TAMPERE POLYTECHNIC, UNIVERSITY OF APPLIED SCIENCES
Paper technology, International Pulp and Paper Technology

Final thesis

Mikko Määttänen

DIE CUTTING OF A SELF ADHESIVE LAMINATE AND REMOVING OF A WASTE MATRIX

Thesis supervisor Lic Tech. Päivi Viitaharju
Commission of thesis by UPM Raflatac Oy, MSc Ismo Pietari
Tampere 2008

TAMPERE POLYTECHINC, UNIVERSITY OF APPLIED SCIENCES
Paper technology
International Pulp and Paper Technology
Määttänen, Mikko Die cutting of a self adhesive laminate and removing of a waste matrix
Thesis work 111 pages + 12 appendices
Thesis supervisor Lic. Tech. Päivi Viitaharju
Commission of thesis by UPM Raflatac Oy, MSc Ismo Pietari
May 2008
Key words self adhesive laminate, die cutting, waste matrix stripping

ABSTRACT

Die cutting of a self adhesive laminate is a process where the self adhesive label gets its final shape. The label shape is formed by a rotating die which cuts the surface of the self adhesive laminate and separates the label and the surrounding web from each others. The surrounding web is also called waste matrix and it consists of the face paper which is surrounding the label. The die cutting of the self adhesive laminate is performed so gently that the blade only cuts the face paper and the adhesive layer beneath it. The die will not reach the silicone layer and the release paper. To achieve so exact performance, all the factors in the converting stage have to be taken into account.

The waste matrix of the laminate is removed from the surface of the release paper after the die cutting stage. The waste matrix is removed as a web form and it is rewound to its rewinding station. The release paper and the self adhesive labels on it are rewound to their rewinding station. This delamination of the waste matrix is a sensitive process and fluctuations in the face paper quality and in the release force are causing instability in the converting process. In order to prevent expensive breaks in the converting machine, the face paper must stand the stress caused by the detachment of the paper webs and the speed.

The aim of the thesis work was to find out an operating window for the converting process of self adhesive laminates where the strength properties of the waste matrix are playing a great role. The operating window includes the factors which are affecting the converting speeds of the self adhesive laminates. The target is to find out ways to prevent the waste matrix from breaking and to search ways for higher converting speeds.

The experimental part was started when the raw materials for the self adhesive laminates were chosen. The laminates were produced with the pilot laminator. The strength properties of the face papers in the laminates were measured before the lamination took place. The ready laminates were tested before the actual converting process. The results of the converting trial and the measurements which were done for the papers were analysed. The results showed that the converting speeds of the laminates are correlating with the strength properties of the laminates. The strength properties are not the only factor affecting the converting speed of the laminates. Other significant factors are the label detachments, the properties of the adhesive in the laminate and the disturbances the Gallus R160 was causing in the converting process.

TAMPEREEN AMMATTIKORKEAKOULU
Paperitekniikka
International Pulp and Paper Technology
Määttänen, Mikko Tarralaminaatin stanssaus ja roskaradan poisto
Opinnäytetyö 111 sivua + 12 liitettä
Työn ohjaaja Tekniikan lisensiaatti Päivi Viitaharju
Työn teettäjä UPM Raflatac Oy, DI Ismo Pietari
Toukokuu 2008
Hakusanat self adhesive laminate, die cutting, waste matrix stripping

TIIVISTELMÄ

Tarralaminaatin yksi jalostusvaihe on stanssaus ja roskaradan poisto. Vaiheet suoritetaan jalostuskoneella, johon usein kuuluu myös painatusyksiköitä. Tarralaminaatin stanssauksessa tarra saa muotonsa. Tarra leikataan pyörivän sylinterin pinnalla olevan stanssiterän avulla muotoon, joka riippuu tarran käyttökohteesta. Stanssaustapahtumassa terä leikkaa vain pintapaperin ja liimakerroksen halki, mutta ei syvemmälle. Jotta näin tarkka suoritus olisi mahdollinen, kaikkien jalostukseen vaikuttavia tekijöitä on pystyttävä hallitsemaan tarkasti. Tarran ympärille jäävää ratamaista aluetta kutsutaan roskaradaksi.

Tarralaminaatin leikkuusta syntyvä roskarata poistetaan stanssausaseman jälkeen ratana taustapaperin päältä. Roskarata muistuttaa tikkaita, joka rullataan sellaisenaan kiinnirullaimelle. Tarralaminaatin taustapaperi ja sen päälle jääneet tarrat rullataan omalle kiinnirullaimelleen. Roskaradan irrotus taustasta on vaativa prosessi ja pintapaperin laatuvaihtelut ja irrokevoiman vaihtelu aiheuttavat ongelmia ja pahimmassa tapauksessa kalliita katkoja jalostuskoneella. Jotta katkoilta vältyttäisiin, tarran pintapaperin pitää kestää jalostuksen aiheuttamat rasitukset.

Opinnäytetyön tavoitteena oli selvittää toimintaikkuna tarralaminaattien jalostusprosessia varten, jossa roskaradan lujuusominaisuudet ovat merkittävässä roolissa. Toimintaikkuna kattaa tekijöitä, jotka vaikuttavat tarralaminaattien jalostamisnopeuteen. Tarkoituksena oli löytää keinoja välttää matriisin katkeaminen ja löytää keinoja, joilla päästään korkeampiin jalostusnopeuksiin.

Työ aloitettiin valitsemalla tarralaminaatteihin sopivat raaka-aineet. Kun raaka-aineet oltiin valittu, niistä tehtiin tarralaminaatteja UPM Raflatacin pilot-koneella. Laminaattien pintapapereiden lujuustasot mitattiin ennen laminointia. Valmiit tarralaminaatit testattiin ennen varsinaista jalostusprosessia Gallus R160 jalostuskoneella. Laminaatit testattiin ja tulokset kerättiin sekä analysoitiin yhdessä lujuusmittausten kanssa.

Tuloksista selvisi, että tarralaminaatin pintapaperin lujuustaso korreloi sen jalostusnopeuden kanssa. Lujuustaso ei ole ainoa asia, joka vaikuttaa tarralaminaatin jalostettavuuteen. Muita ratkaisevia tekijöitä ovat tarrojen irtoaminen stanssauksen jälkeen, liiman käyttäytyminen laminaatissa sekä jalostuskoneen aiheuttamat häiriöt tarralaminaatin valmistuksessa.

FOREWORDS

This final thesis work was done for UPM Raflatac in spring 2008.

Ismo Pietari acted as an instructor of the work in UPM Raflatac and Päivi Viitaharju as a supervisor from the TAMK. I would like to thank both Ismo and Päivi for the help I have received during my work. Without Ismos competence and Päivis encouragement this work would not be completed in time.

I would also point great commendations to the R&D personnel in UPM Raflatac, especially to Pentti Kuusjärvi and Mika Pirisjoki. Pentti and Mika helped me among the others with my work by giving advices and hints concerning the thesis work. I also point thanks to the quality controlling laboratory staff in UPM Raflatac.

And finally I thank all the people who helped me.

”Labor improbus omnia vincit.”

Tampere 09.05.2008

Mikko Määttänen
+358503443230

1 INTRODUCTION

1.1 UPM Raflatac in brief /15/

UPM Raflatac is a part of the forest product company UPM-Kymmene`s self adhesive label business. It is one of the leading suppliers of pressure sensitive label stock in the world and is also a forerunner as regards to radio frequency identification (RFID) tags and inlays.

There are roughly 2500 employees working for the UPM Raflatac worldwide. The net sales of the company were almost one billion euro in 2007. UPM Raflatac has nine production plants and number of sales agencies and cutting terminals all over the world. Production plants are located in Australia, China, Finland, France, Malaysia, South Africa, Spain, United Kingdom, and in USA.

1.2 Typical products of UPM Raflatac

UPM Raflatac has a wide palette of label products in different end use areas. The company is known for its A4 labels, beverage labels, food labels, labels on personal care products, labels in pharmaceutical products, and retail, logistic & transport labels. **/15/**

Self adhesive labels are used in multiple applications in offices, in industry and in private households. Labels are used for giving information e.g. address labels on envelopes, price settings in products, and individualising electronic and parcelled goods products. **/3/**

Self adhesive labels are used in products which are difficult or even impossible to print. These products can be asymmetrical shaped or some special sort of boxes.

Self adhesive labels are produced for vast variety of different end uses and environments. Labels can be manufactured to be either removable or permanently placed. **/3/**

Labels are easy to use and that is making them so popular. They also fit for vast variety of purposes, they are simple to print and they also fit for the electronic printing which is going to be more common. /**3/**

1.3 UPM Raflatac Tampere unit /15/

UPM Raflatac Tampere unit is located in western part of Tampere and it is one of the nine production plants in the world. There about 450 employees in which about 250 are officials. UPM Raflatac`s Tampere unit is concentrated on special products. Products produced in UPM Raflatac Tampere unit are stripe adhered laminates, stripe siliconised laminates, multiply laminates, back-side printed laminates and laminates which have a special face or release materials.

2 THE STRUCTURE OF A SELF ADHESIVE LAMINATE

The self adhesive laminate consists of four main parts which are from top to bottom face paper i.e. label paper, adhesive layer, silicone layer and release paper which is also called release liner (**figure 1**).

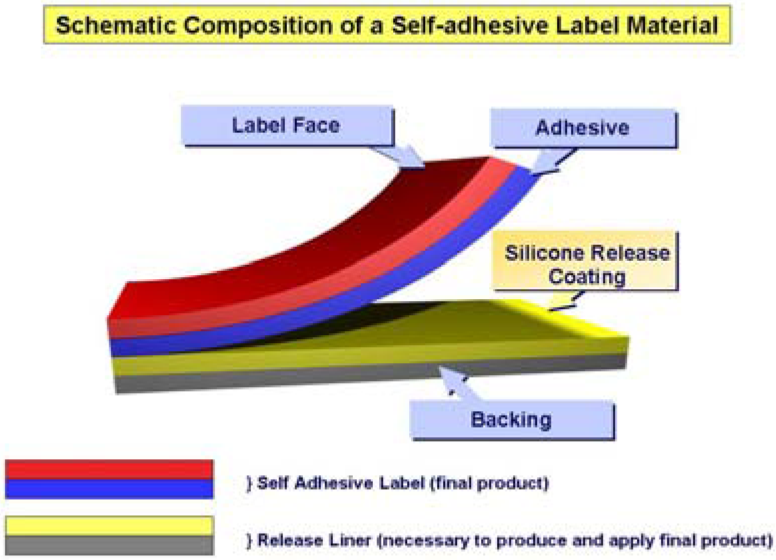


Figure 1 The layout of a self adhesive laminate **/12/**

2.1 The function of a face paper in a self adhesive laminate

Face paper is the layer which the end user of the label i.e. the consumer first notices. It is usually printed, cut into a certain shape and it carries the information concerning the product or a service. **/3/**

The printability and the appearance of the label paper should be good because the label is giving the first impression of the product. The adhesive for the reverse side of the label is chosen according to the end use environment, the life time of the label and the purpose of the label. **/3/**

Typical end uses of the labels are labels on beverage bottles, fruits, products which are itemised and labels on personal care products such as shampoo bottles. **/3/**

2.1.1 The typical properties of the face paper

The label papers usually consist of bleached short and long fibre chemical pulp. **/11/** Pine and birch pulps are the most used pulps in Finland. **/13/**

There are uncoated, gloss-coated, matt-coated, coloured, wet-strength, thermal eco and thermal transfer papers used as a roll form face papers in UPM Raflatac. **/10/** Label papers can also be pigmentised. **/11/** The basis weights of the face papers that are used in UPM Raflatac vary between 60-115 g/m² but the most common ones are somewhere between 65 and 90 g/m². **/10/**

Calcium carbonate is commonly used pigment and coating colour in face paper production. Clay is also used quite commonly when coating the face papers. **/13/** Typical coating method of the label papers is blade coating and the surface is usually finished with an off-line supercalender. **/11/**

2.1.2 Demands for the face paper /3/

One of the most critical properties of the face paper is its high strength over the small strip of paper which is essential for the waste matrix removing stage. The waste matrix removing stage is explained in **chapter 6.**

The porosity of the face paper can not be too high in order to prevent the adhesive from penetrating into the face paper structure or even through it. The penetrating would disturb the latter converting processes and the visual appearance of the face paper. The penetration is seen as small dark spots that grow and expand on the surface of the face paper. One important issue is also making sure that the adhesive and the face paper are chemically compatible with each others. The combination should be chosen so that the properties of the adhesive are not altered by the face paper.

Direct adhesive transfer onto the surface of the face paper may be challenging due to the dimensional changes of the fibres**.** The adhesive is usually applied onto the surface of the siliconised release paper. Label papers are usually internal and surface sized and coated by using resin as an aid chemical. Sizing improves the dimensional stability of the label paper which is a necessity as the labels are printed in multiple colours.

The requirements for the label papers vary a lot depending on the end use. One good example is the labels on beverage bottles. In order to use returnable bottles, the old ones need to be washed well. One stage of the washing is removing of the labels attached on the bottles. The labels should be washed away as a whole and it requires good wet strength. The washing is performed by using strong caustic detergents and they are supposed to detach the label without breaking it. Unbroken labels are easy to remove from the system compared to fractured pieces of labels.

2.2 The function of a release paper in a self adhesive laminate

The function of the release i.e. backing paper is to work as a carrier for the laminate and in latter converting stages as a carrier for the label. The release paper and the label part of the face paper are attached all along the whole converting chain until the dispensing process is taking place. That is where the labels are adhered onto the product. The release paper should stand all the stresses caused by the production and the converting processes in order to fulfil the task as a carrier for the laminate. The release papers usually have very high strength properties compared with face papers. After the dispensing process, the release paper is treated as a waste material even though it is the most expensive part of the laminate. **/17/**

2.2.1 The properties of the release paper

There are two different kinds of release papers in use. One is a glassine type of release paper and the other is a kraft glassine type of release paper. The release papers of the self adhesive laminate are produced of chemical pulp containing bleached kraft pulp. The basis weight range of the release papers used in UPM Raflatac varies between 51 and 100 g/m^2 and the thickness range is somewhere between 53 and 130 µm. **/3/, /10/**

Glassine papers are supercalendered and produced without fillers or with only a small amount of fillers. The supercalendering gives the paper its dense and porous free surface. Glassine papers are also surface sized in order to achieve as uniform a silicone layer as possible when siliconising the release paper. Release papers are often machine glazed, one side coated or polyethylene coated. **/3/, /11/**

Kraft papers are also used as release papers. Kraft papers are not so dense papers as the glassine papers. The density of the kraft papers can be increased by adding fillers and by coating and calendering the paper. Compared to glassine paper, the surface of the kraft paper is porous and rough. Even though the kraft paper can be coated and calendered, the density of the glassine paper is still higher. The relative bonding area of the glassine paper fibres is somewhere about 90 % due to the optimum refining while in the kraft paper fibres it is somewhere around 50 %. It also has an effect on strength properties because the higher the relative bonding area (RBA), the higher are usually the strength values of the paper. **/5/**

2.2.2 Demands for the release paper

Backing paper should have a smooth and dense surface in order to prevent the silicone for penetrating into its structure. If the silicone penetrates into the fibre structure, it will make the waste matrix removal and the dispensing stages impossible by causing a non-uniform silicone layer and thus that uneven release profile in the laminate. Silicone is supposed to cover the whole area of the backing paper and a smooth and a dense surface of the release paper ensures low consumption of silicone. Silicone is a very expensive substance and the consumption of it should be kept low. The surface of the backing paper should still offer some anchoring points for the silicone in order to form a sufficient adhesion between the release paper and the silicone layer. **/11/**

During the die cutting stage the entire self adhesive laminate is undergoing heavy forces caused by the cutting blade. The compression degree depends on the compression stiffness of each individual layer in the laminate and the distance between the blades tip and the pressed point of the laminate. Naturally the nearest point to the blade is undergoing the biggest stress i.e. compression. When the tension reaches enough high level the face paper is bursting as wanted. The tension level drops fast as the die cutting is proceeding and the die cutting unit reaches its culmination point which means that the blade is as close to the backing paper as possible without touching it. This event is setting demands for the backing paper. The thickness standard deviation of the siliconised backing paper must be as low as possible and the z-directional stiffness must be high in order to have successful die cutting of the face paper. **/11/**

Dispensing machines have to detect the moving label web in order to work correctly. To achieve a good dispensing process, the backing paper should have a sufficient level of transparency. This is easily achieved with a glassine type of paper with basis weight of 60 g/m^2. **/16/** As the label dispensing process goes on the feeding must run as smooth as possible to maintain the runnability. To achieve smooth run, the backing side of the laminate must be rough enough. **/11/**

2.3 Silicone layer

The silicone on the release paper is working as a release layer for the laminate (**figure 1** and **2).** Silicone cures after applied onto the release paper. Curing is taking place as the inhibitors in the silicone are evaporated and the catalyst activates a reaction in the silicone structure. **/3/**

Silicone is suitable material for the release layer because one of its properties is easy detachability from sticky and adhesive material. Silicone must cover the release paper as well as possible to ensure right releasing force between the face paper and the release paper even though the thickness of the silicone layer is only about 1.0 µm (**figure 2**). Release force describes the force needed to separate the face paper and the release paper layers of the laminate. Each customer has its own demands for the release force and it is extremely important that it is kept as constant as possible. **/3/, /16/**

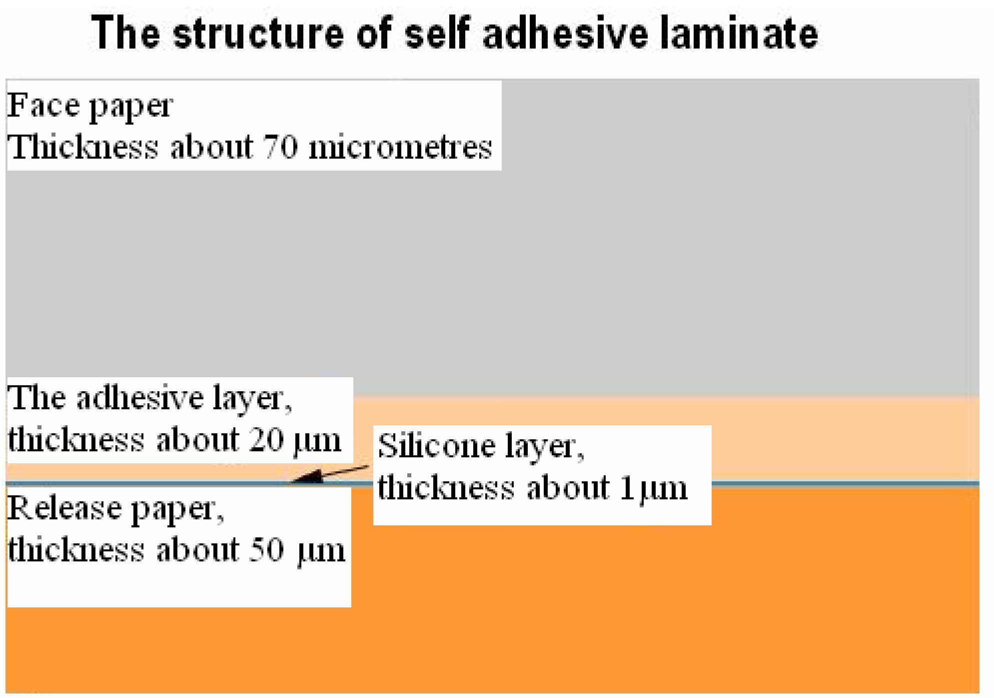


Figure 2 The cross section of a typical self adhesive laminate **/16/**

There are four kinds of silicones available which are solvent based, solventless, emulsion and UV-curable silicones. UPM Raflatac is using only release liners coated with solventless or UV-curable silicone. **/3/, /16/**

Silicones at UPM Raflatac consist of five different components. Base polymer, catalyst, inhibitor, cross linker and modifier form the silicone structure. The ingredients of the silicone are brought to the factory site so that the basic polymer, catalyst and inhibitor are in the same tank. The catalyst and the base polymer are surrounded by the inhibitor. Modifier and the cross linker are delivered separately in their own tanks. **/16/**

2.3.1 Demands for the silicone layer /16/

Siliconising of the release paper is a critical stage concerning the end use properties of the self adhesive laminate. Silicone layer together with the adhesive is defining the release value for further processes and the value must therefore be at a level that the laminate is possible to be converted into self adhesive labels.

The silicone layer must be as uniform as possible in both the cross and in the machine directions. Small fluctuations are not so essential but the goal is to have as uniform silicone layer on the release paper as possible. The adhesion between the silicone layer and the adhesive can not be too high in order to prevent the silicone layer for loosening as the labels are separated from the release paper. Yet it must be low enough for good releasing between the release paper and the waste matrix. Pinholes and stripes may cause peaks in the release force and if the release force is higher than the breaking energy or other strength properties of the paper, the matrix or the label paper usually breaks.

2.4 Adhesive layer

The function of the adhesive is to form a sufficient adhesion between the face paper and the release layer. Surfaces are usually totally different which is making the successful adhering a challenging part of the production of a self adhesive laminate. **/3/** This final thesis work concentrated only on the water based dispersion adhesives.

The adhesive is applied on the siliconised release paper after the silicone layer on the release paper web has cured in a drying tunnel. The siliconised release paper web is cooled down before applying an adhesive. **/16/** The adhesive is chosen differently if the label is temporarily placed or permanently placed. **/3/**

2.4.1 Dispersion adhesive

Dispersion adhesive is quite a common concept when speaking about the lamination adhesive matters. The dispersion as a concept means that a water insoluble solid or liquid material is homogenised with water by altering the surface chemistry of the material and mixing it hard with a powerful mixer or a pump. The steady liquid is also often called latex. **/3/**

Dispersion adhesives are used when laminating paper products or synthetic products. **/3/** The adhesive is applied on the surface of the siliconised release paper and then the water in the adhesive is evaporated away by using heat. The adhesive layer is formed as the water is evaporated away. **/16/**

UPM Raflatac is using acrylate based water dispersion adhesives in Tampere factory. **/16/**

The adhesive is dried by using thermal energy. The water in the adhesive evaporates away as the temperature is increased. Right after the application of the adhesive, water has started to penetrate into the structure of the hydrophilic paper. As the paper web enters the drying tunnel, the direction of the water flow changes and evaporation is taking place. Now the water evaporates away from the paper. Water is transforms into the gas form and it is transported away by the air conditioning. The temperature which is used to evaporate the water can not be too high in order to prevent the blistering effect of the web and to save the adhesive layer from breaking. **/16/**

2.4.1.1 Additives in the adhesive /16/

Main components of an adhesive are a polymer and a tackifier. Polymers are divided into permanent adhesives and removable adhesives. The adhesive which is used is chosen according to the substrate the label is applied on and the end use requirements of the label. Polymers are giving the hardness for the adhesive and they have an effect on the shear values, cold adhesion and bleeding of the adhesive in the die cutting stage.

