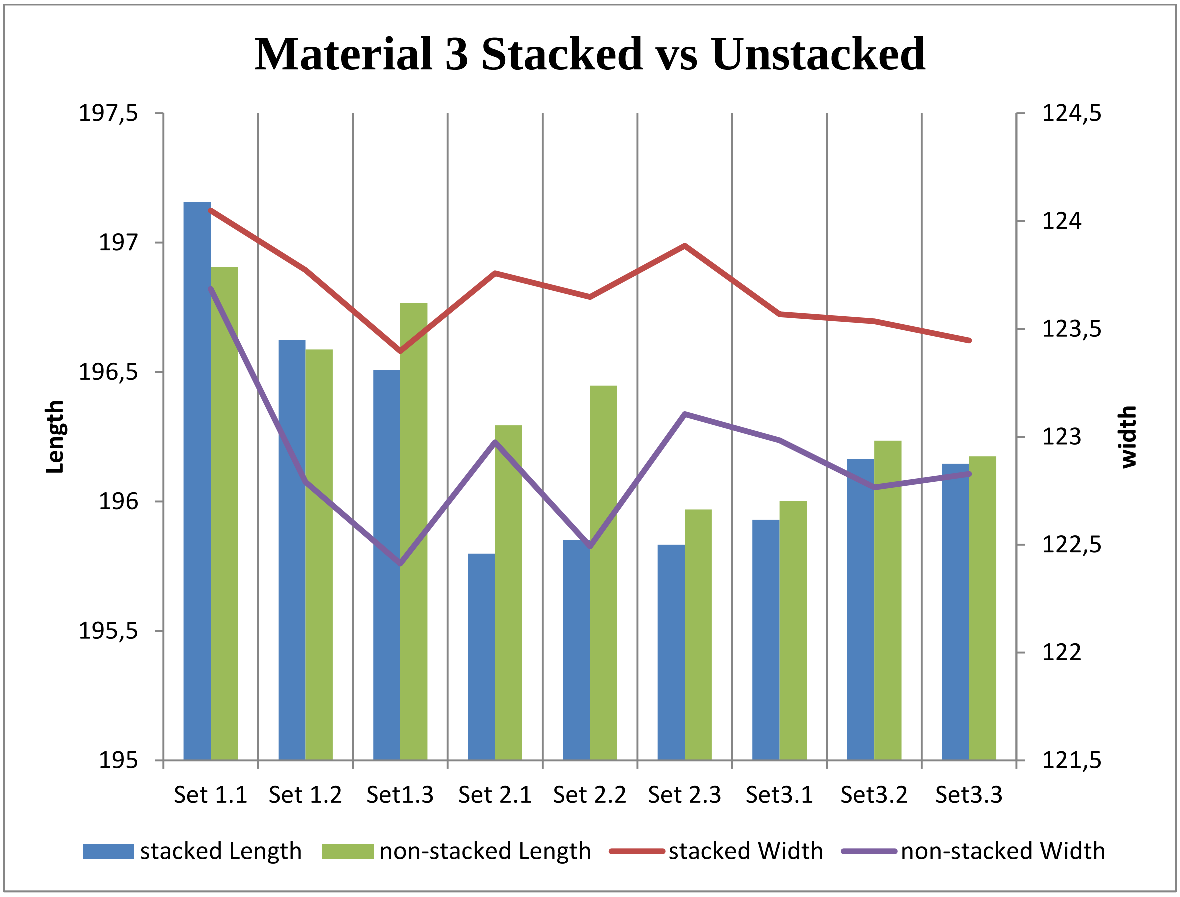


Figure 58. Stacked versus unstacked material 3.

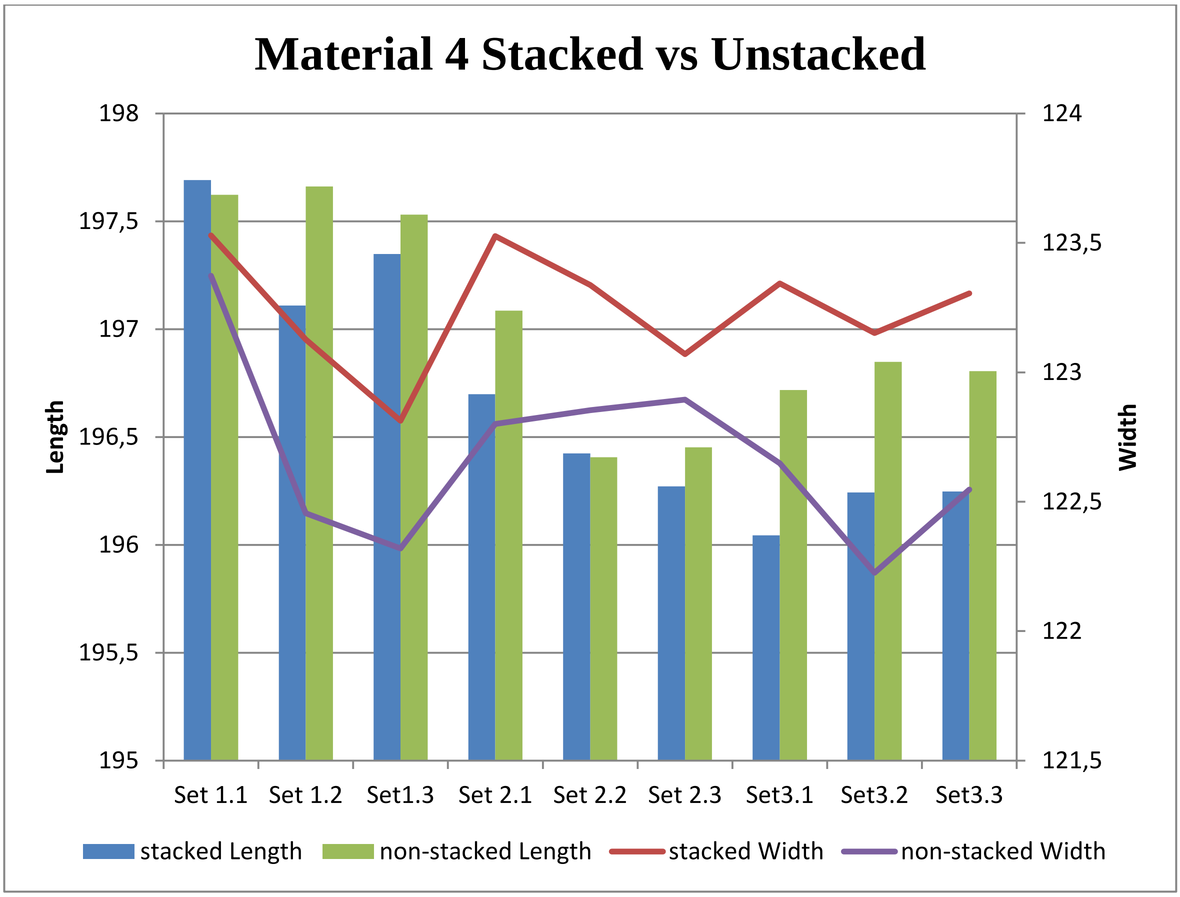


Figure 59. Stacked versus unstacked material 4.