For runnability reasons, number of different additives is used in the adhesives. Defoamers, surfactants, thickeners, preservatives, wetting agents etc. are used to improve the properties of the adhesive and to improve the converting process of the self adhesive laminate.

2.4.2 The quality requirements for the adhesive layer /20/

The adhesive layer must be as uniform as possible and can not contain any holes or defects. Stripes and scratches are not allowed because they are disturbing the converting processes of the self adhesive laminate by causing unexpected failures. To achieve good functional properties for the label, there can not be any variation in the thickness profile of the adhesive layer. Uneven thickness profile is causing variations in the release profile which are disturbing the waste matrix removal process as well as the dispensing process in the final converting stages.

2.5 Primer

The face paper can also be treated with fifth substance which is called primer. The primer is applied on the reverse side of the face paper just between the adhesive and the face paper (**figure 2**). The function of the primer is to prevent the adhesive from penetrating into the face paper structure. If the adhesive penetrates through the face paper, it is causing problems in the converting machine and the appearance of the label might suffer a lot. Other function of the primer is to form a decent adhesion between the adhesive and the face paper so that the labels will not loose too easily from the release paper during the converting process**.** The primer is also anchoring the adhesive onto the face paper. **/3/**

3 LAMINATION OF A SELF ADHESIVE LAMINATE

The term laminating refers to attaching two (or more) web form substrates together. Webs can be either plastic or paper based or there can be both in the same laminate. **/3/** This work concentrated only on paper based substrates.

Lamination of the self adhesive laminate is taking place at a nip formed by two rolls. The nip is called a lamination nip (**figure 3**, lamination nip). The webs are pressed against each others at the lamination nip in order to form one unique web. The surfaces of the webs are pressed together with a pressure so that the auxiliary substances on the surfaces are interlocked. With the help of the pressure, these surfaces are connected in a micro scale which means that single molecules between the both surfaces are in contact. **/3/, /16/**

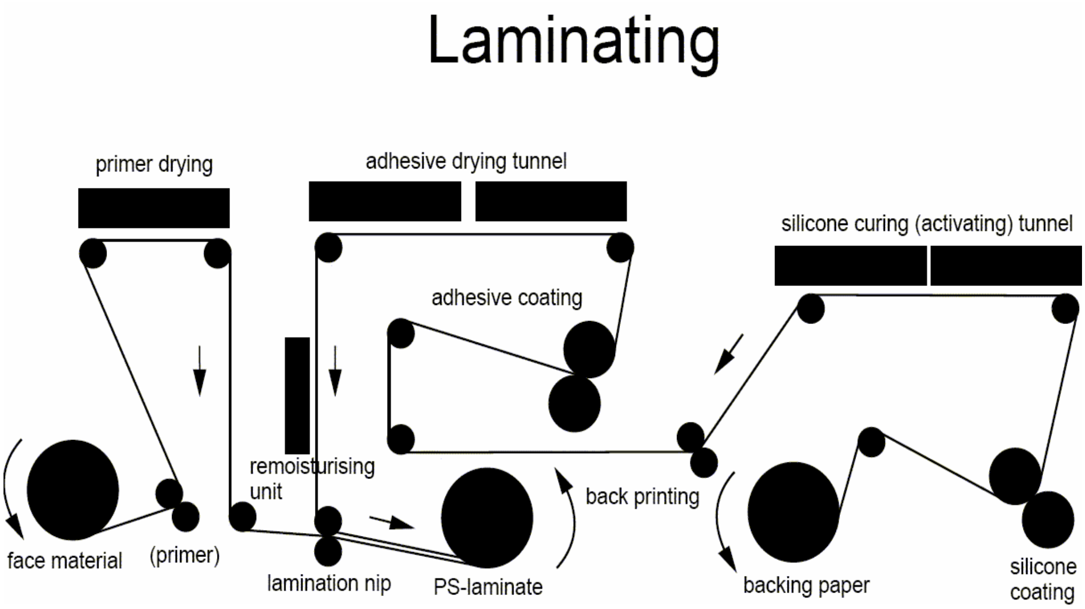


Figure 3 The principal figure of the laminator **/11/**

3.1 Transfer coating

Transfer means that the adhesive is applied directly on the siliconised backing paper (**figure 3**). The adhesive is wet because of water or a solvent. The wet adhesive dries as the solvent is evaporated by means of heat (**figure 3**, the drying tunnel). **/11/**

3.2 Adhesion

Adhesion between the silicone layer and the adhesive layer is starting to develop in the laminator. **/3/** Adhesion is defined as an attraction between matters. Depending on the way the attraction occurs, the adhesive bond is either strong or weak. **/20/** Adhesion is essential in order to keep the labels on the release paper but it can not be too high in order to perform the dispensing of the labels successfully. **/16/**

4 CONVERTING PHASES OF A SELF ADHESIVE LAMINATE

4.1 Converting machine

One machine in the converting process consists of the printing machine where the labels are printed, the die cutting unit where the label shape is cut and the waste matrix removal unit where the matrix stripping is taking place (**figure 4**). There are also converting machines without printing units, only the die cutting and waste matrix removing units. The converting machine is quite vulnerable to quality changes of the self adhesive laminate because all these stages must succeed in order to produce good quality labels. **/3/, /16/**

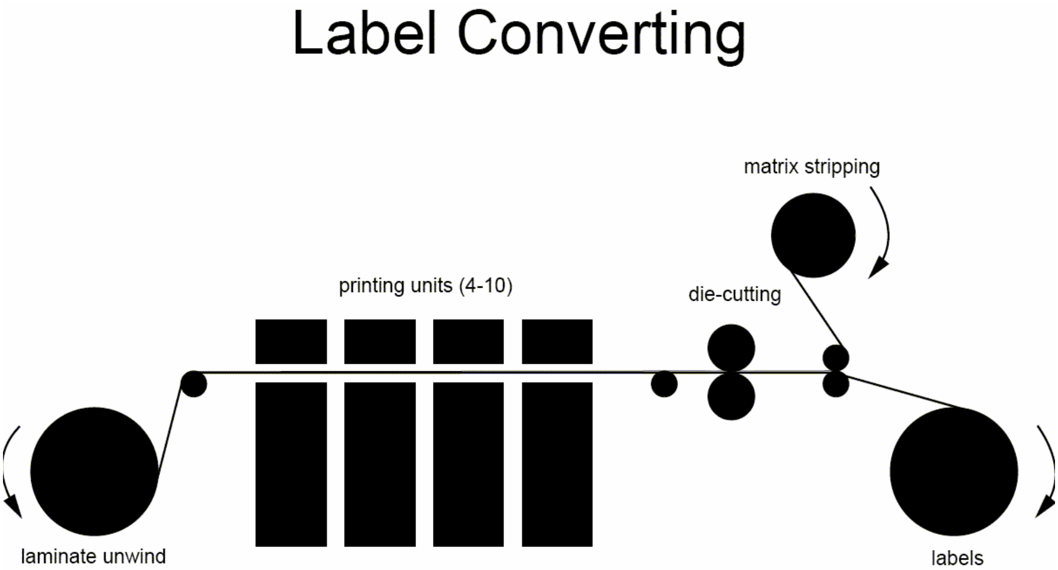


Figure 4 The principal structure of the converting machine of self adhesive laminates **/11/**

4.1.1 The unwinding of the self adhesive laminate /16/

In the printing machine, as in all the other web handling machines, the controlled unwinding is the key point for successful converting.

The unwinding has a significant role in keeping up the right web tension. Right after the roll has started to unwind, the roll is in a state of change. The diameter and the speed of the axle are changing all the time during the length of the roll. It is challenging and essential to keep up the right web tension to ensure good quality of self-adhesive labels.

Besides the successful unwinding, the web has to be centralised in a way that it enables the converting machine to work properly. The production can not be maintained long without breaks unless the web is centralised correctly. The contamination of the converting machine caused by the silicone and the adhesive is usually due to the miscentralised web in the laminator. Cleaning of the defects in the converting machine is shortening the valuable production time.

4.1.2 Printing units in the converting machine

Self-adhesive labels are printed in a roll or in a sheet form. The most common way to print the labels is the roll form and the experimental work was concentrated only on the die cutting of the roll forms. There can be up to 10 printing units in the same printing machine. Usually labels are printed with flexography but also rotogravure and offset printing methods are used. **/3/**

If the printing of the label is complicated, it is usually setting limits for the speed of the converting machine. The lowered speed might help the waste matrix removing process. **/18/** The situation where the ink is dried many times after the printing units and the web temperature is kept relatively high can interrupt the waste matrix removal stage. Increased web temperature is also increasing the temperature of the adhesive and it can turn the adhesive too sticky. Sticky adhesive is making the removing of the waste matrix more difficult because the labels are following the waste matrix. **/14/**

4.1.3 Die cutting as a concept

By die cutting we mean an event where the face paper of the self adhesive laminate and the adhesive layer under the face paper are cut through by a moving die. The function of the die is to cut the face paper and to give the shape for the label but also to separate the label from the surrounding and forming waste matrix. The label and the waste matrix areas have to be separated by cutting so well that the end use requirements i.e. the waste matrix removal and the dispensing stages are carried on well. Die cutting die can not reach the silicone layer and the release paper structure because it will disturb the waste matrix removing process and latter converting processes. **/3/, /16/**

4.1.4 Removing of the waste matrix of a self adhesive laminate /16/

Waste matrix of a self adhesive label consists of face paper and adhesive layer which are left outside the die cut label area. The waste matrix area is not printed. The waste matrix is kept in a uniform ladder shape (**figure 5**) form in order to perform the waste matrix removal well without stops.

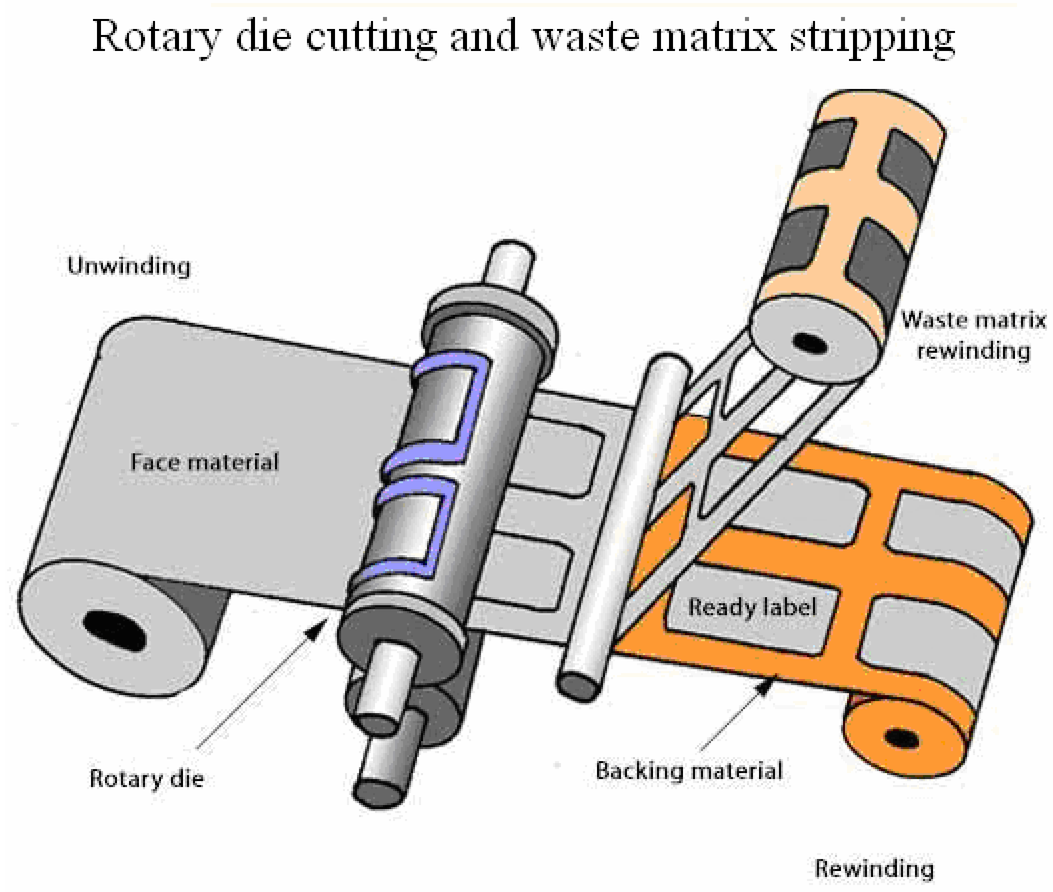


Figure 5 The principal of the waste matrix removing stage **/16/**

5 DIE CUTTING OF A SELF ADHESIVE LAMINATE

Die cutting unit is locating after the printing units. First the face paper is printed, then the ink has to be dried and for the last, the face paper of the laminate is cut into labels. The die cutting method is defining the nature of the printing machine. **/16/**

5.1 Methods for die cutting the self adhesive laminates

There are few different kinds of die cutting methods which the most known ones are a rotating die cutting and a horizontal i.e. flat bed die cutting. A machine which is using rotating die cutting unit runs in a continuous motion. The machine equipped with horizontal die cutting is running with a pulsating speed. **/16/**

This final thesis work was concentrated on rotating die cutting unit which is used in the experimental part of this thesis work.

5.2 Rotating die cutting unit /16/

Die cutting event is taking place in a gap formed by two different sized rolls. Rolls are rotating on upon the other into the same direction.

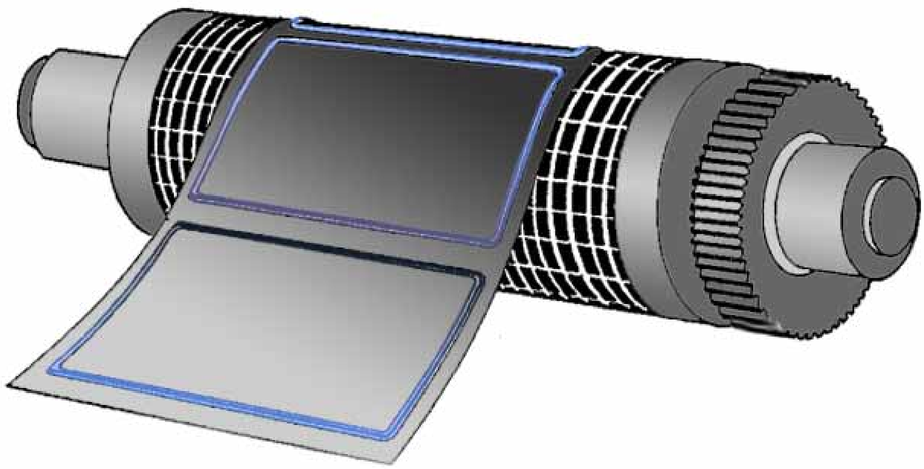


Figure 6 The flexible die on the magnetic cylinder **/16/**

The die cutting rules are either engraved into a solid metal cylinder or the die can be flexible and placed onto a magnetic cylinder as in **figure 6**. The thickest part of the flexible die surface is 0.50 mm and the thinnest one about 0.11 mm. The diameters of the magnetic cylinders are starting from 50 mm. The experimental part of this final thesis concentrated only on the magnetic cylinder and flexible dies.

During rotating die cutting, the web is all the time in a moving motion. Because the paper is in a roll form, the web speeds are often much greater than what they are in flat bed die cutting units.

The die cutting event must succeed as good as possible. In the final converting stage, the labels are dispensed and adhered onto the product at a great speed. Because the speeds of the dispensing lines are increasing all the time, the die cutting quality must be even better in the future.

5.3 The rotating die cutting station

As mentioned in the previous chapter, the rotating die cutting unit is consisting of rotating cylinders. The cylinder, where there can be either an engraved surface or the flexible surface with a die, is called a rotary die (**figure 7**). The die is machined according to the shape of the label and according to the substrate to be cut.

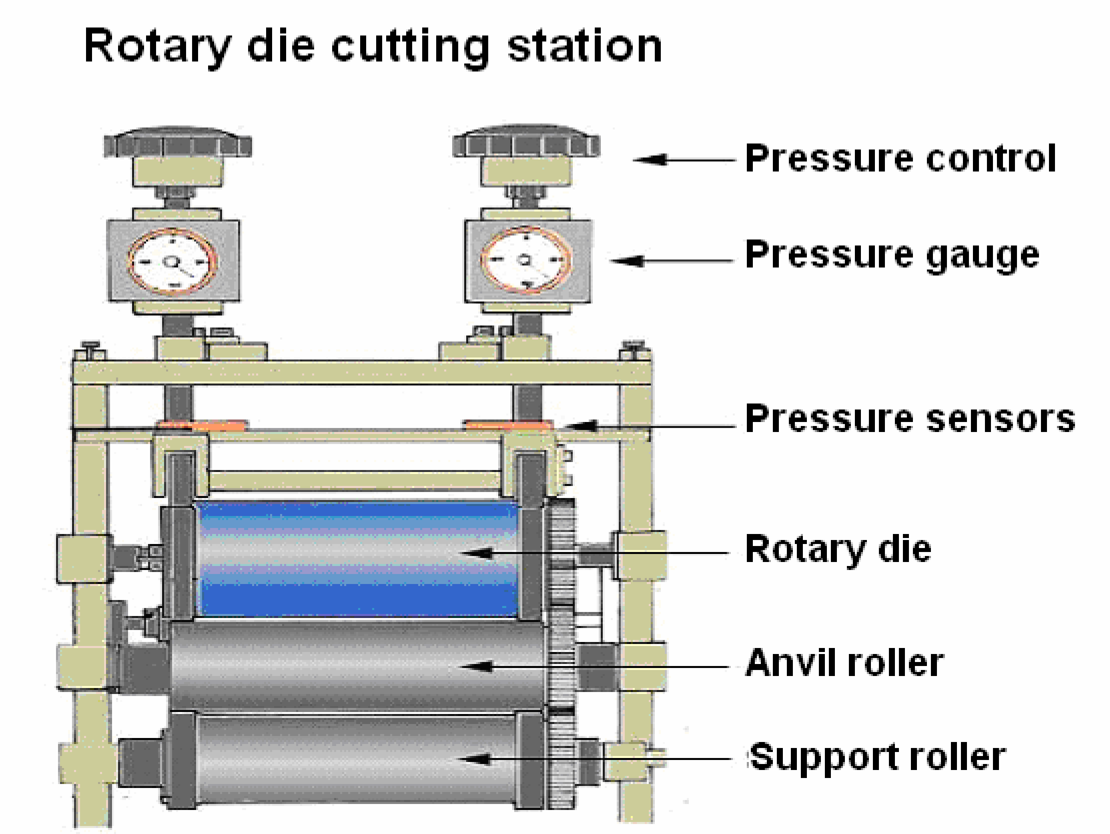


Figure 7 The rotating die cutting unit from behind **/16/**

An anvil roller is located under the rotary die. It forms together with the rotary die the die cutting gap and it gives the counter pressure in the pressing stage of the laminate. There can also be a support roll under the anvil roller. It is improving the rigidity of the die cutting station and thus that improving the quality of the die cutting process by minimizing vibrations. **/16/**

The process parameters are controlled by the compression stress between the rotary die and the anvil roller. Stress is measured by the pressure sensors which transfer the signal to the pressure gauge. **/16/** The pressure has to be adjusted the same in both edges of the rotational die cutting unit. It is allowing a precise cutting and accurate setting. Pressure can not be adjusted too high in order to avoid bearing breaks. **/14/**

Anvil roll has a larger diameter than the magnetic roll i.e. the rotary die. The substrate is defining the die angle and the material of the die. **/14/**

5.4 The gap clearance in the die cutting station

The gap between the rotary die and the anvil roller is standardised into 480 micrometres. The gap between the head of the die and the anvil roller is about 40 µm which means that the release paper can not be much thicker than the extraction between the gap clearance and the die height. /14/

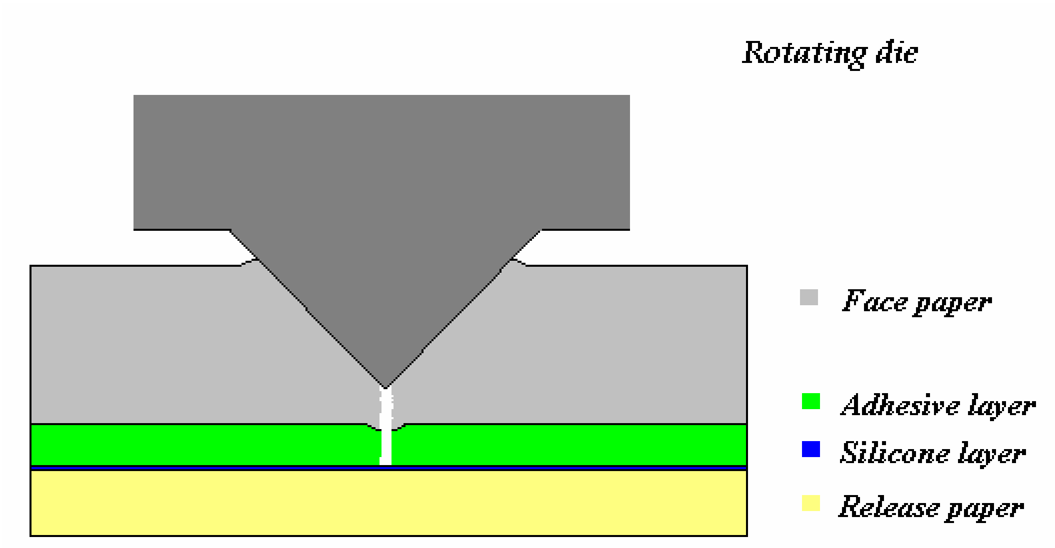


Figure 8 The bursting of a face paper under the die **/14/**

Nowadays there are also die cutters available where the gap between the rolls is adjustable. In the traditional ones and in the one which was used in the experimental part of this final thesis work, the gap is constant. **/14/**

The gap clearance is adjusted by using different kinds of anvil rollers (**figure 9)**. The edges of the anvil rollers are defining the gap clearance. **/16/**

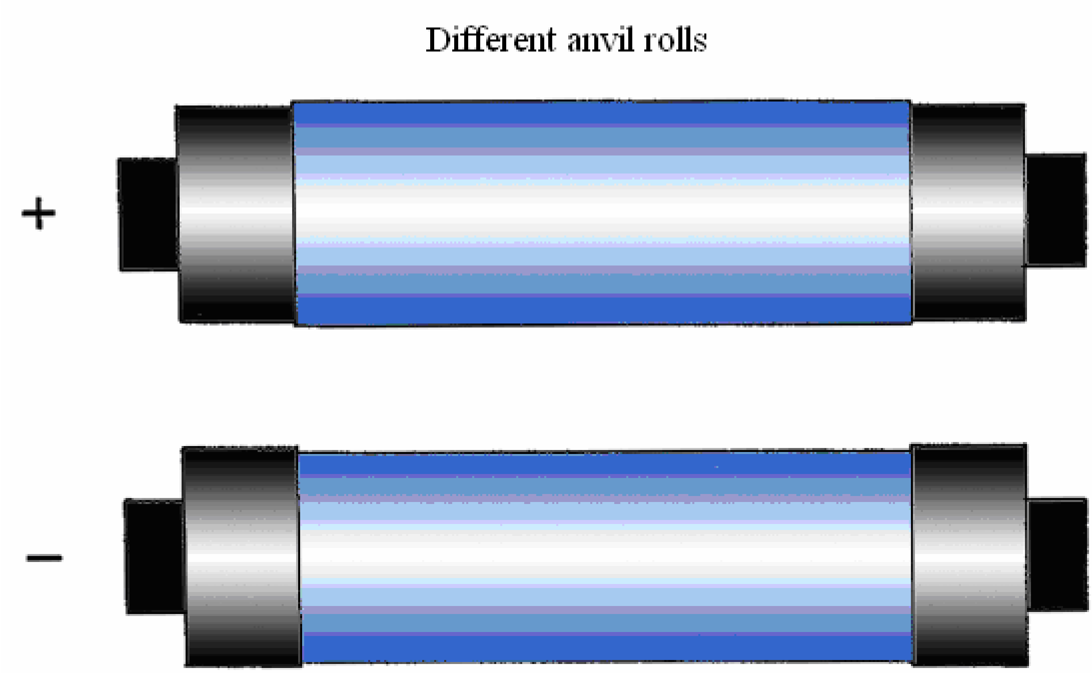


Figure 9 The + and – anvil rollers are used to adjust the gap clearance of the die cutting station **/16/**

5.4.1 The compression in the nip

The self adhesive laminate is undergoing a great compression between the rotary die and the anvil roller. The compression of the laminate is making the bursting stage possible (see **figure 10**).