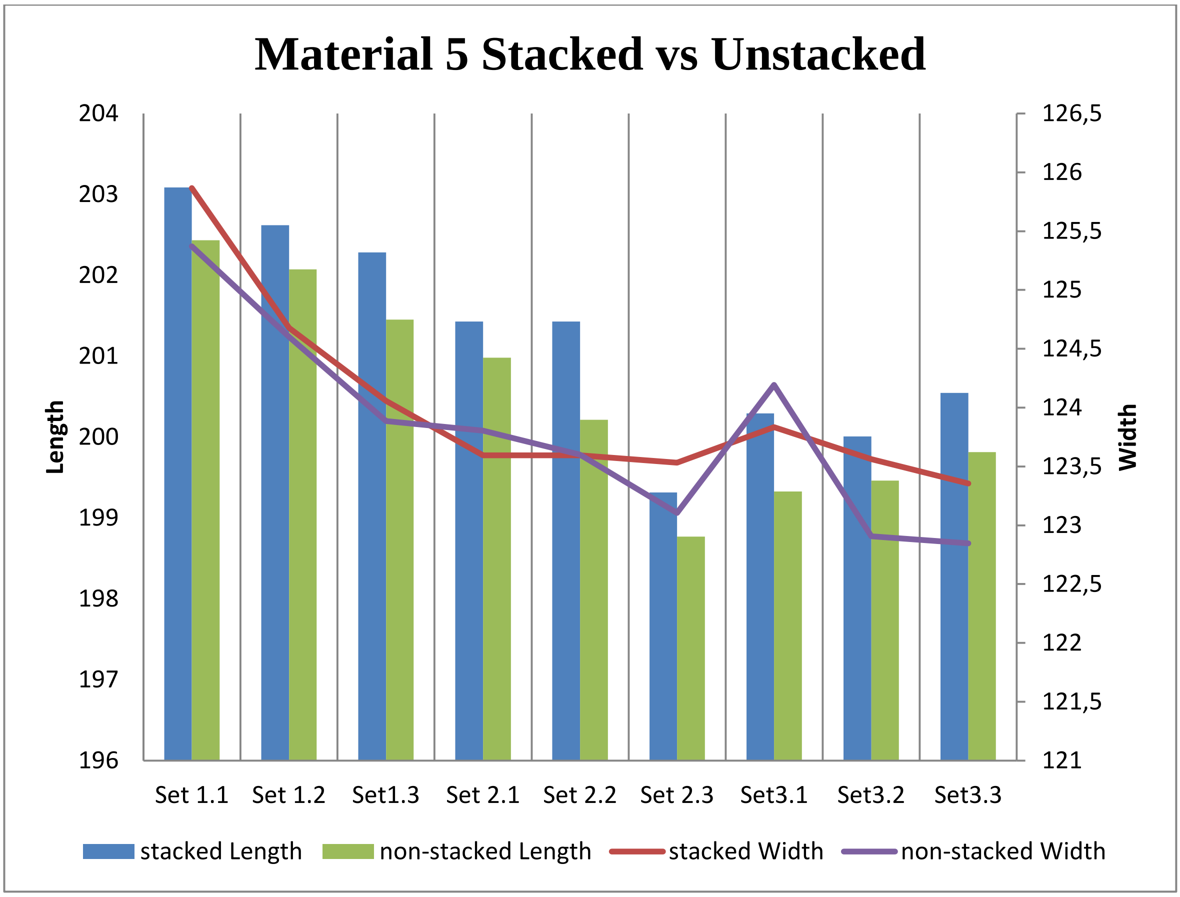


Figure 60. Stacked versus unstacked material 5.

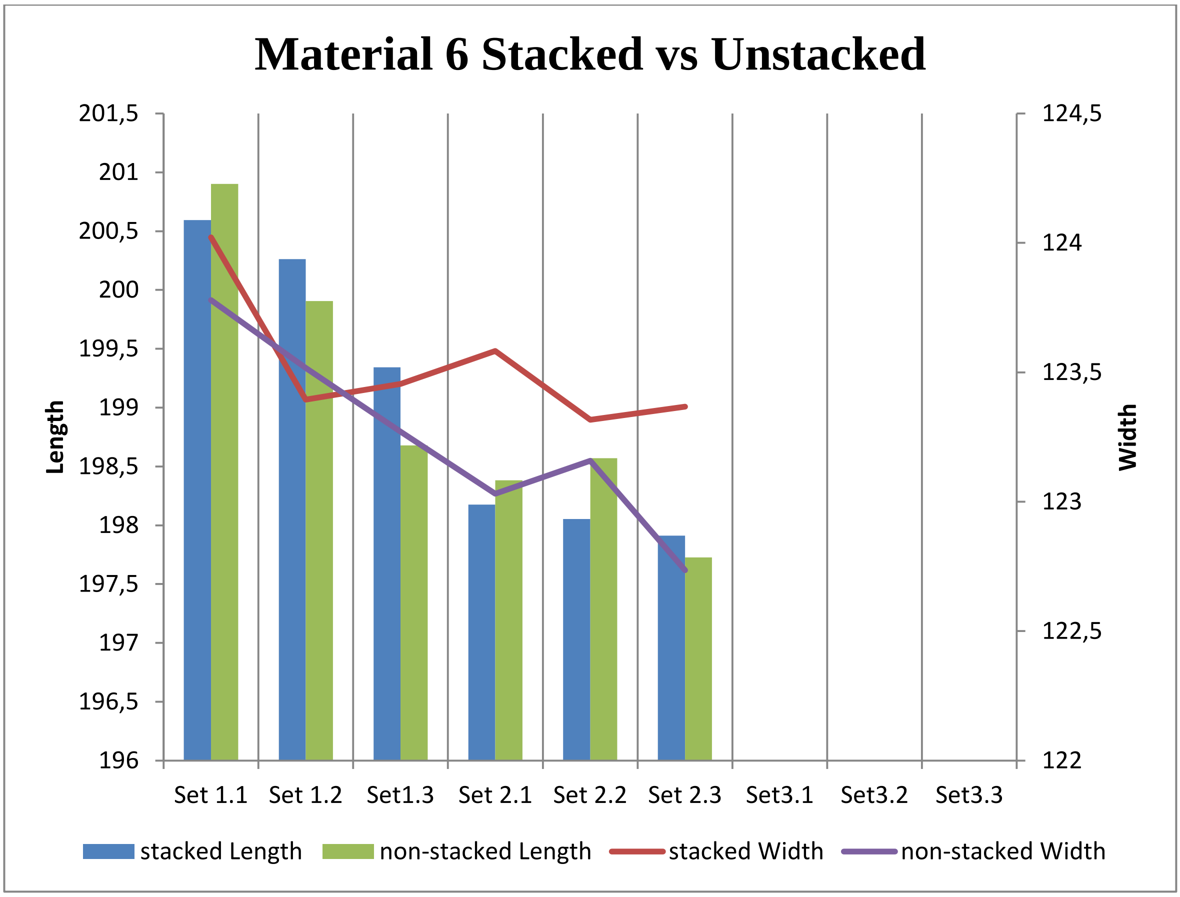


Figure 61. Stacked versus unstacked material 6.