5.5 The stages of the die cutting are divided into four parts

For easier inspection, the cutting stage is divided into stages. By studying those four stages well, it is possible to see how the die is cutting the laminate (**figure 10).**

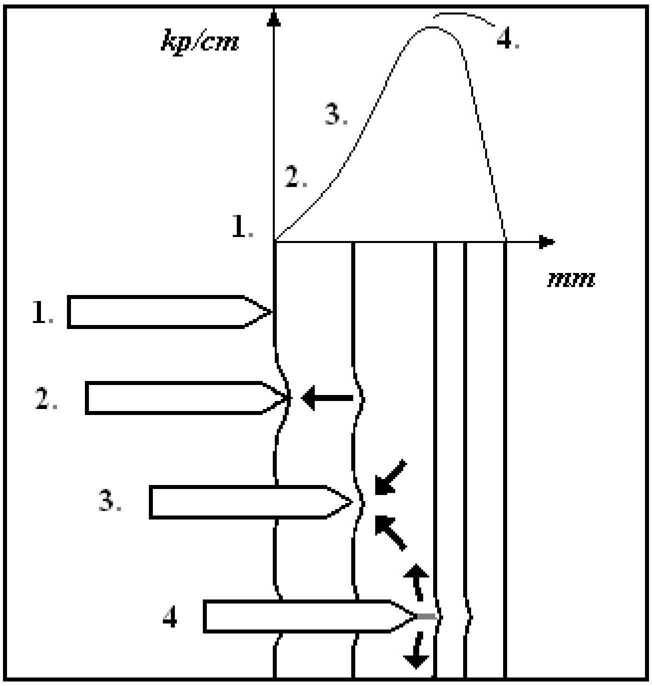


Figure 10 There are four main stages in the die cutting event **/5/**

The time the die is staying on and inside the laminate is only hundredths of a second when running at a production speed. **/16/**

5.5.1 Die reaches the face paper surface (1)

The rotating die cutting is running in a continuous motion. The first stage is (**figure 10**, number 1) as the die reaches the surface of the face paper. The pressure on the surface of the laminate increases immediately after the first contact and then the penetrating takes place. **/5/**

5.5.2 The compression stage (2)

The pressure inside the laminate is increasing steeply as the die is penetrating into the structure of the self adhesive laminate (**figure 10**, stage 2). As the die is moving on, it is displacing the face paper. Part of the face paper is moving aside. The increase of the pressure is easily seen in the graph in the **figure 10**. **/5/**

5.5.3 The pinching stage (3)

The pressure inside the laminate is still rising but after a short moment the growth of the pressure is slowing down (**figure 10**). The die is penetrating all the time deeper into the structure of the laminate towards the culmination point of the die. **/5/**

5.5.4 The bursting stage (4)

The structure of the face paper will no longer hold and bursts (**figure 8,** stage 4). This stage is the point where the pressure in the gap between the rotary die and the anvil roller has reached its highest value and the die cutting is completed. The die is moving only a bit forward after the bursting stage and then it is starting to move further away from the culmination point. **/5/**

The pressure of the die is adjusted into a certain level to avoid vibrations and unsteady motion of the entire station. If the pressure is adjusted too high there might occur irregular cutting and strong wearing of the bearings. **/14/**

5.6 The shape of the die

There are numerous of different label shapes used in the products. The shapes of the labels are chosen according to the brand owners` wishes, the shape of the product in which the labels are adhered, and the costs. Complicated shapes usually cause difficulties in the waste matrix removing stage and are setting limit for the speed of the converting machine. **/18/, /14/**

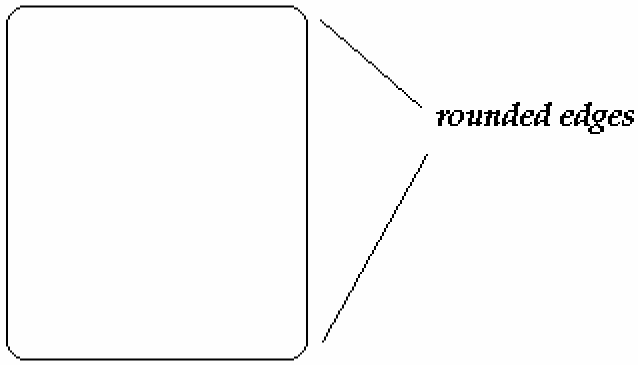


Figure 11 Rounded edges in the die

Rectangular shapes with rounded edges (**figure 11**) are easier to die cut and the waste matrix removal is succeeded better. The shapes with lots of details and sharp edges are the most difficult ones considering the waste matrix removal stage. **/18/**

5.7 Properties of the die

The angle of the die is machined according to the material to be cut and according to the chosen adhesive. **/16/** If the die angle is machined sharp, it will be worn out faster than a blunt one but the cutting mark is sharp and clean. The die with a sharp angle penetrates easier into the structure of the face paper but is also wearing faster. The angle of the die is adjusted usually over 70-90 (blunt angle) degrees when cutting paper substrates. The nature of the blunt die is more compressing which is suiting better for the paper substrates. **/19/** Minerals used in the face paper coating have an impact on the dies life age. Rough minerals are wearing the die more. **/14/**

In the rotating die cutting unit, the cutting depth is defined by the anvil roller. The distance between the die cutting die and the backing roll is controlled by the height of the anvil roller edges (**figure 9**) but the gap can only be adjusted while the machine is not running. **/16/**

When cutting thick materials, the surrounding areas of the cutting mark can rise a bit from the edges (**figure 8**). To prevent this, the geometry of the die is altered. The solution is that only half part of the original die is used. The dies are machined asymmetric to prevent the adhesive for gushing out form the cutting mark when using hot-melt adhesives. **/16/**

The dies are designed according to the cutting quality and the service life of the die. In order to prevent too high abrasive effect, different coverings are made for the dies. Dies can be made of variety of different materials i.e. depending on the used inks. Metals in the inks such as titanium dioxide are causing high abrasive effect into the die. Usually the hardness of the die is altered but extra treatments always cost more. **/14/** As the product to be cut is changed, the dies are also changed into new ones or designed all over again. The quality requirements for cutting the product are different in each material and they have to be taken into notice when planning new dies. **/16/**

5.8 The effect of the die cutting station in cutting quality

Steady die cutting station is a requirement for the successful die cutting. Vibrating and unstable station will interrupt the penetration of the die into the face paper which is ending up in poor cutting quality. Usually problems occur in forms of breaks, in poor cutting quality and problems in the waste matrix removing or even in the customers dispensing processes. Machine parts are chosen in order to prevent any vibrations but still that they can be adjusted as the die angle wears **(figure 12)**. **/14/** An optimum situation would be that the whole run could be achieved with the same equipment. New inventions such as gap master, which is allowing the controlling of the die cutting depth, can be increasing the age of the die but might also be also setting new requirements for the laminate as the die is wearing and becoming blunt. **/19/**

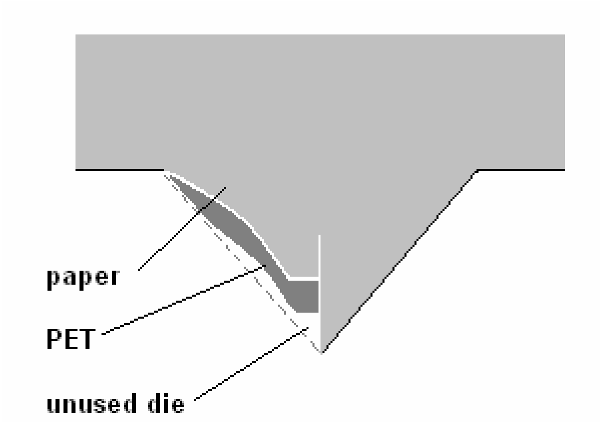


Figure 12 The wearing of the die with different materials **/14/**

5.9 Requirements for the self adhesive laminate set by the converting stages /16/

Each stage is having its own requirements for the laminate and usually the whole converting process is a compromise between the quality and the output of the converting machine. Usually the output of the converting machine is playing a bigger role.

5.9.1 Printing of the self adhesive laminate

In order to have successful converting process, the laminate needs to have straight edges to prevent edge folding and wrinkling in the converting machine. Folds and wrinkles may be causing breaks and stoppages of the whole machine. **/11/**

If the number of printing units is high and at the same time the running web is narrow, the paper is undergoing great stresses. The moisture of the printing units can cause too heavy fibre swelling and changes in the dimensions of the web. It is disturbing the printing and the die cutting stages by causing misregistering. Surface sizing is increasing the dimensional stability of the face paper and is decreasing the misregistering problems. **/11/** The most critical things affecting the dimensional stability are the raw material mixture, the moisture of the laminate, the reeling tension of the laminate and the laminate straightness. **/16/**

5.9.2 A successful die cutting

In order to achieve successful waste matrix removing, the strength properties of the face paper must be high enough. Tear and tensile strength are having a great role when stripping the thin edged ladder shape waste matrix. **/16/** Face papers are made of mixture of chemical hardwood and chemical softwood pulp.

Face papers with low bulk are easier to die cut than bulky papers. This is due to the inelastic structure which bursts easier and is easier for the die to cut. The dies are cutting in better accuracy if the paper is dense and this is also preventing the release paper from sliding in the gap when cutting. **/4/**

Backing paper properties are having a great influence in the die cutting process. The standard thickness variation of the backing paper must be as low as possible in order to prevent false cutting. If the thickness of the release paper is set too low, the die will not cut the label correctly and waste matrix removal will not be succeeded as the labels are still attached to the waste matrix. Therefore the thickness and the thickness profile must be adjusted right. It is important to notice that the moisture in the air is increasing the thickness of the release paper. The bulk of the paper is having similar influences than the thickness and thickness profile variation. The compression strength of the backing paper and the whole laminate are key issues for successful cutting event. Die is cutting the laminate with a constant force and in constant depth. Also the flexibility is a required property in the layers of the laminate. **/16/**

5.9.3 Factors affecting the cutting result

The amount of adhesive is having an influence for total thickness of the laminate. Hard adhesives will not brake when cutting and might lead to situation where the labels are following the waste matrix.

Temperature of the adhesive has an impact the viscosity of the adhesive. If the temperature rises, the softer and stickier the adhesive is. **/19/**

6 REMOVING OF A WASTE MATRIX

The waste matrix is the part of the laminate which is left outside the label area. It can be removed in a printing machine or in a separate waste matrix removal unit. On-line waste matrix removal means that the waste matrix is removed in the printing machine. To achieve good results when removing the waste matrix, the die cutting stage must be performed in a best possible way and the quality of the raw material must be at a suitable level. **/16/**

The experimental part of this final thesis concentrated on online waste matrix removal at Gallus R160 converting machine. **/16/**

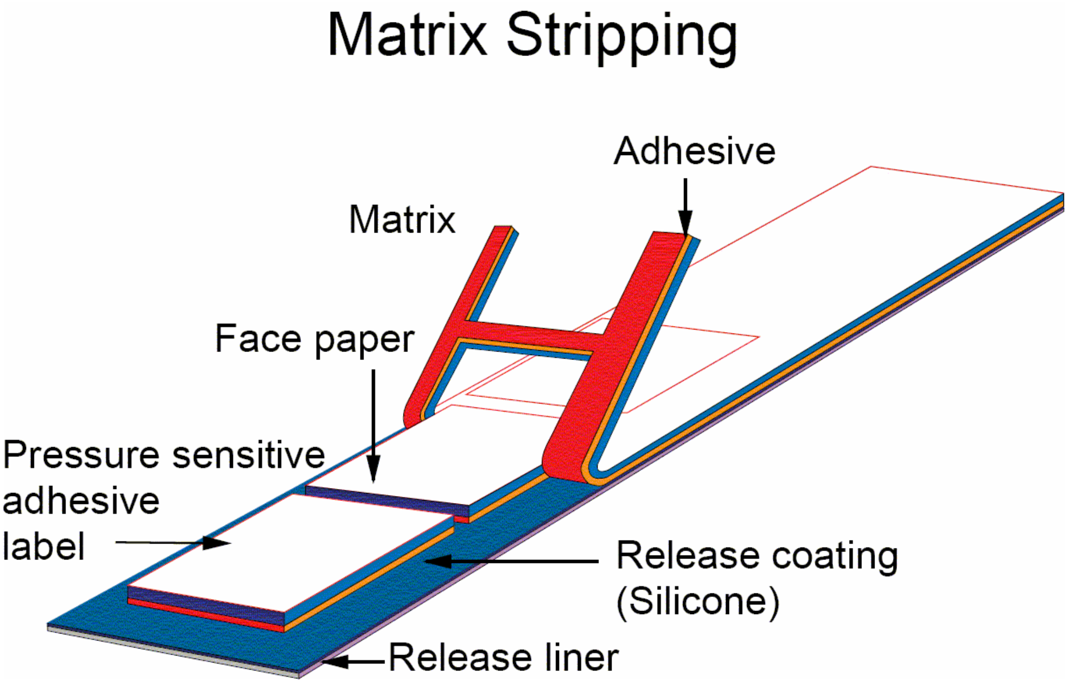


Figure 13 The waste matrix is separated from the release liner as a ladder shape **/11/**

In the **figure 13** the waste matrix structure is seen as a principle. The shape in the figure is relatively simple compared to the real production shapes. The rectangular shape is the simplest on. Some labels are irregular and it also makes the waste matrix structure complicated.

6.1 Removing of the waste matrix

The waste matrix is removed after the die cutting cylinder. It can be removed against the die cutting cylinder or in latter stage depending on the removability of the matrix. After the die cutting station there are either a separate cylinder i.e. the take-up roller which the web is removed against or a blade instead of a cylinder form. **/16/** The waste matrix can be removed also in a certain angle which differs from the laminate web direction (**figure 14**). **/19/**

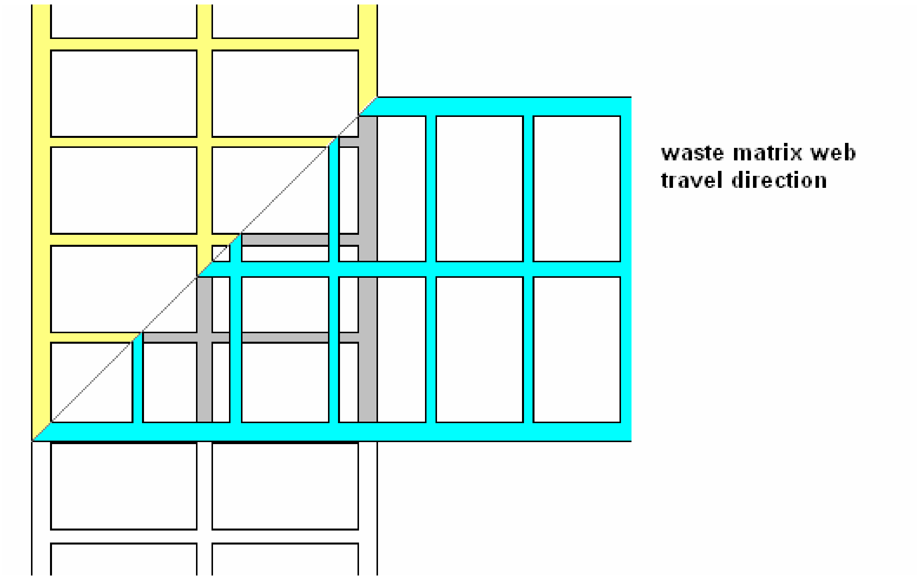


Figure 14 The waste matrix removal

The stripping angle of the waste matrix is influenced by the diameter of take-up roller and by the angle of the blade. Take-up roll with higher diameter is supporting the matrix web more than a rod-like roll and it is usually used with more fragile webs. Well supported web is easier to control and is causing fewer breaks (**figure 15**). **/19/**

Figure 15 The waste matrix is removed against a cylinder **/12/**

The delay time after the die cutting event and the waste matrix removal is an important factor concerning the waste matrix removal. The longer the delay between the stages, the more the adhesive has time to move back into the cutting line. This phenomenon is called bleeding and it occurs when the labels are following the waste matrix i.e. they are attached to the waste matrix by the adhesive. If the adhesive is very sticky, the waste matrix should be removed as close to the die cutting unit as possible in order to prevent the bleeding effect. The speed of the converting machine and the distance between the die cutting unit and the take-up roller are defining the delay time. **/19/**

The waste matrix web is rewound onto its own reeler or there can also be conveyor which is conveying the waste material into a waste treatment. The finished self adhesive labels are rewound onto their own reeler. **/16/**

The waste matrix rewinding is a factor which may cause some difficulties in the converting process. Asymmetrical rewinding usually occurs when the waste matrix is rewound on the cylinder. The irregular shape of the waste matrix roll causes redundant draw and pulsating movement. **/14/**

6.2 Improper die cutting

Situation where the die has penetrated too deep into the structure of the self adhesive laminate is causing severe damage for the silicone layer. As a result of too deep cutting the adhesive layer can penetrate into the structure of the release paper. It is causing an unwanted adhesion between the face paper and the release paper which occurs as a difficult or even impossible detachment of the waste matrix or the label. If the die will not penetrate enough deep into the laminate, the face paper and the adhesive layer will not be cut entirely. The strength properties of the face paper in the waste matrix removing stage are not high enough in order to tolerate the high forces caused by the separation of the label and the waste matrix due to the incomplete cutting. If there still are fibre networks existing between the waste matrix and the labels, it is in some point leading to break or the labels are attached the waste matrix. As the matrix is removed, the paper usually is breaking in some part of the ladder form. A total web break usually occurs if the cutting quality is continuing to be poor. **/16/**

The tension level in the waste matrix is depending on the shape of the labels, the size of the area between the labels and the speed of the laminating machine. The tension levels can be adjusted by making small cuts in the waste matrix areas which are balancing the tension level. Therefore the tension will not reach the highest peak and thus that the waste matrix is tolerating the stress better. **/19/, /14/**

6.3 Release force

Release value is the force that is needed to separate the face material from the release paper. The level of the release force is adjusted according to the customers` wishes. If the release value is wrong or is fluctuating too much, the customer may be having difficulties when removing the waste matrix or in the dispensing processes. **/N/** Holes or other irregularities alter the local release value and are causing problems in form of breaks or as dispensing failures. Wrong modifier amount in the silicone is affecting the large scale release value and is disturbing the waste matrix removal by causing variations in the release profile. **/19/**

Release force measurement is an important measurement when producing self-adhesive laminates. Release force is describing how well the layers of the laminate are adhered to each others. The separation of the laminate layers should be even and the fluctuations in the release force should be minimised. When removing the waste matrix, the release force concentrates mainly on the narrow strips of the matrix. The strength properties of the waste matrix strips must be high enough in order to stand the stress caused by the delaminating of the strips from the release layer. An even release force is an essential quantity in order to have a succeeded waste matrix removal. The face paper and the adhesive must release from each point of the backing paper with a constant force. This is setting demands for the silicone layer quality where pinholes or rough surface are not tolerated. **/11/, /16/** Silicone and the adhesive are the biggest factors affecting on the release values. Also the papers in the laminate, the converting process and the meters have an effect on release values. **/6/**

The chemical and physical properties of the adhesive and the amount and evenness of the adhesive applied on the release paper area playing a great role when the release value of the self adhesive laminate is developing. After the lamination the release value begins to change. Release measurements are considered reliable after a week period from the laminating process. **/6/**

In normal conditions, the release value can be fluctuating in a certain level without causing any problems in the converting stages. When the values are way out of the scale, problems usually occur. Fluctuating release force is more difficult to handle in the production of labels than a release force which is at a constant level but differing from the target value. **/16/**

6.4 Dispensing /16/

The dispensing is the last stage in the converting chain of the self adhesive labels. Dispensing as a term means that the label is removed from the backing paper and attached onto the final product which is then delivered to a retail trade or forward to the next converter. Dispensing is performed manually or automatically.

6.4.1 Manual dispensing process /16/

Manual dispensing is performed by hand if there is no automatic dispenser available, the automatic dispenser is too expensive to purchase or the process is too complicated to perform automatically. This kind of situation is usually when there are sheet form products to be handled, such as A4-forms or continuous stationeries.

Release force is not so vital property when dispensing labels manually because people easily adapt the fluctuations of the release force. The die cutting stage instead is more vital as the labels are dispensed by hands. Badly performed die cutting is disturbing the detaching of the label from the backing paper which is leading the label or the backing material to be break. Too deep die cutting is usually the reason why the detaching process will not be successful because the adhesive layer may become in contact with the backing paper.

6.4.2 Automatically performed dispensing /16/

The automatic dispensing is performed by a machine. The self adhesive label web is fed in roll form and the labels are dispensed in a high speed. Dispensing is done against a small diameter rod or against a sharp angle (**figure 16,** number 4).

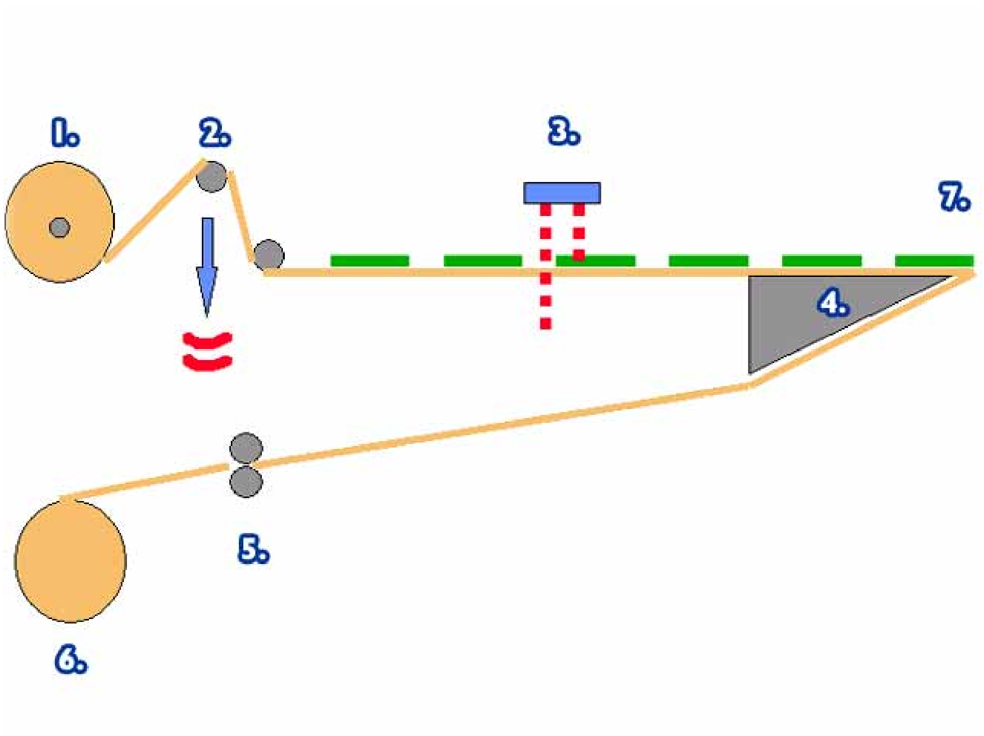


Figure 16 The principal of the label dispenser **/16/**

The most important factor in automatically completed dispensing is the right kind of release force without any fluctuation. Optimizing the release force is saving costs and helping both the customer and the producer by reducing complaints.

If the release force is adjusted too high, the label will not be loosened from the laminate and continues on the backing paper to the backing paper reeler (**figure 16,** stage 7). If the release force is set too low, the labels are loosened in the wrong stage of the process (**figure 16,** e.g. stage 2). This is also called pre-dispensing.

Other factors that influence the dispensing process are the straightness of the front edge of the label and the die cutting quality.

6.4.3 In-line application /16/

Automatic dispensing takes place after the dispensing blade where the label is adhered onto the product. The application is done with a help of pressurised air. Pressurised air (the red ball in the **figure 17**) is blowing the label onto the product surface (blue ball in the **figure 17**). The device which is pressing the label onto the product is a belt dispenser. It is pressing the label against the product in order to form a decent adhesion. Pressurised air can also be based on suction and blowing. The first stage is sipping the label away from the laminate and the second stage is blowing the label onto the product with a high pressure. The label shape is determining the method which is to be used in the process.

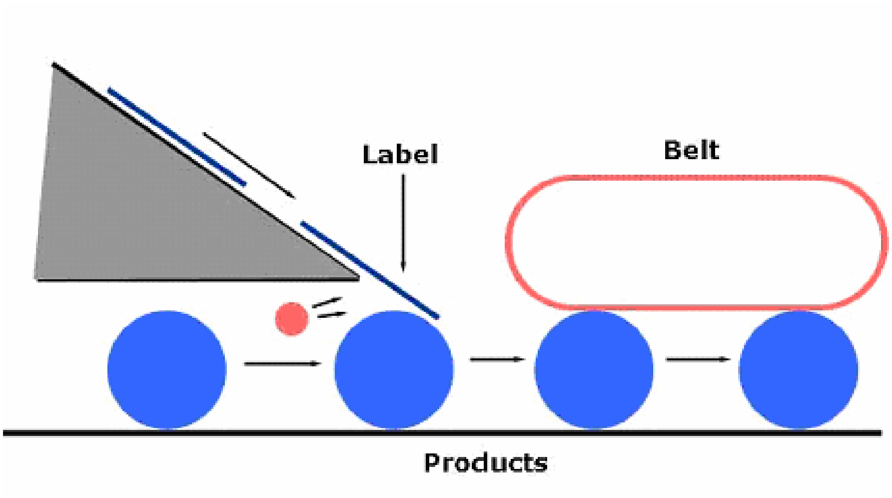


Figure 17 Dispensing of the label onto the product **/16/**

7 STRENGTH PROPERTIES OF THE PAPER

The strength properties of the papers are defined according to the strength value of a single fibre and according to the bond network between many fibres. These bonds, which are also called hydrogen bonds, have a great effect on the strength properties of the paper. The more there are bonds in the paper structure, the higher the strength values of the paper are. **/17/**

7.1 Definition of a tearing resistance

The tear strength or the tearing resistance describes how much force is required to continue tearing where the initial tearing cut is already done. Tearing is done either in machine direction or cross direction and the unit is mN (**figure 18**). The tearing strength of a paper depends among others on the fibre length, fibre strength, degree of bonding between the fibres and the degree of orientation of fibres in the paper. **/11/, /17/, /8/**

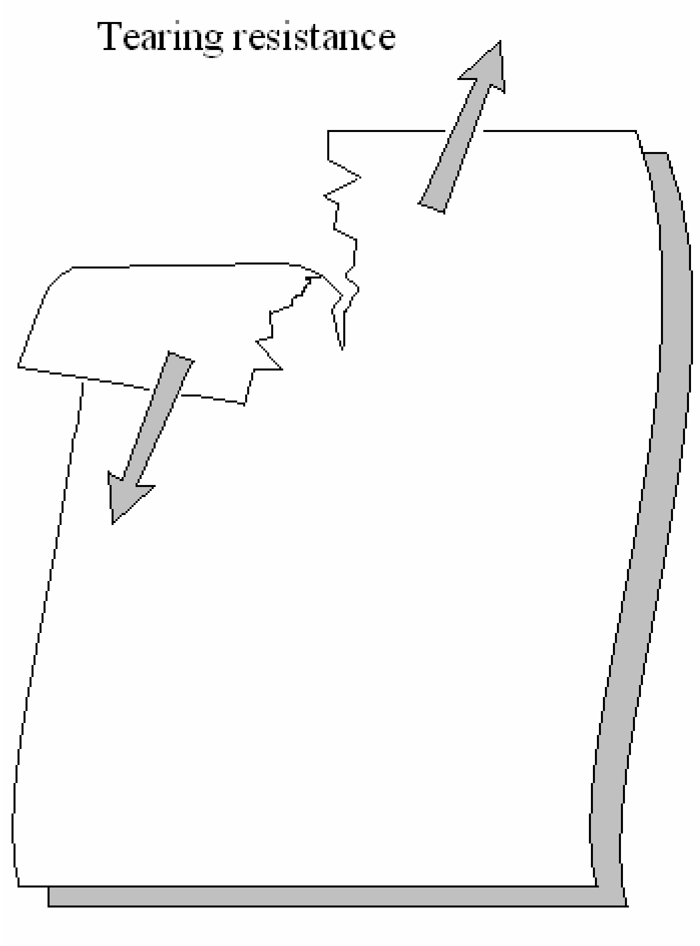


Figure 18 An elucidation of tearing resistance measurement **/17/**

7.2 Definition of tensile strength

Tensile strength describes the strength that paper can stand without breaking when stretched in the plane direction. Tensile strength usually means the machine directional strength and it is describing how paper tolerates tension when the paper is drawn. Stretching always occurs but papers which tolerate it the most will run better than weaker papers. **/17/** The unit of tensile strength is kN/m. If the basis weight of the paper is known, the tensile strength index can be calculated by dividing the tensile strength by the basis weight. **/11/**

7.3 Definition of fracture toughness

The fracture toughness is defined as a property which describes the ability of a material containing a crack to resist fracture. The measurement of the fracture toughness counterfeits a situation where the paper has a defect and the paper is stretched. **/7/**

7.4 Definition of a formation

Formation is a small-scale basis weight variation in the paper sheet. In other words the formation means the mass distribution of the raw materials in the paper. **/11/**

According to ISO-standards, formation explains how the fibres are divided, mixed and grouped to form a paper (**figure 19**). There is always a small-scale basis weight variation in the paper but in some papers the variation is much lower than in others. The pulp has a great impact on formation. It is known that chemical hardwood pulps are giving a better formation than chemical softwood pulps. Also the linear density of the fibres has an effect on formation. The linear density of hardwood pulp is lower than in softwood pulps. **/17/**

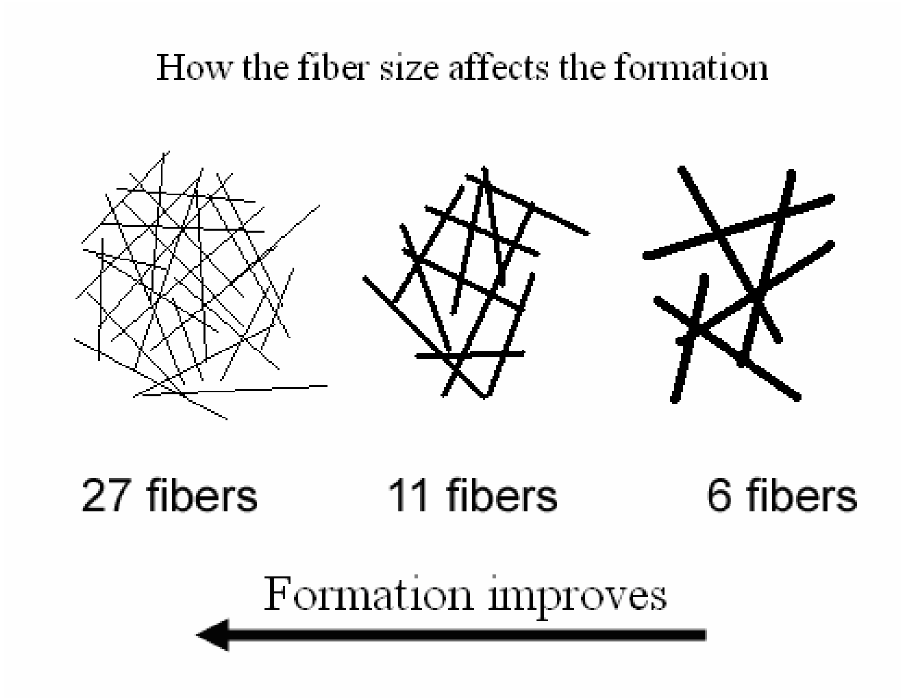


Figure 19 An elucidation how the fibre size affects the formation **/17/**

7.5 The effect of raw material on paper strength properties

There are number of factors which have an effect on strength properties of the paper. Strength properties are a combination of many factors and depending on the end product requirement, the strength properties of the paper are attempted to adjust right. Some factors which have an effect on the strength properties are collected and explained briefly below.

7.5.1 Wood species /11/

The strength properties of the paper are totally different depending on the used wood species, the pulping method and the treatment done to the fibres. The face and the backing papers of self adhesive laminates are produced totally of chemical pulp (some exceptions) and therefore they are called wood-free papers. Depending on the end uses of the paper both hardwood and softwood chemical pulps are used to produce the self adhesive label stock products. The harvesting time of the wood have an effect on fibre properties and therefore on the strength properties. Most commonly used wood species in chemical pulp in Finland are pine and birch.

The relative fibre length of softwood species is normally longer than in hardwood species and therefore they are used as reinforcement pulp in many papers. Reinforcement pulp gives the paper its high tensile strength but also increases tear strength if the pulp is refined into a right level. Fracture toughness increases as fibre length increases. Refining is explained in the latter chapters. Tensile strength of the paper depends on individual fibre strength and mainly on the degree of bonding between fibres.

Birch species are called hardwood species. The fibres in hardwood species are shorter than in softwood species and therefore they have lower tear resistance and tensile strength in paper. Tear strength increases as a function of fibre length. Hardwood fibres are not used because of the strength properties, but their ability to improve the formation and giving good smoothness and optical properties for the paper. Chemical hardwood pulp improves the formation.

7.5.2 Refining

Fibres are treated in a specific ways in order to change their behaviour in paper machine but also to affect on the end products properties as wanted. **/11/**

Refining is done to improve some strength properties of the paper. Refining is done with straight plate or conical disc shape plate. Refining improves the fibrillation of fibres and the more there are fibrillated fibres, the better are the strength properties. The relative bonded area of the fibres grows significantly as the fibrillation is taking place. The higher the RBA, the higher the strength values usually are. Refining increases the relative bond area of the fibres significantly by fibrillating them. Side effect of the refining is that it is breaking fibres as it continues longer. It is important to find a certain level where refining is worth doing and then stop. **/17/, /11/**

7.5.2.1 Softwood chemical pulp /11/

Tensile strength and fracture toughness increase as function of beating even though the refining cuts the fibres.

At first the tear strength of softwood fibres increases slightly but after a while it starts to drop. Tensile strength increases as a function of beating time. The combination of wanted strength properties is a key issue.

7.5.2.2 Hardwood chemical pulp /11/

Tear strength of the hardwood fibres increase significantly at the early stage of refining but after it has reached the peak, it starts to drop fast. Hardwood pulp needs to be refined as little as possible because the long refining time has negative influence on both the brightness and the opacity levels.

7.5.3 Fillers /11/

Number of different chemicals and additives are used to produce different papers. The aim of using chemicals is to alter the natural behaviour of fibres and fillers in the stock or in the end product.

Fillers amount do not disturb the strength properties so much until the level has reached a certain amount. High filler amounts disturb the paper which is made of chemical pulp and which is refined well to achieve good bond forming between the fibrillated fibres. High filler levels always decrease the strength properties because they block fibre network and reduce potential fibre bonding area. In some cases, adding fillers might even increase the tear strength in low levels.

7.5.4 Formation

Formation is in a significant role when tensile strength is developing. Tensile strength becomes lower if the formation of the paper is getting worse. **/11/** On the other hand, formation is not having so great effect on tearing strength values. **/17/**

7.5.5 Basis weight

Higher basis weight increases both tear strength and tensile strength. The strength of paper consists of the strength of individual fibres in the paper structure, the strength of fibre bonds which is a matter of fibre properties and the degree of bonding. When the basis weight decreases, the strength properties are lower compare to heavier paper. The amount of fibres per square metre and in cross section is in lighter paper lower and thus that the strength properties decrease. Strength index is the strength level divided by the basis weight of the paper. **/17/**

7.5.6 Internal sizing and surface sizing

Surface and internal sizing improve the paper strength properties by increasing the number of hydrogen bonds. **/11/** Starch is usually used as a coating colour when wood-free papers are surface sized. Surface sizing also improves the internal strength of the paper and improves the wet strength by changing the paper more hydrophobic. The face paper of a self adhesive laminate is usually surface sized in order to improve the dimensional stability and the dry-strength. **/11/, /17/**

7.5.7 The effect of humidity on strength properties

Tear strength improves slightly as the humidity level increases. This is explained so that the energy required for the tearing is divided into a bigger area and therefore it is needed more energy to tear the specimen.

Generally speaking the strength properties decrease as the humidity or the moisture content of the environment increases (**figure 20**). **/11/**

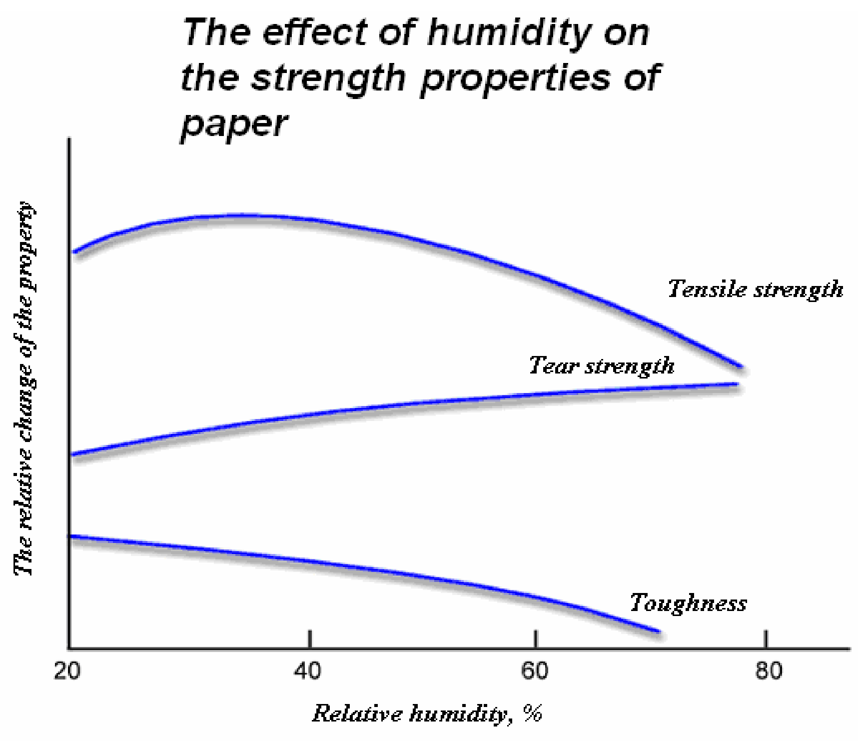


Figure 20 The effect of humidity on the paper strength properties **/17/**

7.5.8 Super calendering

The main goal for calendering is to improve the smoothness and the gloss of the paper. If the calendering is performed at enough high moisture level with a soft super calendar, the number of fibre bonds will increase and thus that the strength properties of the paper are improved. **/17/**

8 THE EXPERIMENTAL PART

8.1 Introduction of the experimental part

The aim of the experimental part was to find an operating window for the converted laminates which were produced in the pilot laminator. The operating window includes the constraints in the converting process which are affecting the converting speed.

The face papers, the siliconised release papers, the adhesives and the primer were prepared for the pilot laminator. The goal was to choose suitable raw material combinations, produce different laminates from the raw material, convert them into labels, analyse the results and to make conclusions about the runnability of the different combinations.

All the standard measurements concerning the face papers were performed in the paper laboratory of TAMK University of applied sciences. The release papers were also tested in the TAMK laboratory.

The pilot laminator runs at UPM Raflatac were divided in two different runs according to the used adhesive. Both runs consisted totally of six different laminate combinations. After the pilot runs were finished, the total amount of different self adhesive laminates to be tested with the Gallus R160 converting machine was 12.

In order to perform the test trials with the Gallus R160, the laminate rolls had to be cut into suitable widths and lengths. With two different flexible dies, the amount of test points reached totally 24.

The release measurements were performed for the samples taken from the trial rolls before the testing started in the Gallus R160 converting machine.

8.2 Paper sampling

Conditioning of the samples was performed according to the ***EN 20187:2005*** standard. The humidity and the temperature of the laboratory were at an acceptable level during the whole measuring period. The samples were appointed as seen in the **table 1**.

Table 1 The abbreviations which were used in the laminate combinations

Part	Code
Face paper 1	**RL**
Face paper 2	**RC**
Face paper 3	**RB**
Primerised face paper 1	**RLp**
Primerised face paper 2	**RCp**
Primerised face paper 3	**RBp**
Release paper with silicone 1	**Rmod0**
Release paper with silicone 2	**Rmod20**
Adhesive 1	**Rp**
Adhesive 2	**RR**

9 PRODUCING OF THE SELF ADHESIVE LAMINATES AT THE PILOT LAMINATOR

Lamination was performed with the pilot laminator similar as in the chapter 2 (**figure 3**)**.** The principal of the lamination process was almost the same as in the **figure 3**, even though the machine itself is a lot smaller than the production scale laminators. The biggest differences are in the adhesive coating stations, where in the pilot laminator it is an air brush.

The lamination speed was kept at a constant level which was 30 m/min. The production time of one 1000 metres Gallus trial roll with the constant speed took about half an hour.

The adhesive amount applied on the release paper was adjusted according to specifications given by the UPM Raflatac adhesive amount specification (**table 2**). The amount of adhesive per one square meter was adjusted into a level of 18-19 g with fluctuation of 2 grams.

Table 2 The target adhesive amount per one square meter of laminate **/9/**

	g/m²	**fluctuation, g/m²**
RP	19	+/- 2
RR	18	+/- 2

After the lamination, each produced pilot roll was named and stored in a plastic pack in order to prevent the changes in the moisture content of the roll. The rolls were stored in a place where the temperature changes were minimal. The rolls were kept in the plastic packs until the slitter winding stage. After the rolls were cut into suitable widths and lengths, they were packed again.

Lamination was divided into two different runs according to the used adhesive. First run was performed with the adhesive number 1 (**RP**) and the second run with the adhesive number 2 (**RR**) (see **table 3** and **table 4**).

The target length of each laminate roll was 1000 m. The initial widths of the laminate rolls produced by the pilot machine were 510 millimetres but the usable width of the mother roll was about 450 mm which was enough for three Gallus rolls (135 mm +135 mm +155 mm).

9.1 The laminate combinations in the first pilot laminator run

First run consisted of six different laminates which can be seen in the **table 3**. The combinations for the first pilot run were made of three different face papers (**RL, RC, RB**), one release paper with two different silicones (**Rmod0** and **Rmod20**) and adhesive **RP**.

Table 3 The six laminate combinations in the first laminator run

Combination	RL-RP-Rmod0	RC-RP-Rmod0	RB-RP-Rmod0
Face paper	RL	RC	RB
Adhesive	RP	RP	RP
Silicone	Rmod0	Rmod0	Rmod0
Release paper	R	R	R

Combination	RB-RP-Rmod20	RC-RP-Rmod20	RL-RP-Rmod20
Face paper	RB	RC	RL
Adhesive	RP	RP	RP
Silicone	Rmod20	Rmod20	Rmod20
Release paper	R	R	R

9.2 The laminate combinations in the second pilot laminator run

The pilot laminator runs differed from each others by the used adhesive. The face papers in the second run also needed to be primerised due to the nature of the adhesive RR.

The primer treatment of the face papers in the second pilot laminator run was performed offline before the actual lamination run. Primerising needed to be done in order to achieve enough good adhesion between the removable adhesive RR and the face paper and in order to prevent the adhesive from penetrating through the face paper. Second run laminate combinations are listed in the **table 4.**

Table 4 The six laminate combinations in the second laminator run

Combination	RLp-RR-Rmod20	RCp-RR-Rmod20	RBp-RR-Rmod20
Face paper	RLp	RCp	RBp
Adhesive	RR	RR	RR
Silicone	Rmod20	Rmod20	Rmod20
Release paper	R	R	R

Combination	RBp-RR-Rmod0	RCp-RR-Rmod0	RLp-RR-Rmod0
Face paper	RBp	RCp	RLp
Adhesive	RR	RR	RR
Silicone	Rmod0	Rmod0	Rmod0
Release paper	R	R	R

10 METHODS FOR MEASURING THE PROPERTIES OF THE PAPERS AND THE LAMINATES

The measurements were divided into two categories which are standard measurements and special measurements. Basis weight, thickness, tensile strength, fracture toughness and tearing resistance tests are explained under the standard measurements title

10.1 Standard measurements

10.1.1 Denver instruments scale

The scale is manufactured by Denver Instruments.