4 ANALYSIS

Laboratory test of paperboard mechanical properties will be compared to the evaluation criteria tables. The best settings for moulding each paperboard material will be shown and discussed.

4.1 Maintenance analysis

The polishing of the male and female tools had some effect on the performance of the forming of the trays. It was noticed that less tears and fractures where present. Also the realignment of the female mould to the male mould decreased tearing in the corner of the tray and helped in a more uniform tray shape. Can be seen in figure 41 where the alignment was measured.

4.2 Analysis of laboratory test results

The test result show that Material 4 and 5 has the lowest static friction TS/MD and TS/CD. The information from these result should show that Material 4 and 5 may have a greater mouldability advantage that the other paperboard materials in this figure due to top side having less friction. Material 4 has the greatest static friction on BS surface which might affect negatively mouldability. Results can be seen in figure 42.

The test result show that material 5 has the lowest kinetic friction TS/MD and TS/CD. The information from these result should show that material 5 may have a greater mouldability advantage that the other paperboard materials in this figure. Material 4 has the greatest kinetic friction on BS surface which might affect negatively mouldability. Results can be seen in figure 43. Kinetic and static friction laboratory results will vary significantly when compared to the mould pressing process (Tanninen, 2015). The materials that had low friction value in the laboratory test the does not show that these materials would mould better than the others. Results can be seen in figure 43.

Material 4 shows that it has the best internal bond strength. Also the materials that had high Scott bond strength and the breaking position are on the bottom layer made for better material for converting process. Results can be seen in figure 45.

Tensile strength in CD was even throughout for the exception of test material 6 being slightly lower. Tensile strength in MD was even but for the exception of material 5 that had larger tensile strength than other. Tensile strength in paperboard material is important for the press moulding process but in these laboratory results it did not show that one with higher tensile strength would have the advantage. Results can be seen in figure 44.

The test material 1–6 test results showed that all materials moulded positively but material 1 and material 3 had pinholes. Random sheets where tested for pinholes and only the solid unbleached sulphate (SUS) surface that was polymer coated had the presence of pinholes. Pinholes where present in material 1 and material 3 where caused by solid unbleached sulphate surface. These pinholes present in material 1 –3 may have been caused by the laminating process and not by the converting process. All pinholes present in material 2, 4, 5 and 6 where present in the exact spot at the end of a crease. These pinholes where most likely caused by the flatbed die-cutter tool. The figure of the pinhole can be seen in the appendix 2.

4.3 Analysis of evaluation criteria of trays

The entire material 1 trays failed the evaluation criteria this was mostly due to poor coating of the polymer that made pinholes. The figure shows low heat and high blank holding pressure made the most defects. The increase in heat had a positive effect on mouldability. When comparing the figures results to the laboratory test shows that kinetic and static friction is satisfactory and tensile strength in MD and CD was also satisfactory and this would not result in poor values. Scott bond test showed that the breaking position is on the surface and this could result in the tears and wrinkles. Best setting for this material was test setting 3.2.

In material 2 we can see the effect of temperature has on the mouldability of the tray. When the blank holding is increased and heat is insufficient the paperboard material tends to tear and wrinkle. Pinholes in Material 2 where present in the same spot at and end of a single corner. Best setting for this material was test setting 3.2.

In material 3 we can also see the effect that temperature has on moulding especially in test settings 1.1 – 1.3 where the blank folding force pressure increase causes more cracks and wrinkles. Best setting for this material was test setting 3.2.

Material 4 had the best mouldability of all four test materials in group one. We can see again how the increase in heat affects the mouldability of the tray. Pinholes where present in the same spot as material 2, 5, and 6. The best result for this material was test setting 3.2. But if TS3.2 and TS3.3 corner are compared more closely 3.3 has better corner forming. The pinholes could be removed by slight adjustment of the flat bed die cutting tool or a new die cutting tool because the old die cutting tools are slightly worn and can cause slight problems.

Material 5 failed the evaluation criteria. The reason for failure was wrinkles on the flange and cracks in the corners. When the blank holding pressure was increased it caused greater defects to the tray. This may be caused by improper mould clearance. Material 5 has a heavier g/m^2 mass than the other test materials and so is thicker. The mould clearance was not adjusted during the press forming process. Also layering of the test material may cause wrinkles on the side wall. Heat should a positive effect on moulding but the increase in blank holding force affected the moulding of the tray negatively. Best test setting for this material is 3.1.

Material 6 failed the evaluation criteria. This was mainly due to tears in the corners and wrinkles on the flange. Wrinkles may be caused by the layering of the test material. The polymer layer in the middle of the substrate could be the cause this is same for test material 5. Delamination of the bottom layer occurred during high heat and test stetting 3.1 –3.3 could not be done due to sticking to the tools. Delamination was caused by rapid steam expansion in between the layers. It is possible that the middle polymer layer trapped moisture and this moisture could not escape during the press forming process. Figure 62 below shows bubbling and delamination of the bottom of the tray.

Figure 62. Delamination of layers due to steam explosion.

4.4 Analysis of stacked versus unstacked tray results

When comparing the stacked and unstacked results the stacked tray width is greater and the length is shorter. This could be the result of rapid cooling of the paperboard material. Therefore the unstacked tray became more narrow and longer than the stacked tray that cooled much slower. The unstacked trays were also less uniform and slightly more warped than the stacked trays.

4.5 Other analysis and observation

In press forming the paperboard material has a tendency to spring back. The paperboard material wants to return to its former shape. The test material in this experiment did the opposite reaction it tended to curl inward especially on the longer sides and the flange. This could be due to the polymer forcing the paperboard material to curl inward instead and resisting the spring back of the paperboard material. This can be seen in the dimension of the shape. The material tended to be of smaller dimension than the female mould.

Temperature of the moulds was measured and there is uneven when measured. When the length side wall measured was hotter than the width side wall of about ~10°C. This temperature difference will have an effect on the moulding of the paperboard. The elongation of the paperboard will be greater on the side with the increased heat.