10.1.2 Thickness meter

The thickness meter is manufactured by Compac Geneve and the type of the meter is 523 G.

10.1.3 Tensile and fracture toughness tester

The tester (**figure 23**) is manufactured by Lorentzen & Wettre (L&W). It is capable of testing both the tensile strength and the fracture toughness at the same time.

Figure 21 L&W tensile strength and fracture toughness meter

10.1.4 Tearing resistance meter

The pendulum tearing resistance tester is manufactured by L&W. The tester is Elmendorf pendulum type. **/8/**

10.2 Special measurements

10.2.1 Instron low and high speed release meters

High and low speed meters are meant for measuring the release value i.e. the force needed to separate the face paper and the release paper from each others in an angle of 180°. Because the release value is not constant, the value must be measured at different speeds.

10.2.2 Low speed release meter

Low speed release meter is working at a 300 mm/min (0.3 m/min) speed (**figure 22**)

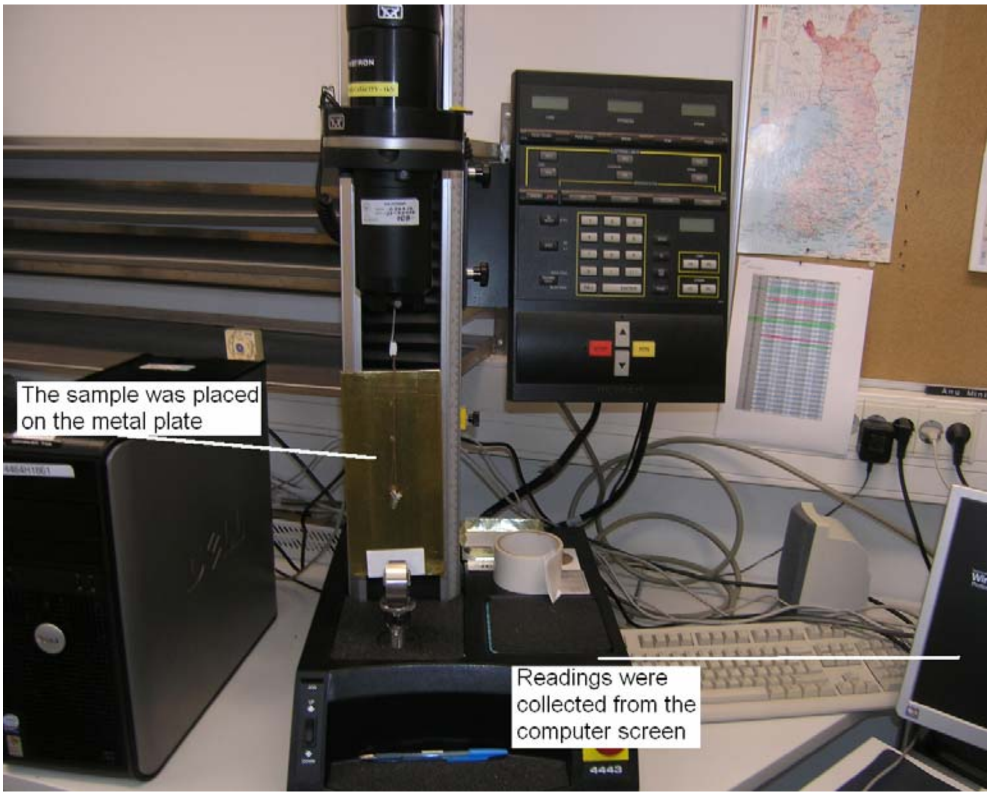


Figure 22 A low speed release meter

The paper sample for the test is prepared 50 mm wide and 300 mm long (see **figure 23**). A small fold was made into the face paper where the drawing device was attached. The sample was placed onto the metal plate which had an adhesive layer and the folded face paper is then attached to the meter. The test began as the meter started to pull the face paper sample upwards. The speed of the meter is constant and the computer program registered the release force. The results were then collected and another sample was the placed on the metal plate. The results were divided by two (50 mm wide sample) to get comparable results with the high speed release measurements.

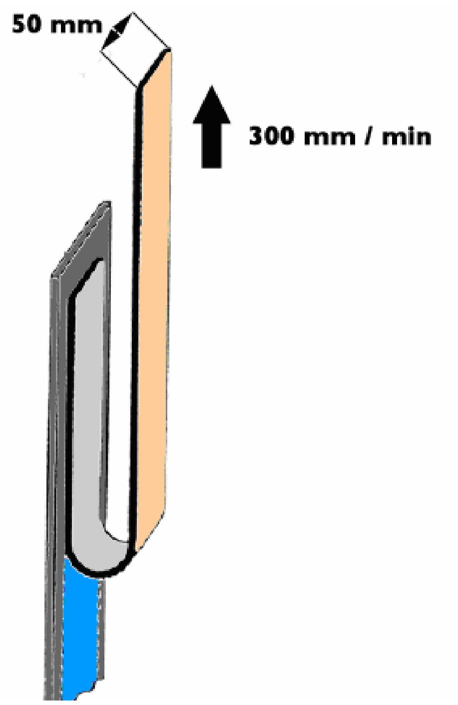


Figure 23 The performance of the low speed release test

10.2.3 High speed release meter

The high speed release meter (**figure 24)** is suitable for measuring release values closer to the converting speeds of the self adhesive laminates.

The laminates were cut to 25 mm wide and at least 250 mm long in order to perform the test. After the laminate sample was prepared, a small fold was made onto the face paper of the laminate. The release paper and a narrow strip of an aid paper were attached together by a tape. The folded face paper was attached to the left end of the meter and the aid paper strip to the right end (**figure 24**). As the machine started, the release paper and the face paper were separated with a constant speed e.g. 100 m/min and the release force values were given as a function of time by the computer program.

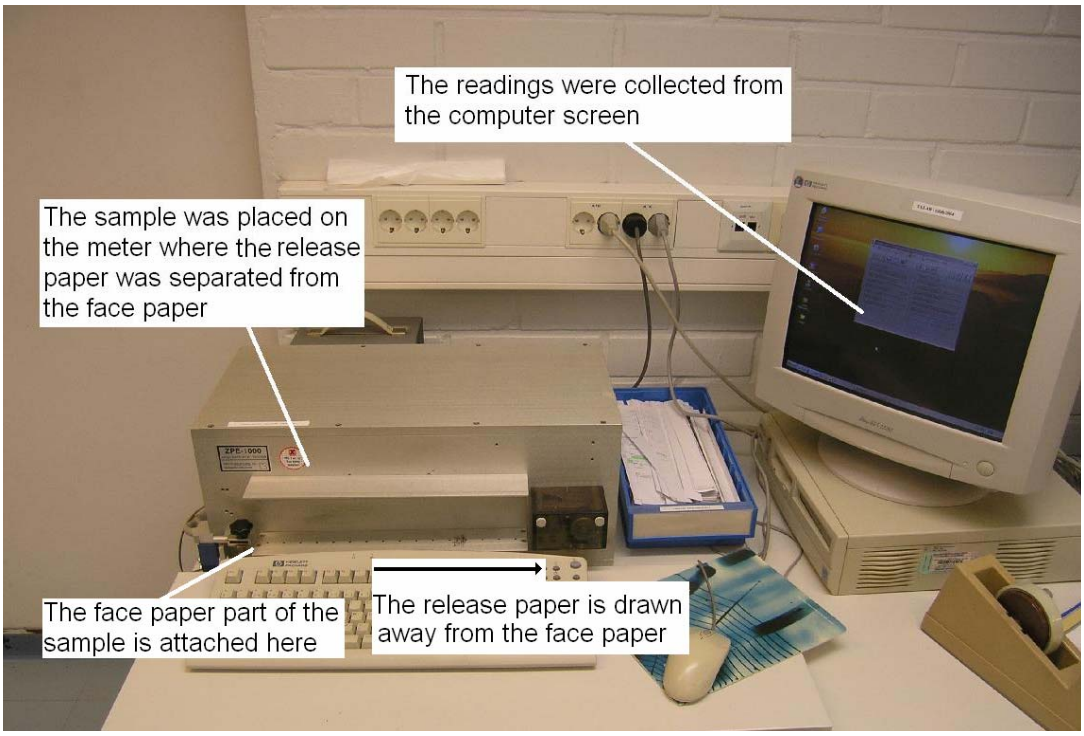


Figure 24 The high speed release meter

10.3 High speed video camera

Citius imaging C10 high speed video camera was used in the experimental part of the work. High speed video camera is capable of taking 500 frames per second which is extremely useful when examining the breaks of the waste matrix in high speeds. **/1/**

10.4 Gallus R160 converting machine

Gallus R160 is the converting machine where the experimental die cutting and the waste matrix removing tests were performed. Gallus R160 (**figure 25**) consists of unwinding unit, one dancing i.e. web tension control roller, rotational die cutting unit, waste matrix removing unit, control panel and rewinding unit. Despite the fact that Gallus has a rotating die cutting unit, it still has an additional dancer roll. **/2/**

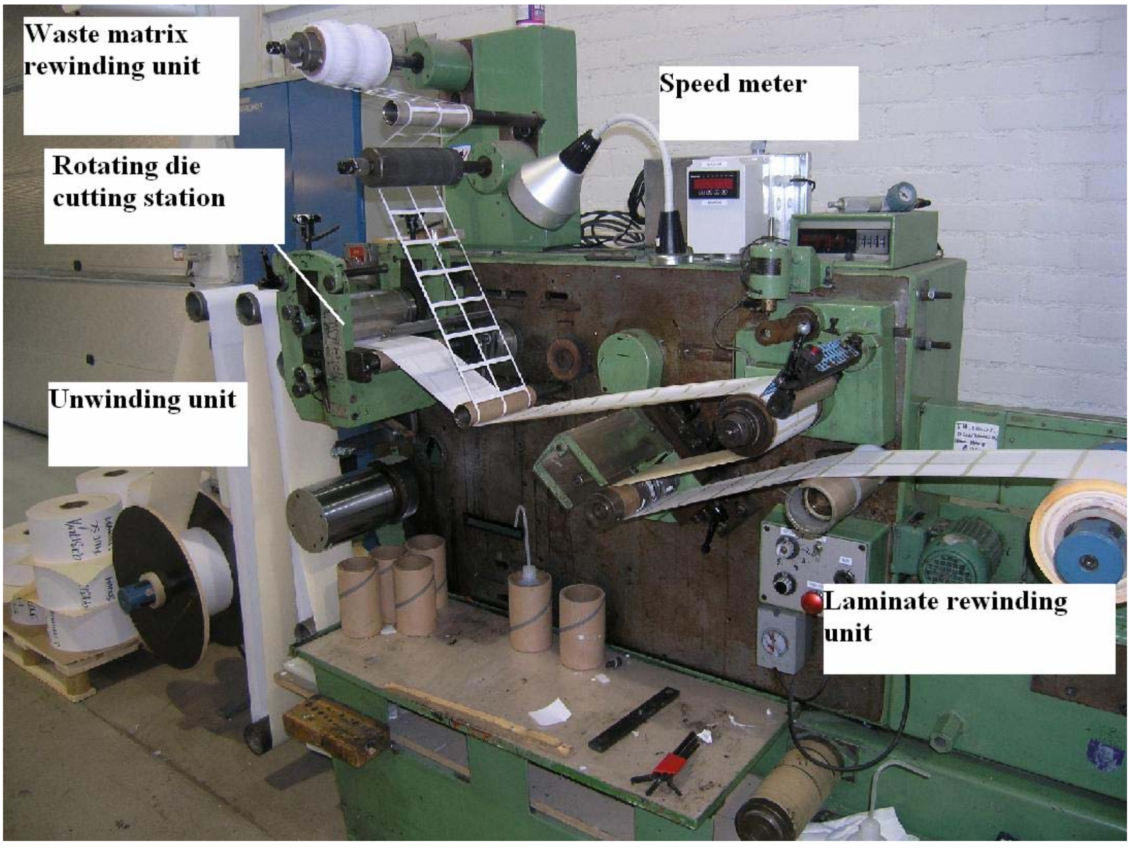


Figure 25 The Gallus R160 converting machine

The laminate roll was placed at the unwinding unit on the left side of the **figure 25**. After the web tension controlling rollers, the laminate goes through the die cutting station. Laminate is die cut and right after the cutting unit, the waste matrix is removed from the release liner. The waste matrix is rewound to its own rewinding unit and the ready laminate with the labels on is rewound to the laminate rewinding unit. Speed meter was showing the speed of the converting machine.

10.4.1 Technical details /2/

The length of Gallus R160 is 2750 mm and the width 900 mm. The maximum web width that can be run in the machine is 180 mm. The maximum working speed is about 160 m/min.

10.4.2 Flexible dies

There were two different die cutting forms chosen for the Gallus R160 test trial stage. First of all, to be able to compare different waste matrices, two different flexible die forms were used in the test. The laminates which were cut with these dies had different strength and structural characteristics.

10.4.3 The 135 mm flexible die

Each Gallus run consisted of rolls with two different web widths. The width of the narrow Gallus roll was cut to the width of 135 mm. This die was chosen in order to get 5 mm wide strips for the edges (**figure 26**). The width of the centre stripe was in this case 5 mm and the width of the cross directional stripes were 4.5 mm.

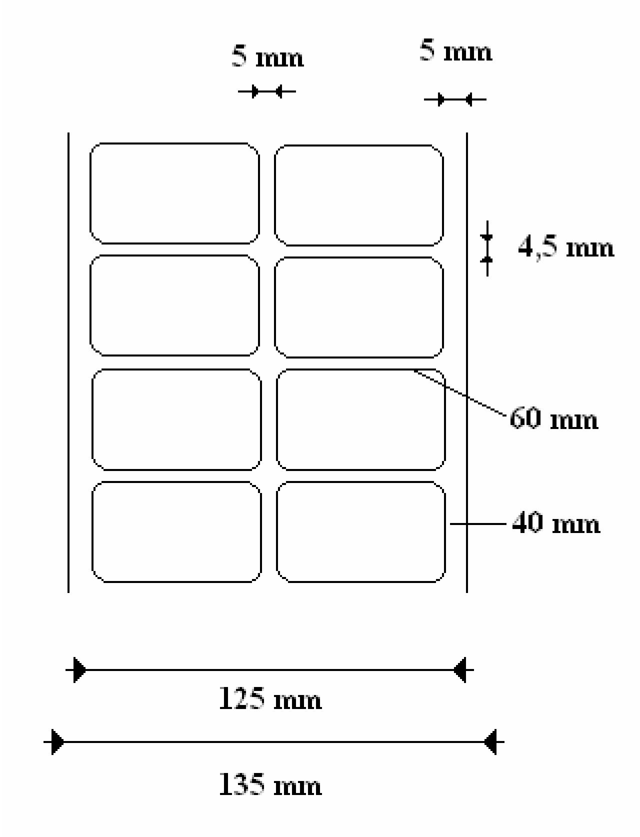


Figure 26 The dimensioning of the laminate cut with the 135 mm wide flexible die in the Gallus R160

10.4.4 The 155 mm flexible die

The total width of the wider web was cut earlier to the width of 155 mm to achieve right dimensions for the narrow strip i.e. the edges of the matrix after the die cutting. With the flexible die 2, the edges of the matrix were dimensioned into 5.0 mm (see **figure 27**). The width of the centre MD stripe of the matrix was 5 mm and the width of the cross directional stripes were 7 mm.

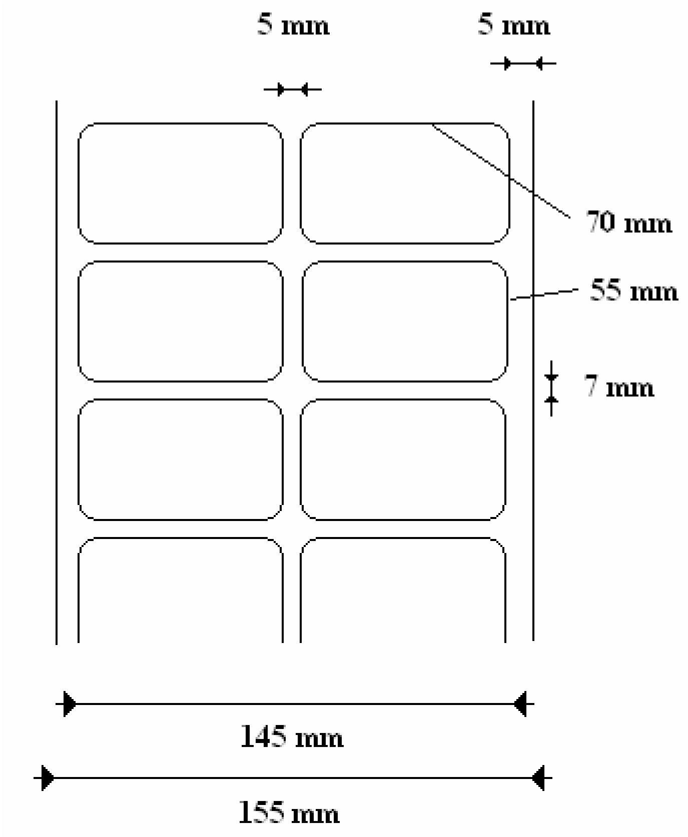


Figure 27 The dimensioning of the laminate cut with the 155 mm wide flexible die in the Gallus R160

11 MEASUREMENTS, RESULTS AND ANALYSING

11.1 Basis weight measurement

The basis weight measurements were performed according to the **EN ISO 536:1996** standard. The number of samples in the basis weight measurement was 20 where the dimensions of one sample were 100 mm* 100 mm. The results are seen in the **appendix 1**.

11.1.1 Basis weight values of the face paper samples

Based on the measured values, the basis weight of the RL is an average of 20 individual measurements.

Table 5 The basis weights of non-primerised and primerised face papers

[g/m^2]	Basis weight	Stdev of basis weight
RL	59.4	0.45
RC	76.0	0.44
RB	85.0	0.75
RLp	63.4	0.41
RCp	80.3	0.67
RBp	87.7	0.84

The results are easier to examine when drawn into a pile diagram (**figure 28**). The basis weights of the face papers are arranged from the lightest face paper on the left towards the heaviest on the right.

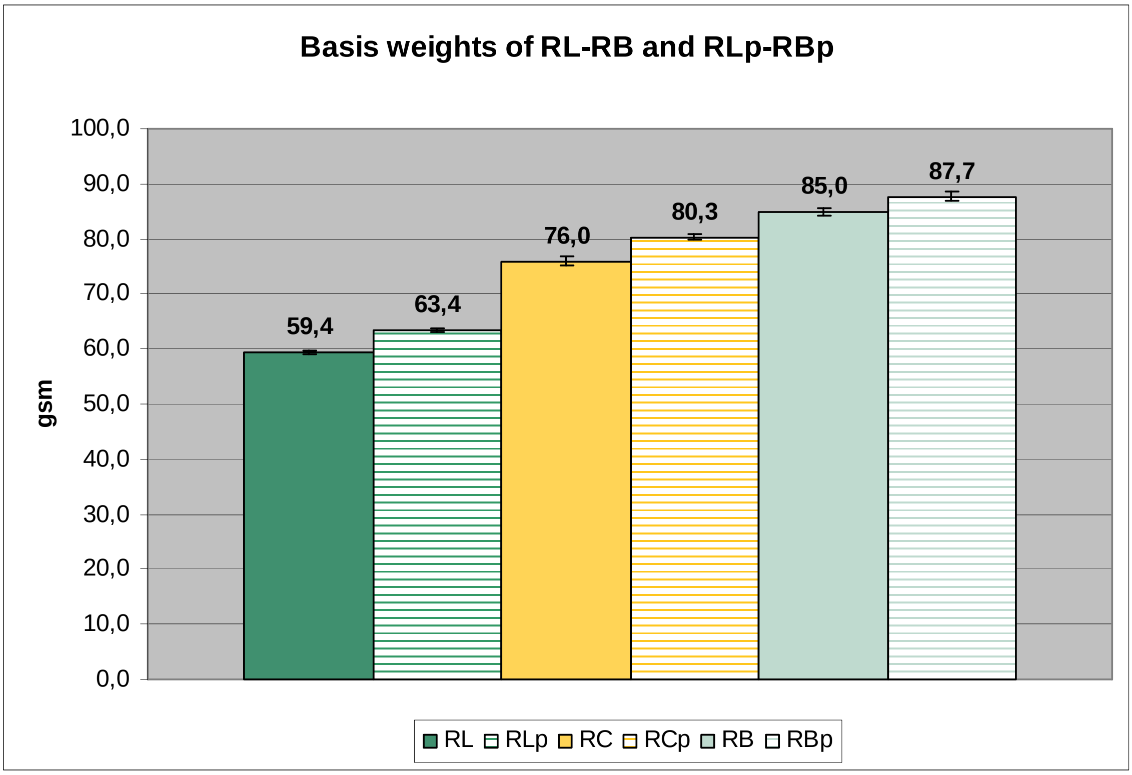


Figure 28 Basis weights before (RL-RB) and after (RLp-RBp) the primer treatment with standard deviations

Logically the primer treatment increased the basis weight values of the face papers (**figure 28**, every second pile). The sample RL gained weight 4.0 grams, the RC sample 4.2 grams and the heaviest sample RB gained 2.7 grams during the primer treatment. The differences in the gained weights can be explained by the surface properties of the face papers and the fluctuations in the application of the primer. If the surface is tight and closed, the primer will not penetrate so deep in the paper structure. Thick and porous structure will more easily absorb higher primer amount. Most likely the differences in the primer amounts are caused by the fluctuations in the primer coating station.

11.1.2 Basis weight values of release papers

The silicone treatment was performed in the UPM Raflatac facilities with an online siliconising machine. The basis weights of the release papers were expected to be almost the same after the silicone treatments.

Table 6 Basis weight values of Rmod0 and Rmod20

[g/m^2]	Basis weight	Stdev of basis weight
Rmod0	58.6	0.34
Rmod20	59.9	0.45

The basis weight difference between the two release papers (**table 6**) was 1.3 grams which is more than what was expected. The modifier amount is quite small in the Rmod20 and the standard deviation of the samples was quite small so the fluctuations in the basis weights are more likely to be caused by the production of the release paper and the errors in the basis weight measurement such as improper cutting of the samples.

11.2 Thickness

The amount of measurements per each face and release paper was kept in 20 in order to have reliable results. The dimensions of a one sample were 100 mm* 100 mm. The results of the thickness measurements are shown in the **table 7**. The unit of each measurement is micrometers.

11.2.1 Thickness values of all the face paper samples

The average thickness of the RL sample is 52.9 micrometers (**table 7**). The fluctuation between the minimum and maximum thickness values of the samples was noteworthy, being as high as nine micrometers with the sample RL (see **appendix 1**). The paper thickness measurements were performed according to the **ISO 534:2005** standard.