5 DISCUSSION

Whatever type of converting process used to convert tray, plates or cups the process is reliant on three joining parameters that are oppositely proportional in some order. The main parameters that effect the converting process in this thesis was blank folding pressure, heat and as for dwell time was constant. Studies in finding the fastest production speeds using heat and dwell time while producing quality trays would be interesting. Press forming paperboard trays into a desired shape and acceptable rigidity requires heat from the press forming moulds with moisture of the paperboard and pressure from the dies to deform paperboard fibres to mould the material into the shape of a tray. Therefore when the paperboard is drawn into the mould the diameter of the blank is reduced and this will cause overlaps in the tray this is why creases are made to the blanks. The forming forces from mould tools and heat will press these creases in the tray together forming layers that are welded together and this will give structural rigidity to the tray. The increase of pressure of the moulds cannot exceed too high. High pressure fill decrease the trays rigidity and also cause the paperboard fibres to be crushed.

The three parameters must be oppositely balanced to a certain degree to produce quality trays. For example when high temperature is used in press forming then the dwell time is less and vice versus. Increasing the heat of the mould tools the blank holding pressure can be increased. The increased pressure of the blank holding force will aid in better moulding of the tray. Paper board materials moisture content plays an important role in forming and it is important that the moisture content be suitable for the paperboard grade- More study of how moisture effects different paperboard grades and to find the optimal moisture percentage would be useful for future press forming.

Moisture from the paperboard turns into steam and escapes the die. This can be compared to steam pressing. Therefore the creases are steam pressed in the tray giving it structural integrity. Press forming process demands a combination of heat, pressure dwell time, good creases and moist paperboard to produce a quality product.

The importance of maintenance to produce quality trays must not be overlooked. Good maintenance is to have the machine running properly without any unexpected machine failures. This is why it is important to follow the maintenance schedule. Maintenance will increase the dependability of the press forming equipment. In this thesis the dependability of the machine was increased by following proper maintenance control.

The test materials used in this thesis showed that how each material requires different press forming parameters to produce a quality tray. The laboratory results showed that how it is difficult to interpret the behaviour of the test material. A material that performs well in the laboratory may not have good moulding characteristics. All test materials performed well at certain test settings. Test setting did show how some materials where more tolerant to higher press forming forces. Also some materials had tendency to shrink inward on the sides this was strange because it was studied that paperboard want to return to its original state and tray walls expand outward. This observation was not confirmed was it the result of the paperboard or the polymer coating that caused the shrinking effect. This shows that how difficult is to predict how a paperboard will mould in the press forming machine. This is why extensive press forming test are done when new paperboard grades are created.

While doing this study it was noticed that one should take time to learn the press forming machines adjustments and operation. This is important to performing quality trays and to save time due to production of poor quality trays. Also good knowledge of how the machine works plays an important role in the operator safety.

Future studies in paperboard material science would be to find a better material and more cost efficient paperboard that has better mouldability for the press forming process. Developing paperboard material that would work with existing packaging machines that are meant for plastic packaging would be a great breakthrough.

Development of press forming machines parameters adjustment for fine tuning and could be easily adjusted. Developing mould tool materials that would have less surface friction and would last longer.

Developing an environmentally sustainable package for foodstuffs is vital for today's market. Market demand for food stuff package will grow in the future. Also finding a way to make a cost efficient and desirable package for the consumer is imperative for a successful package design for the market.

Press forming paperboard into trays is a difficult process because one must take in so many different matters. From material selection to find best grade of paperboard that has good moulding characteristics. From preparing blanks depth of creases that play a role in forming and rigidity. From polymer coating that play role in rigidity, forming and good barrier properties. From press forming machine parameters that must be mated to the properties best suited paperboard. From start to finish while producing mouldable packaging there are many things that can go wrong that and this is why this subject should be studied more intensively.

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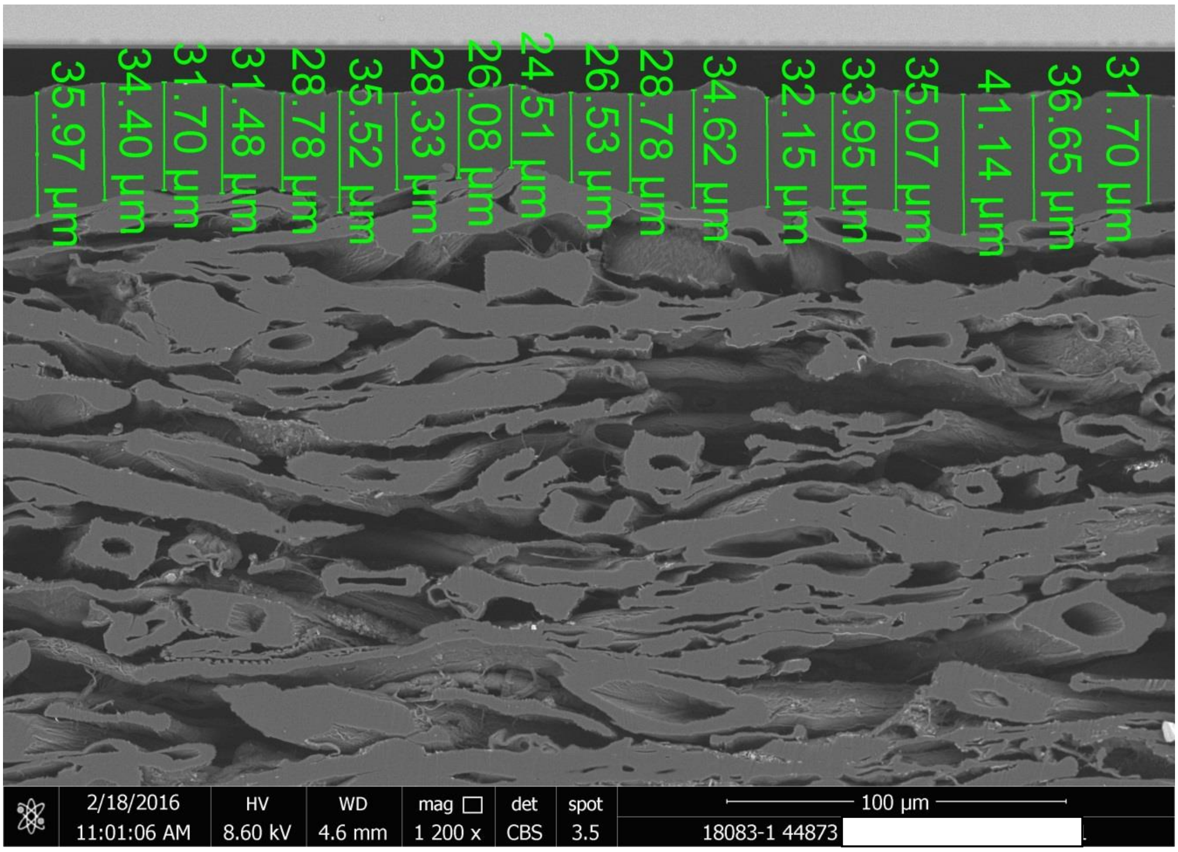
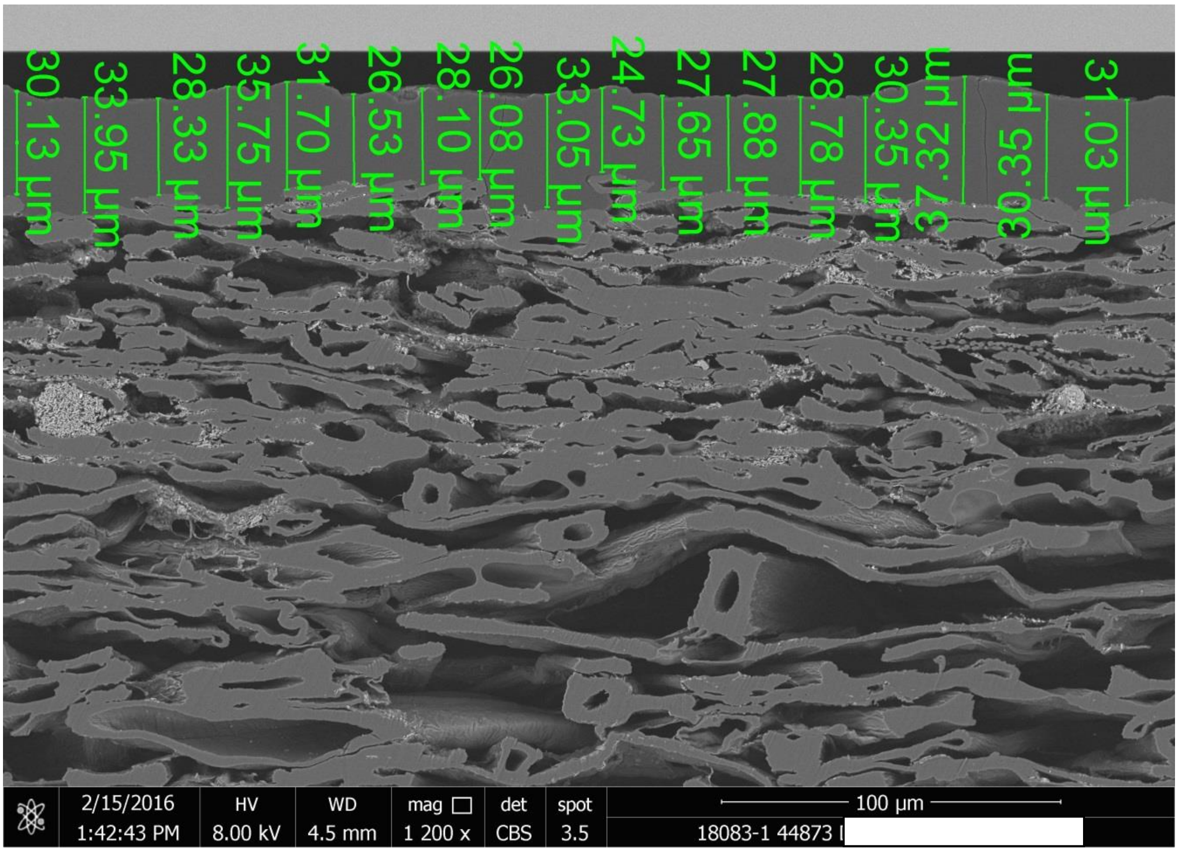
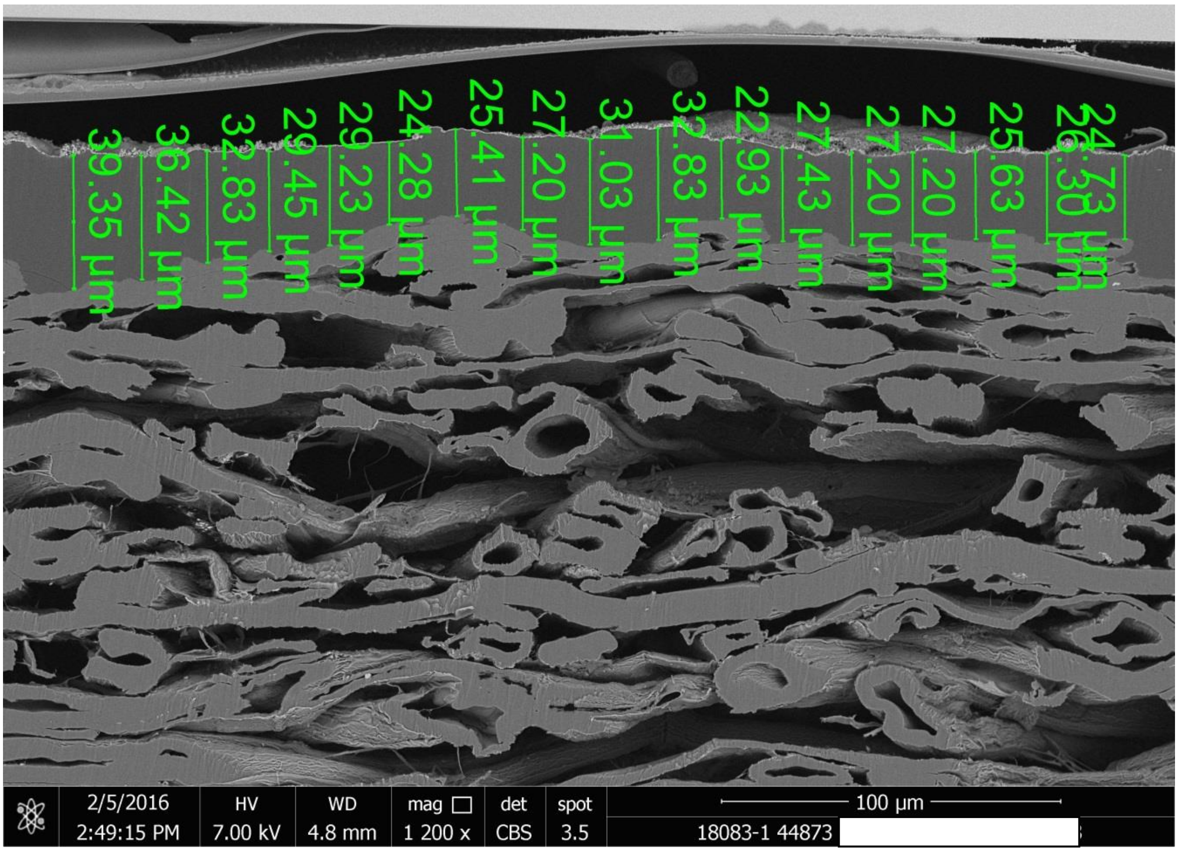
Layer structure of test material 1 and polymer coating thickness.