Table 7 The thickness values of non-primerised and primerised face papers

[µm]	Thickness	Stdev of thickness
RL	52.9	2.13
RC	70.4	0.94
RB	73.6	2.14
RLp	56.5	1.93
RCp	68.5	1.15
RBp	69.3	2.07

The standard thickness deviation values were drawn into the pile diagram (**figure 29**) with the measured thickness values.

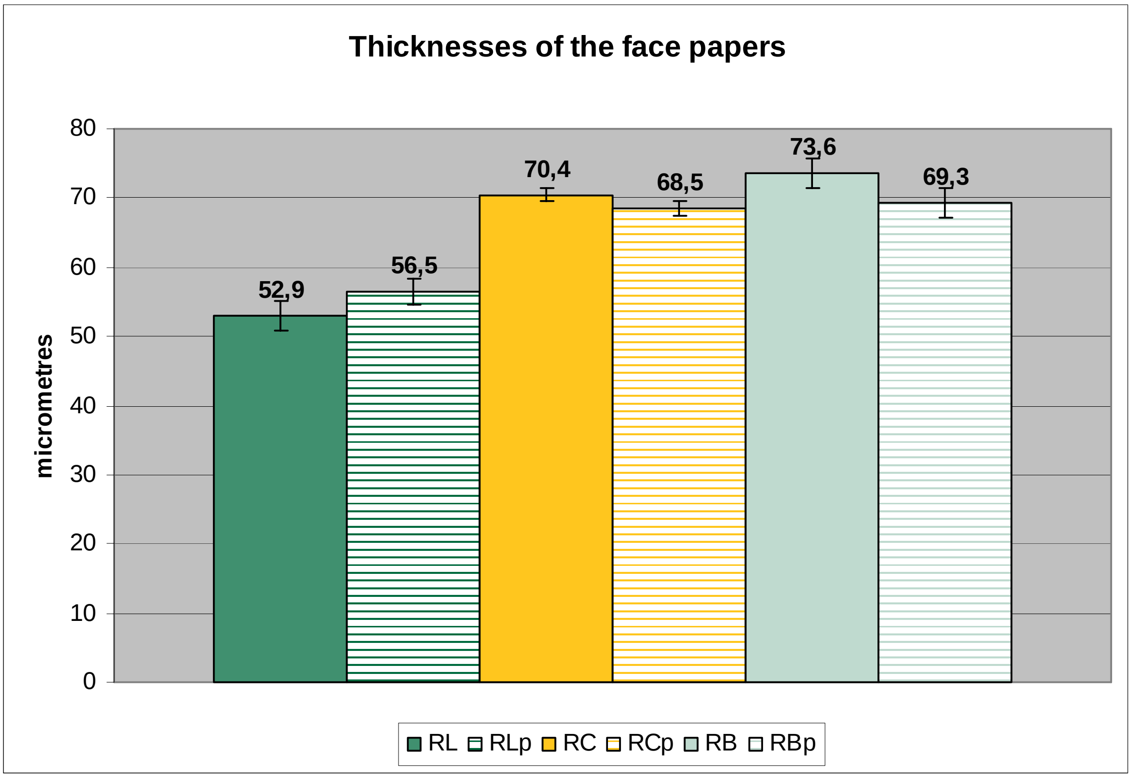


Figure 29 The thicknesses of RL-RB (before primerising) and RLp-RBp (after) with standard deviations

The primer treatment shows **(figure 29)** that the thickness of the RL increased due to the primerising 3.6 µm. The standard deviation is worth noticing when comparing the differences after the primer treatment. When observing the standard deviation values, it is seen that the differences between the non-primerised face papers and the primerised face papers are not as obvious as they are in the pile diagram. The fluctuation between the samples is relatively high which is most likely to be caused by the nature of the elastic primer and the fluctuation in the primer amount on the paper. The thickness value of the thinnest paper in the test seemed to be increasing and the thickness values of the RC and RB samples are showing indications of decreasing.

11.2.2 Thickness values of release paper samples

Release papers were tested after they were siliconised in the UPM Raflatac facilities. The results of the measurements are listed in the **table 8**.

Table 8 The thickness values and the standard deviations of the release papers Rmod0 and Rmod20

[µm]	Thickness	Stdev of thickness
Rmod0	54.1	2.61
Rmod20	52.1	2.20

The standard deviations of the release paper samples are big even though the amount of tested samples reached 20 per release paper sample.

11.3 Strength measurements of the face and release papers

In order to perform the strength measurements, the basis weights of the face paper samples had to be calculated beforehand. The sampling of the face papers was done in the conditioning room.

11.3.1 Tensile strength and fracture toughness of the face papers

The program was adjusted to measure both the tensile strength and the fracture toughness tests at the same time according to the **SCAN P67/P77** standard.

As expected, the strength values are following the basis weights values of the face papers (**figure 30**). The differences between the RC and RB samples were not so high even though the basis weight difference was as high as nine grams.

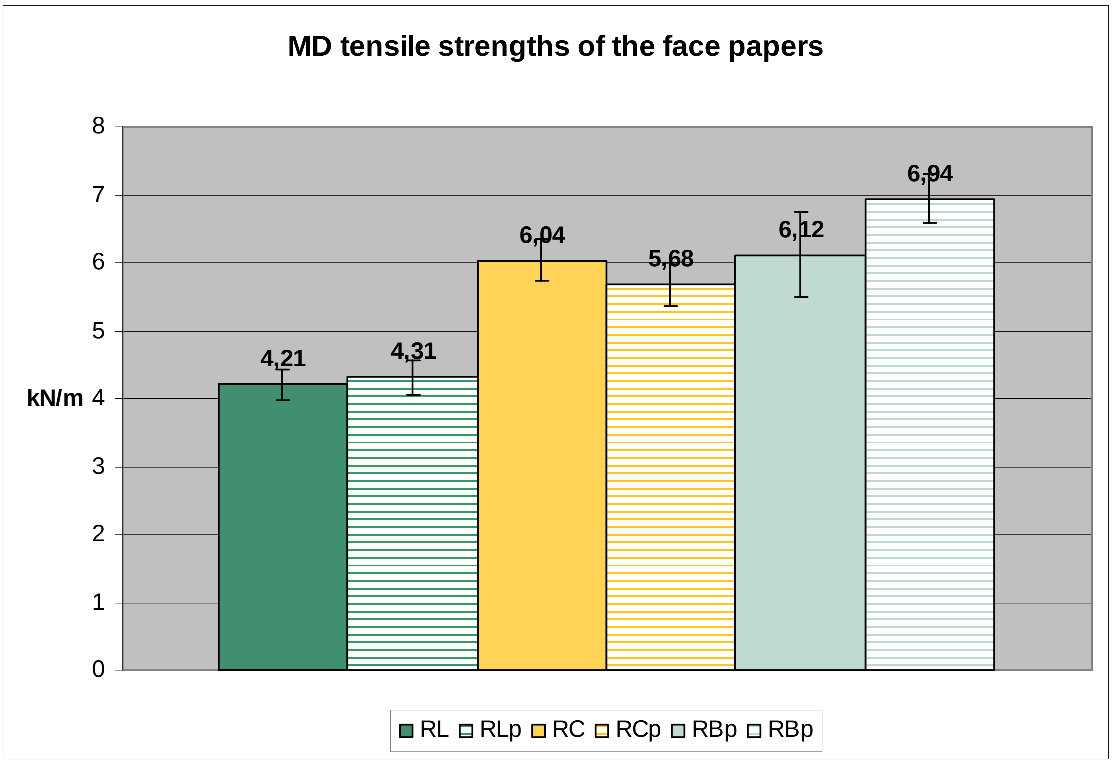


Figure 30 MD tensile strengths of the face papers before (RL, RC, RB) and after RLp, RCp, RBp) the primer treatment

The effect of the primer treatment caused for the face papers is seen in the **figure 30**. Every second pile from the left is the face paper after the primer treatment. The figure shows that primer treatment might be increasing the tensile strength of the face papers slightly but no exact conclusions can be made due to the small data amount and the high standard deviation values. The RC samples are almost having the same strength values as the RB samples but after the primer treatment the differences are higher.

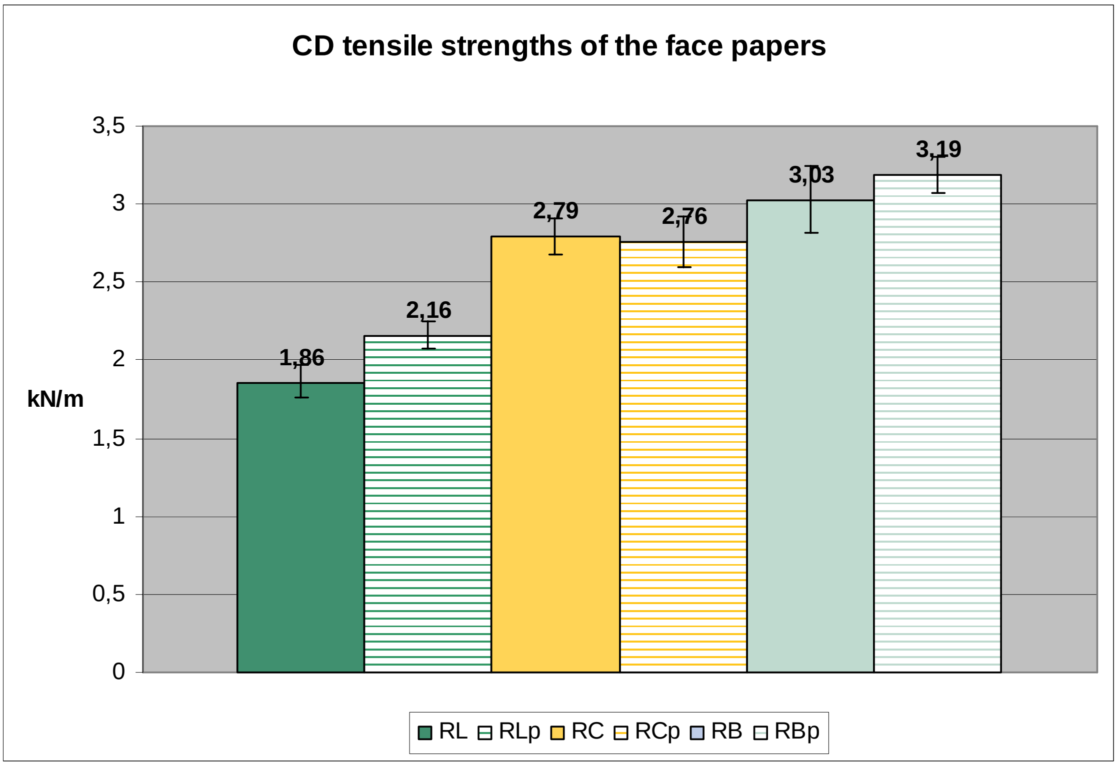


Figure 31 CD tensile strengths of the face papers

The same trend what was shown in the MD tensile strength values is showing also in the CD tensile strength values in the **figure 31**. The primer treatment shows small growth in the tensile strength values but the differences are relatively small in order to make any exact conclusions. In both cases, in the **figure 30** and in the **figure 31**, the primer treatment has decreased the tensile strength level of the RC face paper.

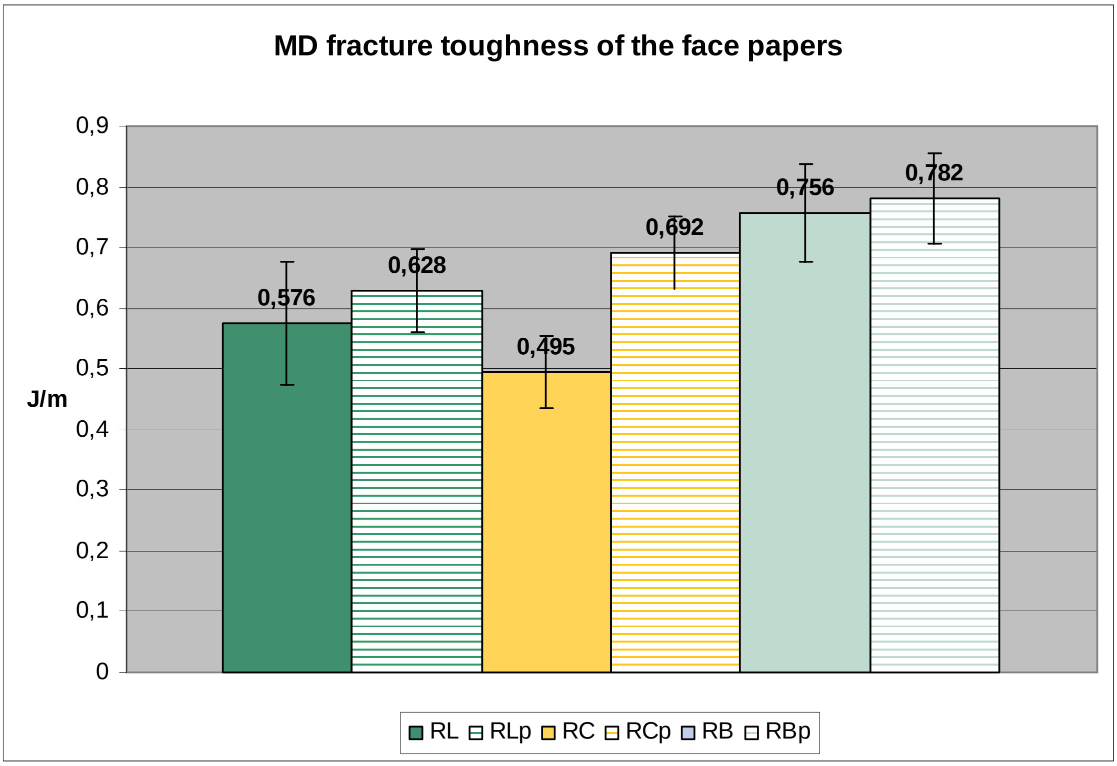


Figure 32 Fracture toughness in the machine direction before (RL, RC, RB) and after (RLp, RCp, RBp) the primer treatment of the face papers

The MD fracture toughness values are showing small increasing after the primer treatment in every face paper but the changes are so small that they only give an indication how the primer treatment might alter the values (**figure 32**). The standard deviation is relatively high and the results are therefore more difficult to analyse. The drop in the fracture toughness value of the RC sample is significant compared to the RL and the RB. The standard deviations in the test were at a high level (c. 10-20 %, see **appendix 3**) which for its part questions the reliability of the results.

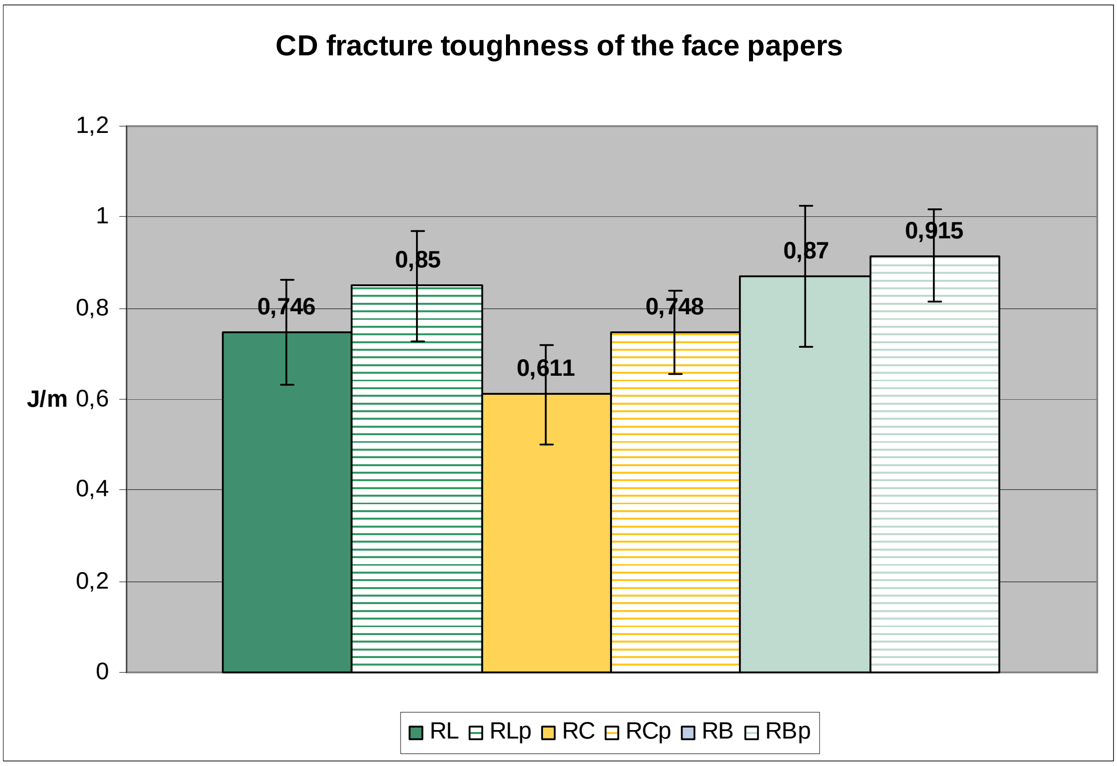


Figure 33 Fracture toughness in the cross direction of the face papers

The CD fracture measurements (**figure 33**) are showing unexpected results as they were showing also in the **figure 32**. The CD and MD fracture toughness levels of the RC and RCp samples are clearly at a lower level than they are in the samples RC/RCp and RB/RBp. It was notable that all the CD fracture toughness values are increased after the primer treatment. Yet the standard deviations are at quite a high level. MD fracture toughness values in general were showing indications of increased strength values after the primer treatment already in the **figure 32**.

11.4 Tearing resistance values of the face papers

The measurements were performed according to the **ISO 1974** standard. Total 40 samples were prepared for the MD and 40 for the CD direction. The standard deviation was calculated by the program of the meter. The average tearing resistance value i.e. the mean value of the RL is 292 milliNewtons. Standard deviation with the same RL samples was 29 mN. The maximum and minimum tearing resistance values are shown in the **appendix 3**.

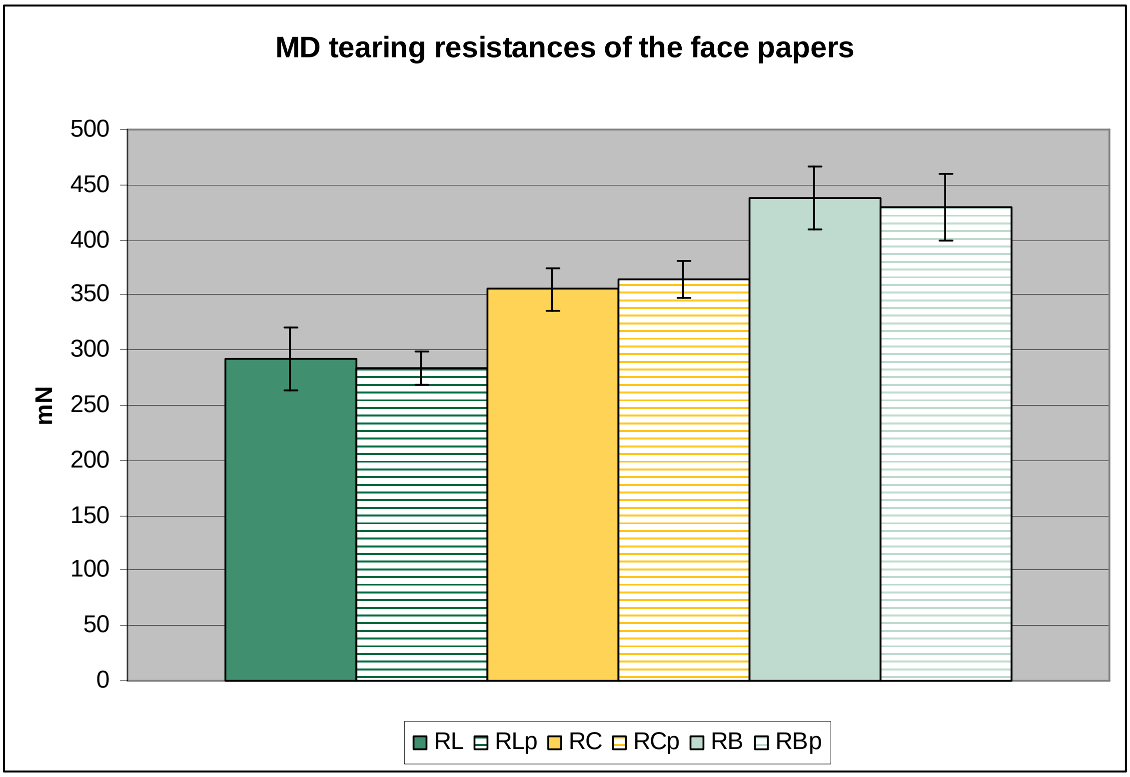


Figure 34 The tearing resistance of the face papers in machine direction

Tearing resistance is acting as expected as a function of the basis weight (**figure 34**). The papers with higher basis weight are having higher tearing resistance values. Noteworthy is that the difference between the RL and RLp compared to RC and RCp are not so significant even though the basis weight difference is as high as 16.6 grams. The primer treatment is showing small decreasing concerning the tearing resistance values even thou the RC sample seems to have higher tearing resistance value after the treatment.

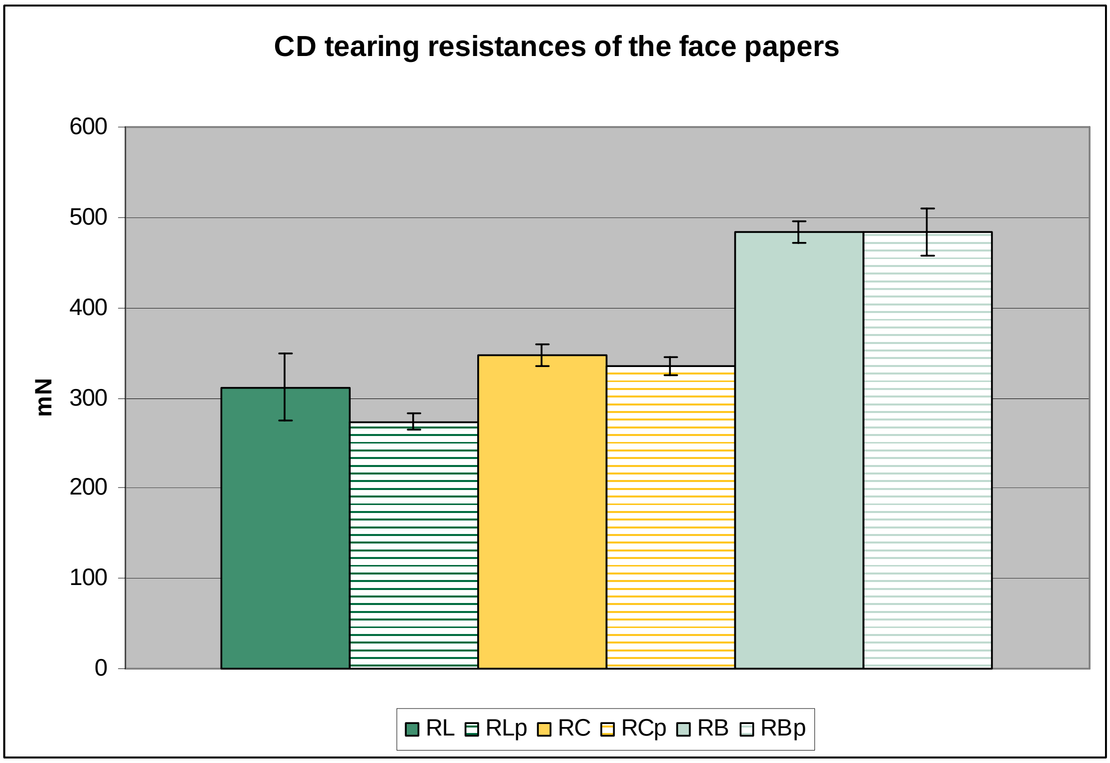


Figure 35 The tearing resistances of the face papers in cross direction

The CD tearing resistance values are showing the same kind of results in the **figure 35** as the MD values in the **figure 34**. The tearing resistance level of the RL and RLp are relatively high compared to the RC and RCp. The tearing resistance values of the RB and RBp samples are clearly at a higher level than the other samples. The primer treatment slightly decreased the CD tearing resistance values but the standard deviation is still too high in order to make any exact conclusions.