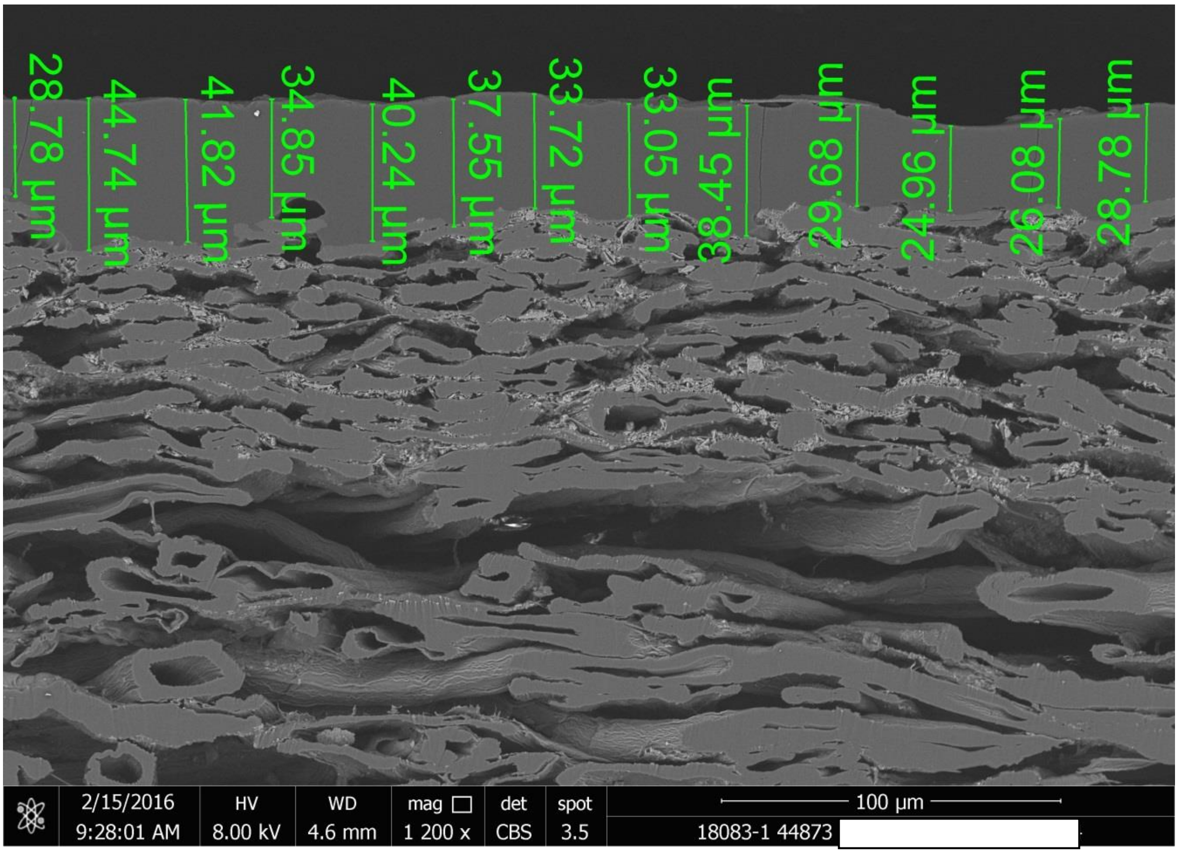
Layer structure of test material 2 and polymer coating thickness.



Layer structure of test material 3 and polymer coating thickness



Layer structure of test material 4 and polymer coating thickness



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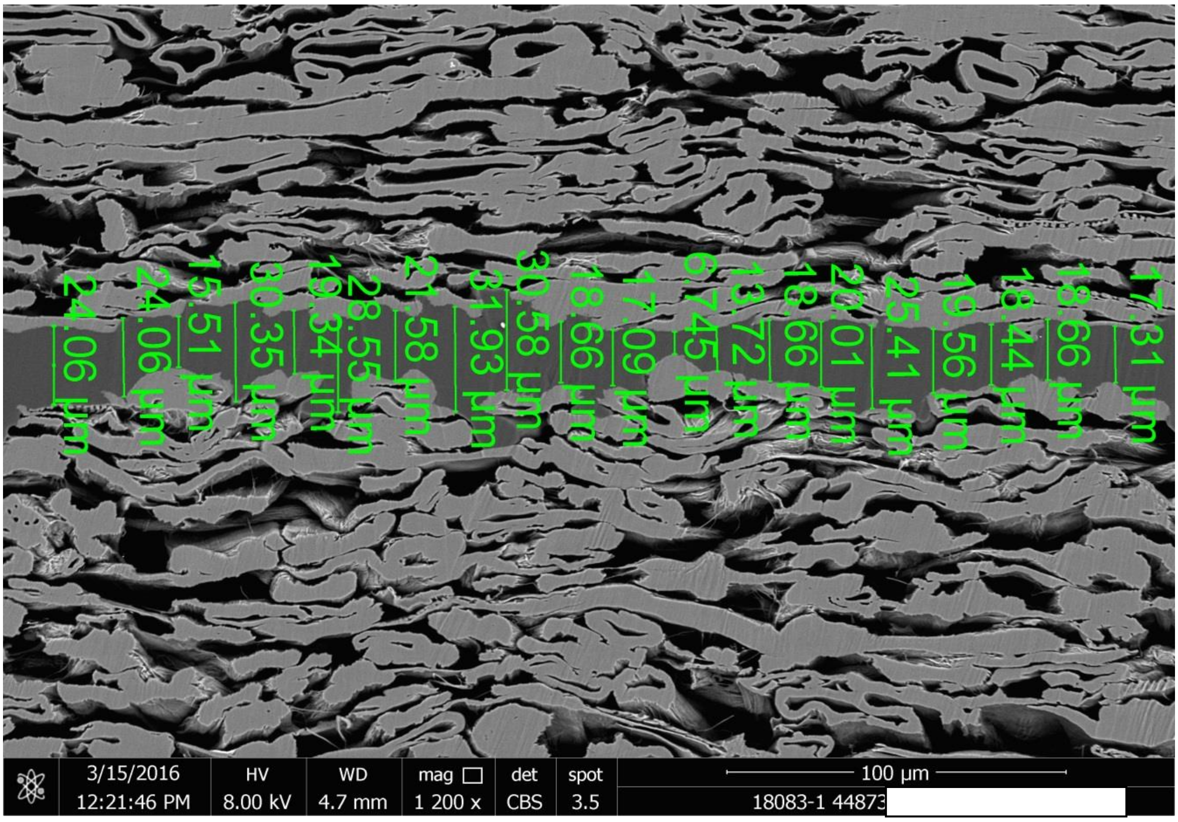
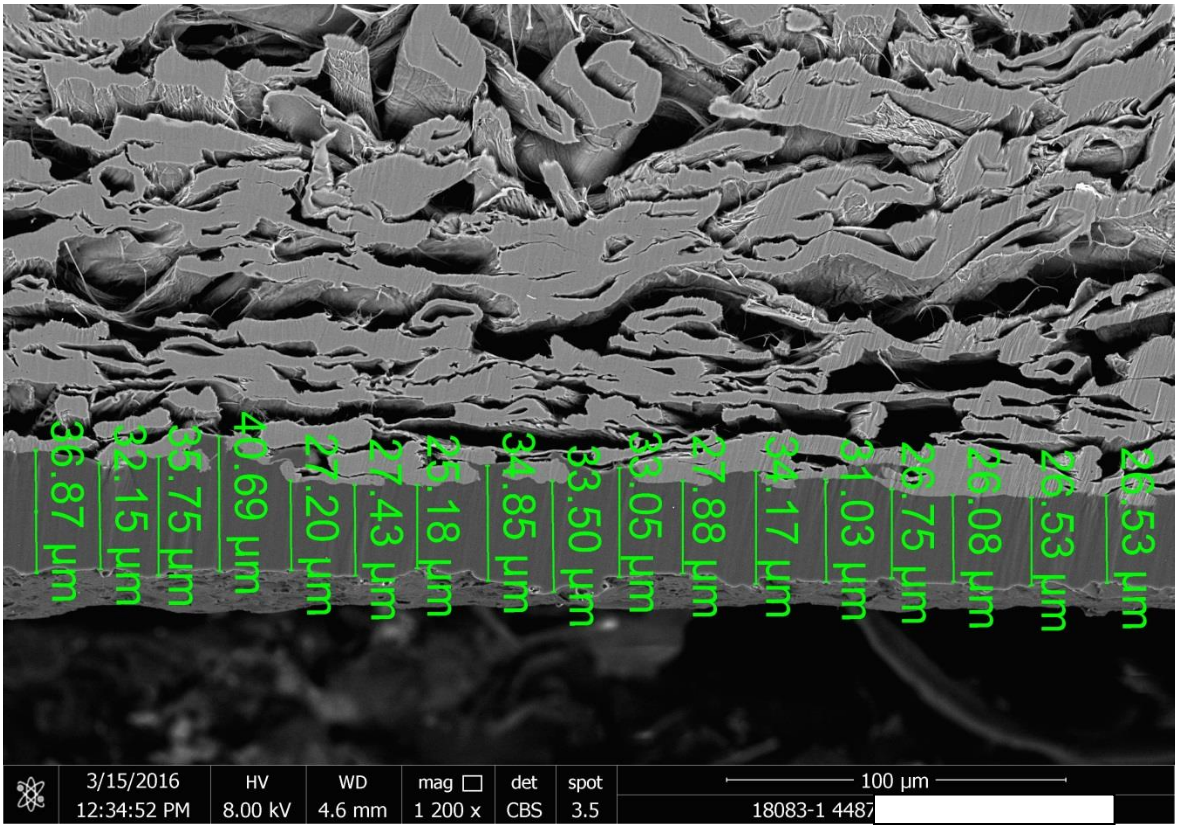
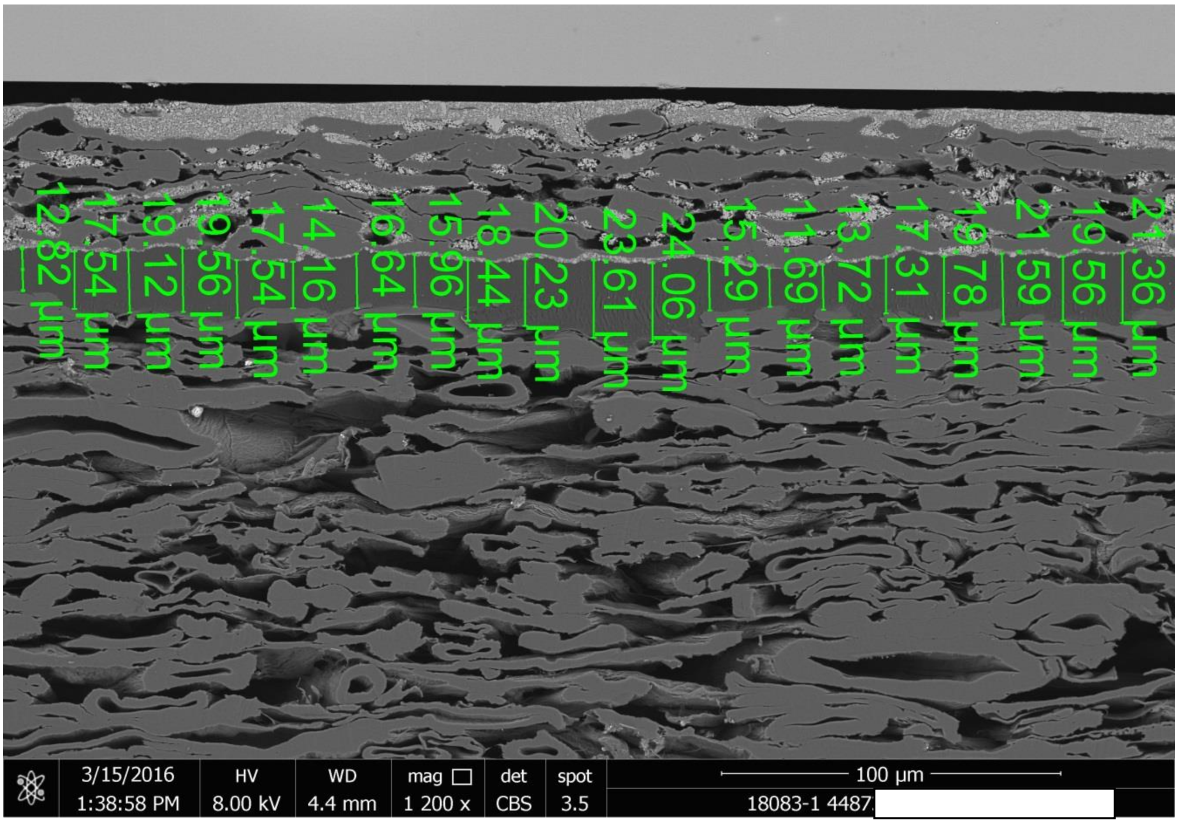
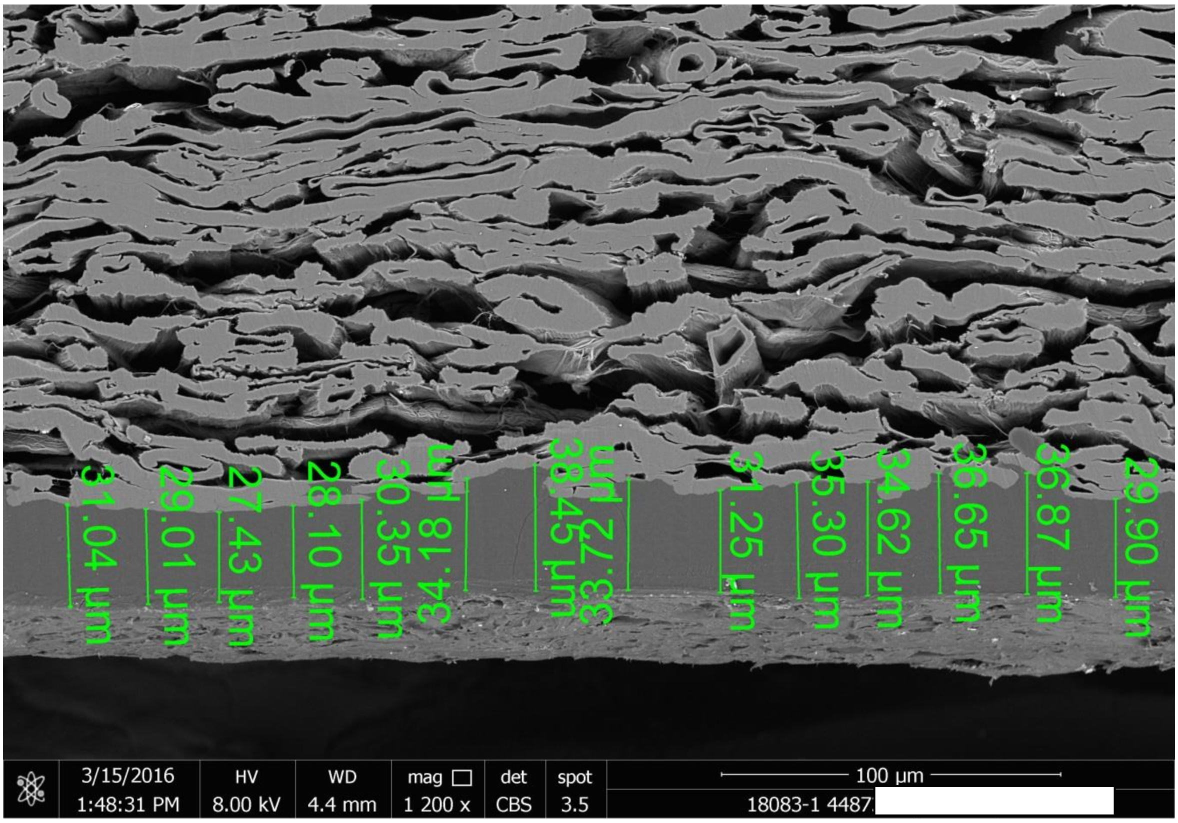