11.5 Release measurements

Both the low speed and the high speed release measurements were performed for each laminate. The tested samples of the laminates were taken right before the test run at Gallus R160.

11.5.1 Low speed release measurements (LSR)

The used standard was **FINAT test method number 3 2001** (FTM3; 2001) which is meant for the low speed release testing.

There were two samples taken from each Gallus test trial roll (if possible) and the average of the low speed release value was calculated. The data was edited so that the first two seconds of the data was not included into the result.

11.5.2 The low speed release measurements after the first pilot laminator run (LSR)

As seen in the **figure 36** the data is collected as a function of time. The data was sent in the computer program where the average values were collected and edited further on.

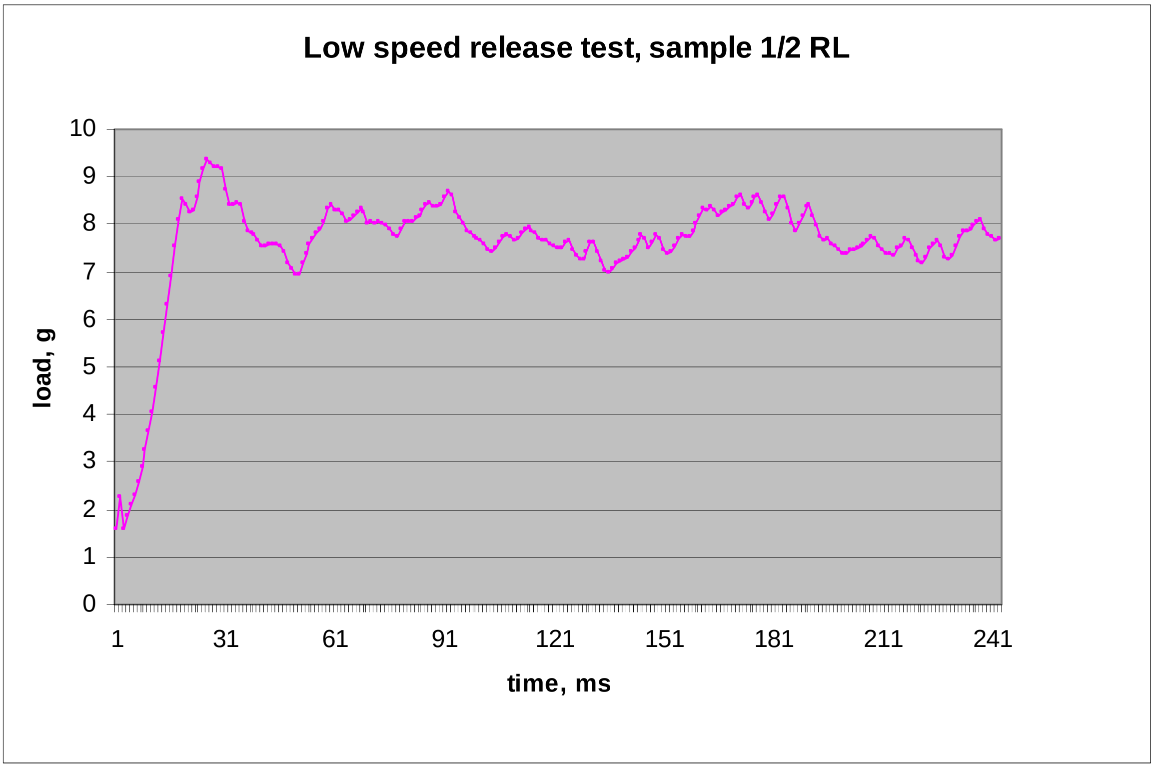


Figure 36 One example of the collected data from the LSR measurement

The used 50 mm wide samples are twice as wide as the samples used in the high speed release measurements. The values of the LSR results are divided by two in order to compare the results (see **appendix 6**). Because the low speed release measurement only gives one result, the results were combined with the high speed release measurements into a larger compilation in the data analysing part in the **figure 40** and **figure 41**.

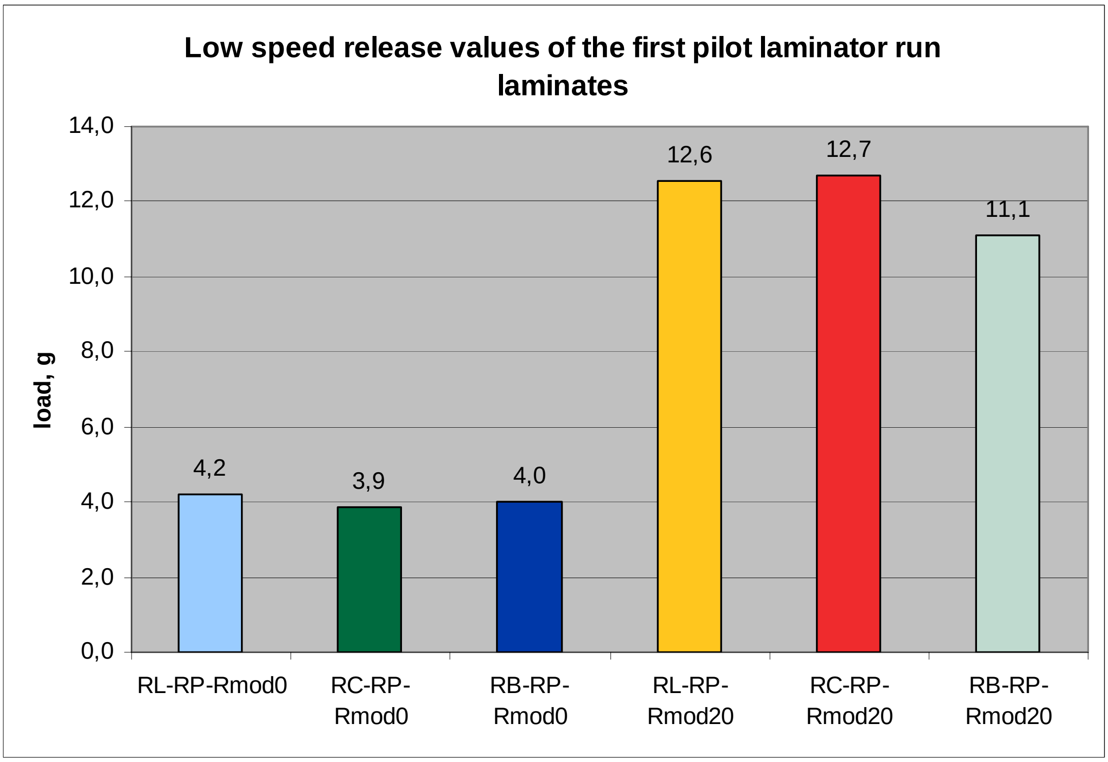


Figure 37 The low speed release values of the first pilot run laminate combinations

The difference between the laminates without modifier (**figure 37,** first three from the left) and the laminates with 20 % modifier amount is clearly seen. The modifier amount in the silicone alters the release value. The lower the modifier amount in the silicone, the lower is the release value. The release value is almost three times lower between the laminates with and laminates without modifier in the silicone.

11.5.3 Second pilot run low speed release measurements (LSR)

The second Gallus R160 test run started poorly. The laminates did not work as planned in the waste matrix removing stage. The RR adhesive seemed to be the reason for the bad waste matrix removing and it was decided to lower the temperature of the laminates. The cooling treatment was supposed to alter the nature of the aggressive adhesive into neutral direction and thus that to improve the waste matrix removing. Both low speed release measurements (before and after the cooling treatment) are collected in the **figure 38**. High speed release measurements were performed for the second pilot run laminates only before the cooling treatment.

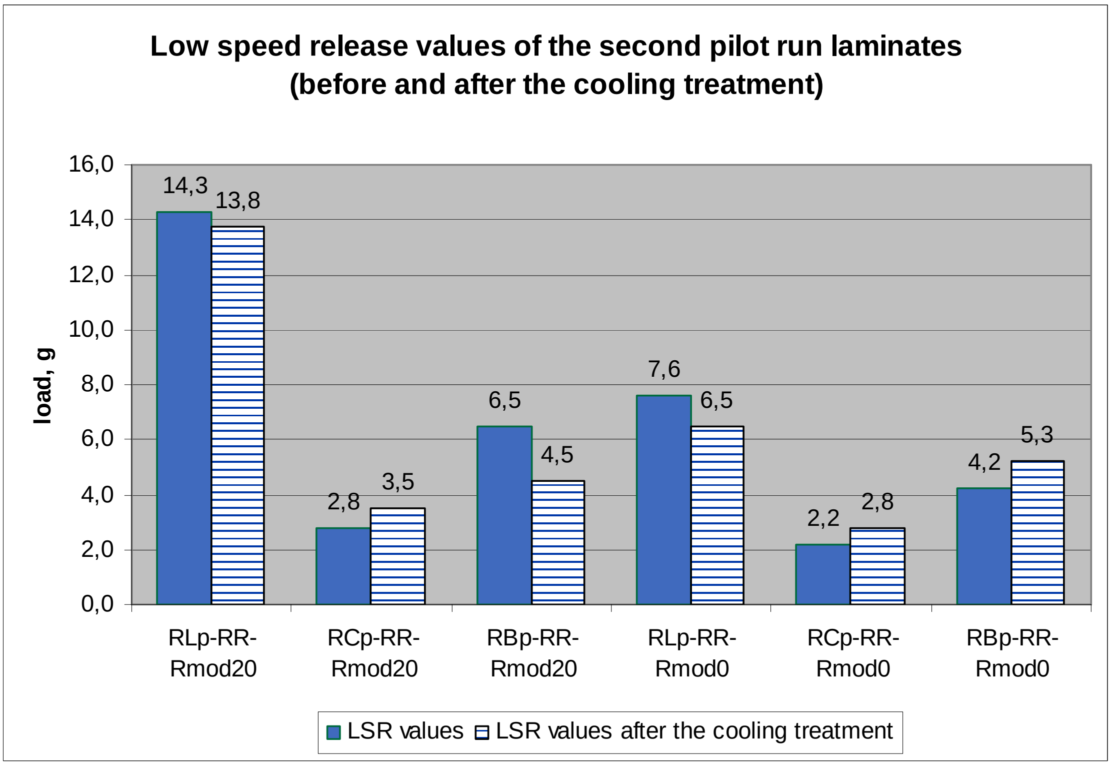


Figure 38 Low speed release measurements before (left pile) and after (right pile) the cooling treatment

The differences in the release values between the same laminates before and after the cooling treatment in the **figure 38** are not big. What was expected did not happen. The values changed but not as much as what would be needed in order to make any reliable conclusions. The differences can not be explained according to the used modifier either because the values are scattered. The release levels should depend on the combination of the silicone and the adhesive. The analysing is easier to make if the samples are ordered again. Therefore the samples are arranged according to the basis weight of the face papers (**figure 39**).

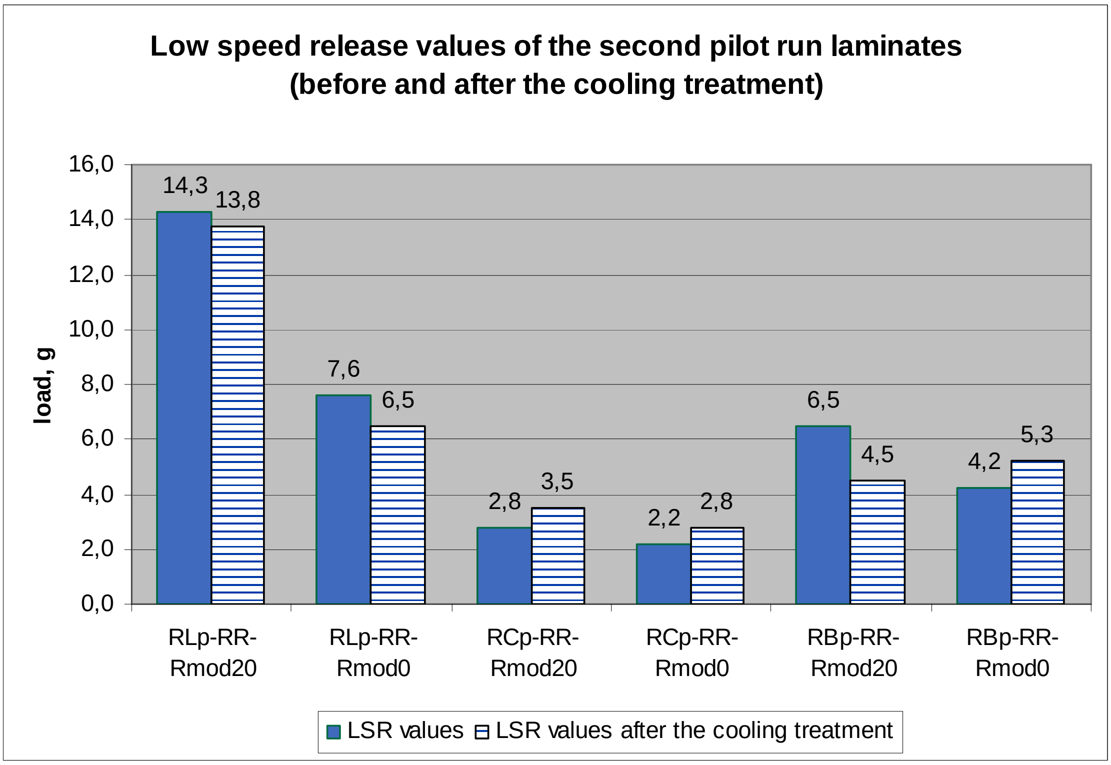


Figure 39 LSR measurements before and after the cooling treatment arranged by the basis weight of the face papers

The samples are arranged according to the face paper and the used modifier in order to make some conclusions. Even though the meaning of the face paper should not be in a great role, some analysis can be made according to the **figure 39.** The release value is little bit higher if the silicone is treated by the modifier i.e. the Rmod20 (see **table 3,** the laminate combinations). Clearly the highest low speed release values were gotten with the laminates with the lightest face papers. Surprisingly the RC and RCp samples had the lowest release values while they had the highest in the first run laminates. The fluctuations between the samples are caused by the differences between the paper samples and the fluctuations in the primer treatment and amount.

11.6 High speed release measurements (HSR)

The used standard in the test was **FINAT test method number 4 2001** (FTM4; 2001). There were four different speeds used in the test which were 10 m/min, 30 m/min, 100 m/min and 150 m/min. The program of the device calculated the average values of each individual test after the measuring area was edited. The editing part includes setting the limits for the measured time. The test was performed twice for each test point meaning that the total number of test points reached 48.

11.6.1 First laminator run high speed release measurements (HSR)

The release values of the first run were collected and drawn into graphs. Release profiles (**figure 40**) were simple to create and they are showing how the release values are acting as a function of speed in each laminate.

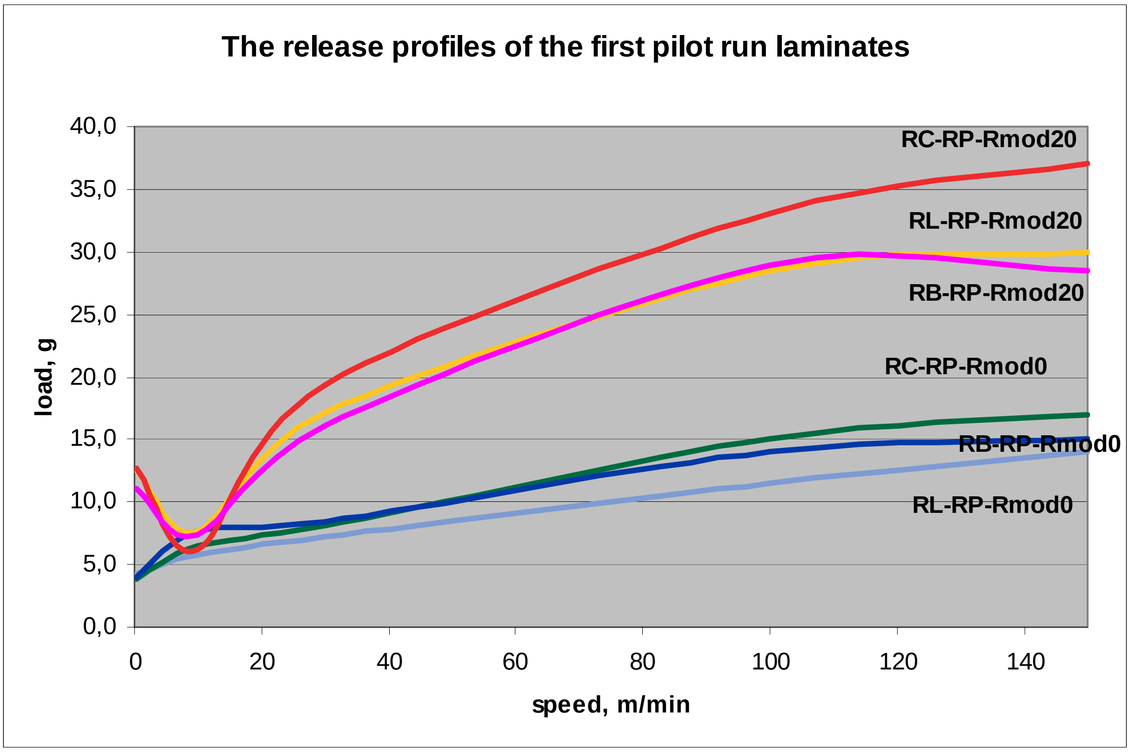


Figure 40 The release profiles of the first run laminates

The release profiles are acting logically as a function of the speed. The release value increases as the converting speed or the testing speed is increased. The difference between the modifier amounts is easily seen in the **figure 40** as they were already in the low speed release measurements. The laminate samples (RL-RP-Rmod0, RC-RP-Rmod0 and RB-RP-Rmod0) which have no modifier in the silicone have lower release values in every speed. The drop in the release values at the speed level of 10 m/min is more likely to be caused by the errors in the test. Errors in the test happened if the sample was placed improperly on the meter.

11.6.2 The high speed release measurements of the second laminator run (HSR)

The release samples were taken before the Gallus R160 test run from the surface and from the bottom of the test roll.

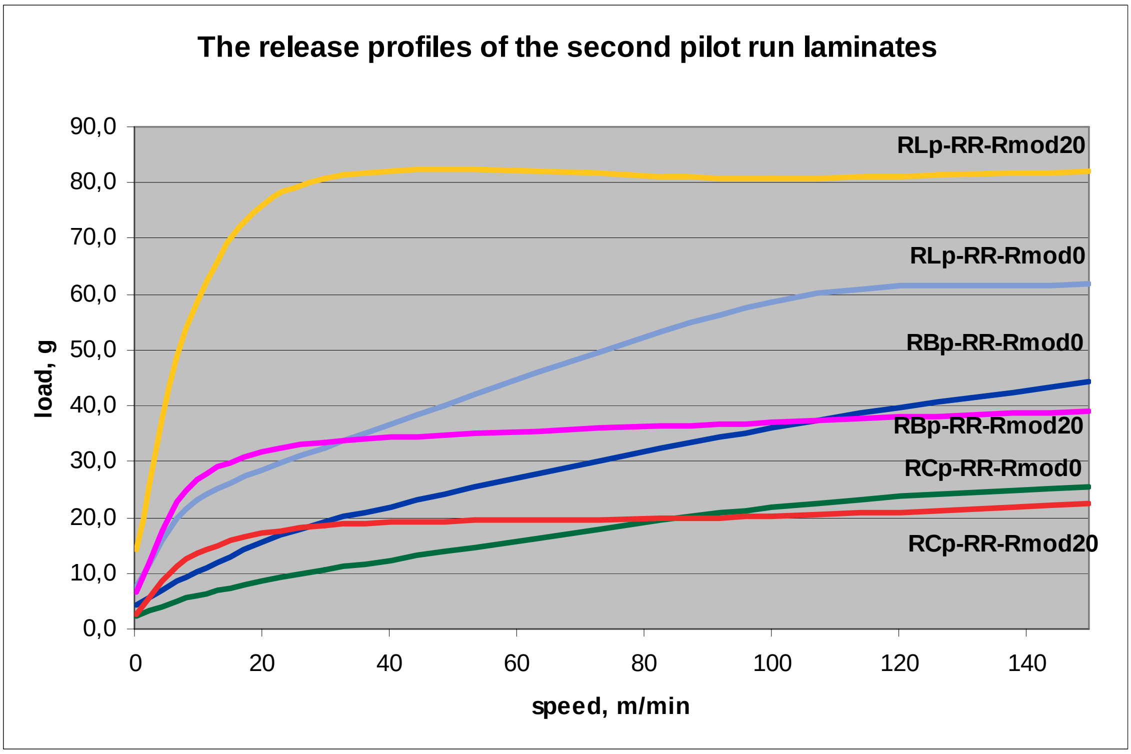


Figure 41 Release profiles of the second run laminates

The release profiles of the second pilot run laminates in the **figure 41** are acting totally different than the ones in the first run (**figure 40**). The curves in which the release values are growing strong at the beginning and after they have reached the certain level they do not grow anymore have the modifier Rmod20 in the silicone. It is seen that the results are paired according to the face paper e.g. the laminates with the face papers RL and the RLp are having greater values than the laminates with the face papers RC/RCp or RB/RBp. This was already seen in the low speed release measurements. The laminates with face papers RB and RBp are having the second highest release profile values. It is also seen in the **figure 41** that the release values got with the silicone with modifier Rmod0 are growing rapidly at low speeds and after they reach a certain level they do not change so much even though the speed is increasing. The release values with the Rmod20 are growing more steadily at lower speeds but after a while the values are passing the release values of the laminates with the silicone Rmod0 and the values keep on growing as the speed increases. This is probable due to the differences between the primer amounts on the face papers and the errors in the test such as improperly placed samples.