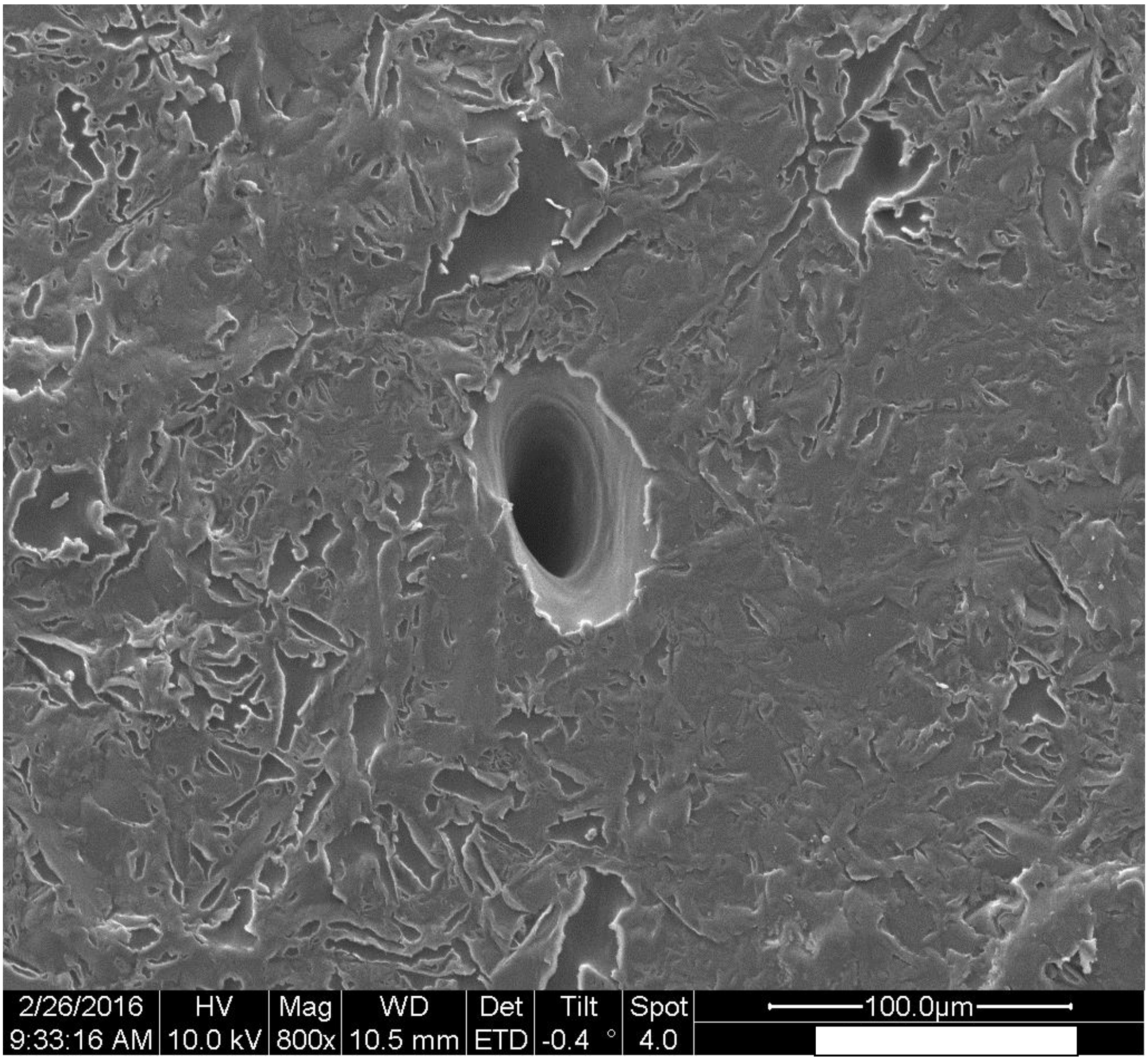
Layer structure of test material 6 and polymer coating thickness





APPENDIX 2

Pinhole of test material



APPENDIX 3.1

Test material trays bottom

APPENDIX 3.1

Test material trays top