11.7 High speed video camera

High speed video camera was useful when examining the breaks but on the other hand it has restricted capacity of taking video material. The prediction of breaks is almost impossible. It was mainly used when artificial breaks were made and examined and if some laminate acted always the same way in certain speed. The video material was studied but not involved in this work.

11.8 Converting speeds at Gallus R160

The maximum speed is defined so that the paper has to hold the stress caused by the converting factors about 15-20 seconds before the speed is taken into results. This had to be decided beforehand because the roll length was constraining the trial. Results of the first Gallus R160 are shown in the **table 9**. The laminates of the both trials were examined after the runs in order to see is the die adjusted right considering the release paper thickness. The results from the test showed that the die is adjusted right and the cutting depth was optimum.

Table 9 The maximum converting speeds of the first Gallus run laminates with two different web widths and six different laminates.

	135 mm	155 mm
RL-RP-Rmod0	150	130
RC-RP-Rmod0	130	100
RB-RP-Rmod0	159	162
RL-RP-Rmod20	110	40
RC-RP-Rmod20	120	50
RB-RP-Rmod20	162	130

The converting speeds of the first Gallus R160 were arranged into a pile diagram in the **figure 42**. Some of the speed values could have been higher but the converting machine set the limits for the speed.

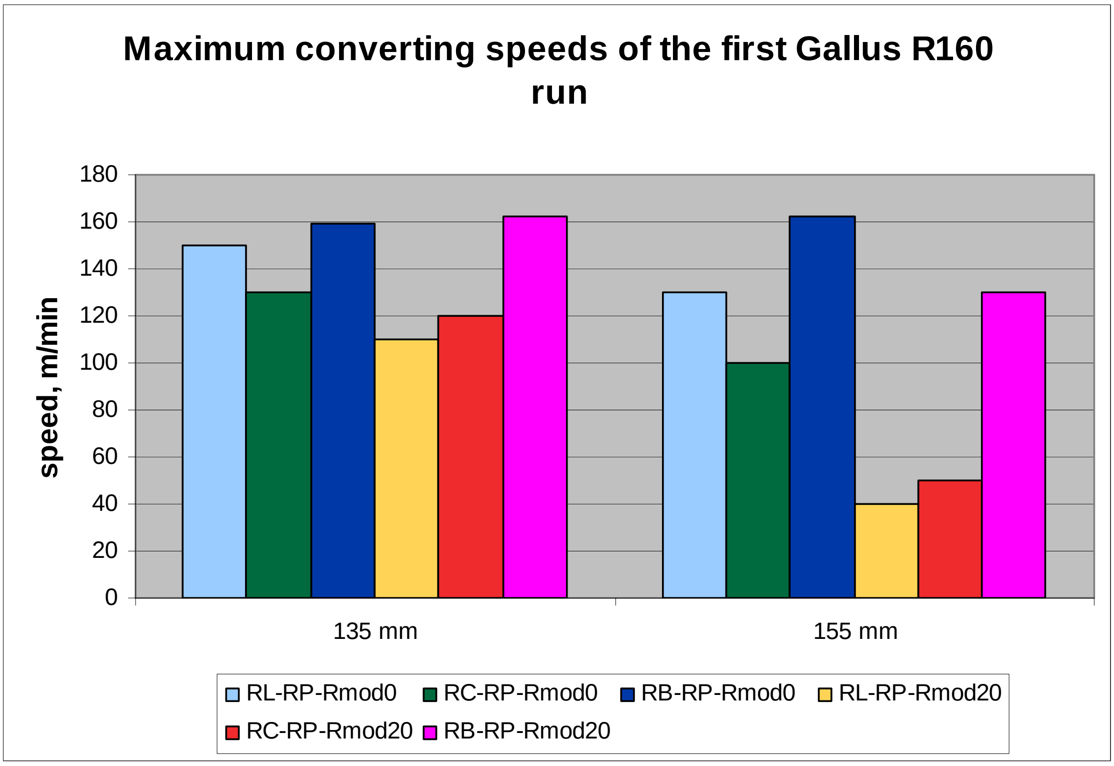


Figure 42 The converting speeds of the 1st run arranged by the web width of the laminates

The laminate RC-RP-Rmod20 acted differently than what was expected after the strength measurements in both web widths. The result differs a lot from the maximum speeds of the other laminates using the Rmod20 which can be explained by the higher release value which can be seen in the **figure 40** and by lower fracture toughness values. The difference in the release values is about 5 grams higher in RC-RP-Rmod20 than what it is other laminates with Rmod20. This could be the reason for the lower speed. It is also seen that the RC face papers are having relatively low fracture toughness and tearing resistance values which for its part can be a significant constraining factor for the speed.

The release values at the break point were studied with the help of the release profile figures. Each laminate could be examined afterwards and the release values at the break pint were collected to the **table 10**. The results are acting logically with the both web widths.

Table 10 The release values in the converting speeds where the break occurred in the first run laminates

load, [g]	135 mm	155 mm
RL-RP-Rmod0	14.0	13.0
RC-RP-Rmod0	16.2	15.0
RB-RP-Rmod0	15.2	15.2
RL-RP-Rmod20	28.8	26.7
RC-RP-Rmod20	34.6	29.0
RB-RP-Rmod20	28.4	28.7

The first Gallus run converting speeds were examined by comparing the laminates with same face papers **figure 43**.

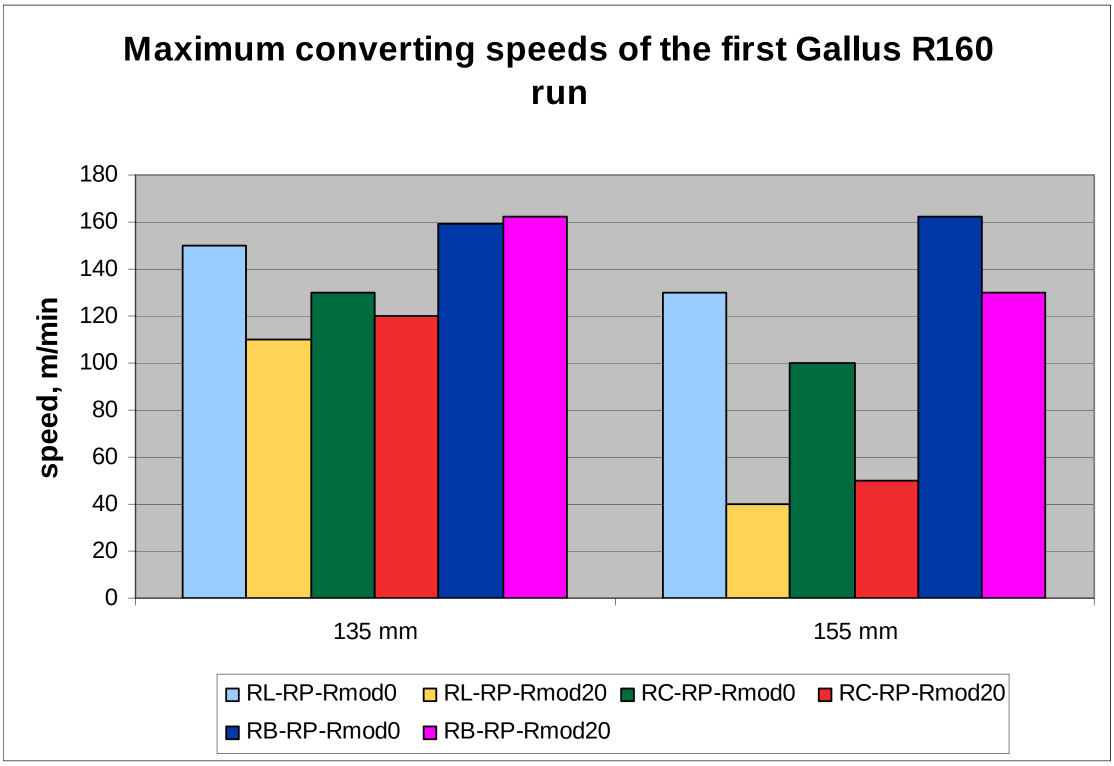


Figure 43 The converting speeds arranged by the basis weight order of the face papers in the laminates and by the web widths

In the **figure 43** the RL-RP-Rmod0 laminate has clearly ran better than e.g. the laminates with RC face papers in both web widths. The reason for that is unknown. The laminates with 155 mm wide web did not run so well because the web was not as stable as it was in the 135 mm wide laminates. the lower modifier level is shown in the higher converting speeds.

In the second Gallus run the trials were difficult to perform as the labels loosened along with the waste matrix. The rest of test trial rolls which could not be tested were placed in a cooling room for 24 hours without any protection against humidity.

This is due to a failed tail threading, unstable waste matrices, uneven release properties of the laminates and the aggressive adhesive RR. The tail threading was difficult because the labels began to detach already in tail threading speeds between 0 and 10 m/min. The amount of labels was high and therefore a calculation of the labels was considered futile. If the tail threading succeeded, the rewinding stage was not successful. Too many labels were loosened and the winding could not be started or completed well. This was performed dozens of times in order to have some results. The waste matrices acted very unstable because of the loosened labels. RR adhesive was sticky which led the adhesive to bleed. This caused the labels to follow the waste matrix web and it caused breaks.

The laminates were not so stable and therefore the results were scattered. The laminates needed to be tested in two pushes. After the first push the samples were taken into a cooling room for 24 hours in order to see are they possible to be tested after the cooling treatment. This was based on an assumption that the RR turns harder when cooled down and thus that the laminates might be easier to die cut.

The compilation of the final converting speeds was created according to the results of the both pushes. The results are written in the **table 11**.

Table 11 All the maximum converting speeds of the second Gallus run laminates with two different web widths and six different laminates

[m/min]	135 mm	155 mm
RL-RR-Rmod20	80	**20**
RC-RR-Rmod20	**154**	**156**
RB-RR-Rmod20	157	65
RL-RR-Rmod0	100	35
RC-RR-Rmod0	-	100
RB-RR-Rmod0	120	**35**

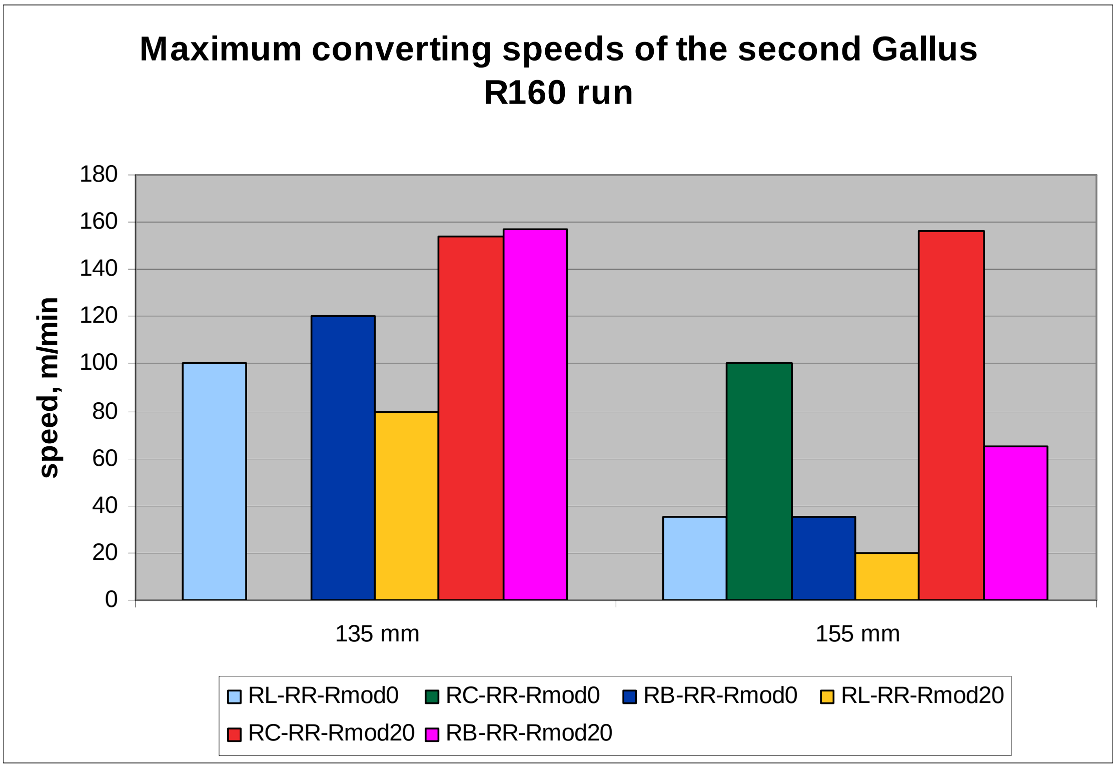


Figure 44 All the maximum converting speeds of the 2nd run laminates arranged by the two different web widths

As seen in the **figure 44**, the narrow laminates run better than the wider ones. It seems that the higher modifier level got better speed values due to the more stable detachment from the release paper. The 135 mm wide RC-RR-Rmod0 laminate could not be tested properly and therefore any result could not be achieved (**figure 44**). The release values of the second pilot run laminates are listed in the **table 12**.

The cooling treatment seemed to be helping the situation. After the cooling treatment, it was possible to run few laminates which were not possible to run before the treatment. An assumption was that the adhesive turns less aggressive after cooling and as the temperature declines it increases the viscosity of the adhesive and therefore improves the die cutting result.

Table 12 The release values in the converting speeds where the break occurred in the second run laminates

load, [g]	135 mm	155 mm
RLp-RR-Rmod20	80.60	78.36
RCp-RR-Rmod20	22.58	22.66
RBp-RR-Rmod20	39.77	35.08
RLp-RR-Rmod0	58.69	65.50
RCp-RR-Rmod0	14.10	21.70
RBp-RR-Rmod0	39.28	20.40

In the both Gallus runs, the web width seemed to have an effect on the results. The narrow 135 mm is acting more stable in the run and is not so vulnerable for tearing effect as the waste matrix is separated from the release paper at the take-up roll. Therefore the maximum speeds of the 135 mm wide laminates reached higher values as they had fewer breaks (**figure 44**). The 155 mm web is not as stable as the 135 mm wide web especially in low speeds and it is constantly vacillating which might lead in time to a small defect and a break. Tail threading with the 155 mm wide is more difficult because the structure of the waste matrix is not stable. The strength level of the paper influenced the results. Weaker papers were more vulnerable to fluctuations on the converting stage e.g. the tension peaks or the instability of the waste matrix web.

Factors which also had a great effect on results are the loosened labels and the movement of the die cutting cylinder in cross direction. The labels were in some cases loosened from the surface of the release paper along with the waste matrix. As the waste matrix was rewound the detached labels made the rewinding discontinuous (**figure 47**) which lead to peaks in the tension of the web and the waste matrix was broken. The movement of the die cutting cylinder caused fluctuations in the edge strips of the waste matrix. The movement was estimated to be as high as 1.5 mm which caused the narrow edges to break under the stress. This situation led to breaks. The movement of the cylinder was higher as the speed of the machine increased.

11.9 Number of detached labels in the first Gallus run laminates

One extra test was involved in this work as the test trials started. The number of loosened labels indicates the convertibility of the laminate and it is a restricting factor for the converting speed. The number of labels is a rough estimate but it correlates with the convertibility. The scale is adjusted between 0 and 5, 0 being the best and 5 the worst (see **table 13**).

Table 13 Number of detached labels in the Gallus R160 test trial run with six different grades (0-5)

grade	number of detached labels
-	no result
0	0-2
1	3-6
2	6-14
3	14-25
4	25-40
5	over 40

Depending on the speed of the converting machine the number of detached labels changes. In the **table 14** the first figure is the speed and then comes the grade of the detached labels in parenthesis. In some cases the trial could be continued even if the labels were detached. The number of detached labels was marked down in every speed the laminate could be run successfully. The grades are not exact but they are giving some information concerning the trial.

Table 14 The number (grades 0-5) of detached labels in different web speeds in the first Gallus trial run arranged by the two different web widths

[m/min (0-5)]	135 mm	155 mm
RL-RP-Rmod0	0	0
RC-RP-Rmod0	0	0
RB-RP-Rmod0	100 **(1)**	100 **(2)**
RL-RP-Rmod20	70 **(2)**, 90 **(2)**	80 **(1)**, 90 **(2)**, 120 **(4)**, 130 **(5)**
RC-RP-Rmod20	60 **(2)**, 80 **(3)**, 90 **(4)**	60 **(2)**, 70 **(4)**, 80 **(5)**
RB-RP-Rmod20	90 **(2)**, 100 **(3)**, 130 **(5)**	120 **(1)**, 130 **(3)**, 140 **(5)**

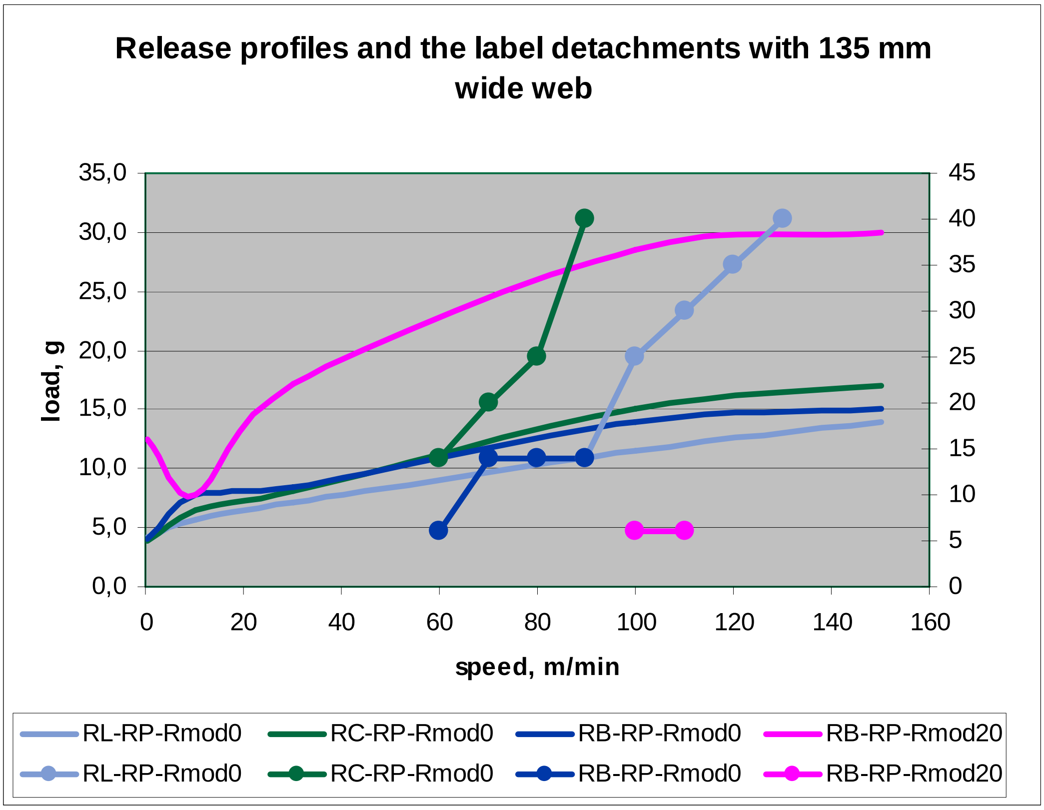


Figure 45 The label detachments of different laminates which are named in the figure with 135 mm wide web. The colours of the laminates and the label detachments for the specific laminate are the same

In the first Gallus run, the results are clearly divided into two categories. The laminates with no modifier lost most of the labels as the release force i.e. the force which keeps the labels on the release paper is smaller.

Only exception was the laminate **RB-RP-Rmod0** in speed of 100 m/min. Laminates where the modifier was added into the silicone acted totally different. Labels started to loose as the speed reached 60-70 m/min. The number of detached labels increased as the speed increased. As the acceleration stage took on, the number of detached labels dropped slightly during the acceleration until the target speed was reached. Then the labels started to detach again (**figure 45**).

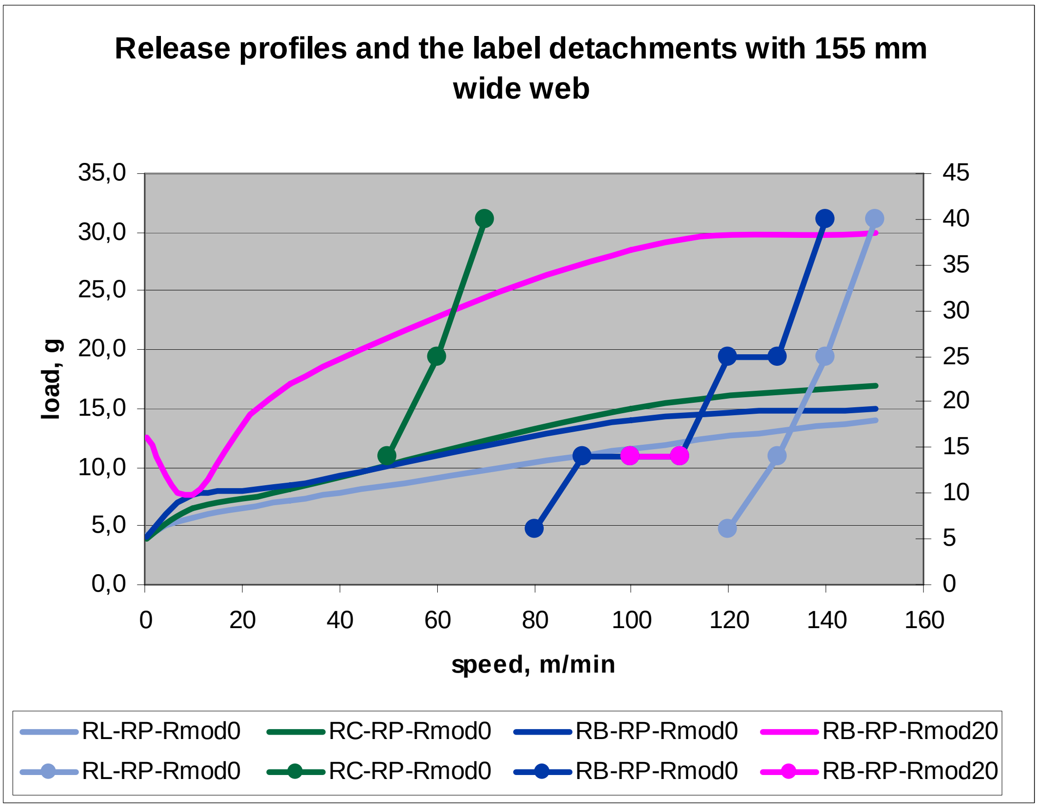


Figure 46 The label detachments of different laminates which are named in the figure with 155 mm wide web. The colours of the laminates and the label detachments for the specific laminate are the same

The label detachments of the wider web (**figure 46**) started at higher speeds which can be due to the structural differences of the waste matrix webs. The impact of the label detachments is seen in the **figure 47**. The loosened labels made the rewinding roll asymmetrical which led to breaks.

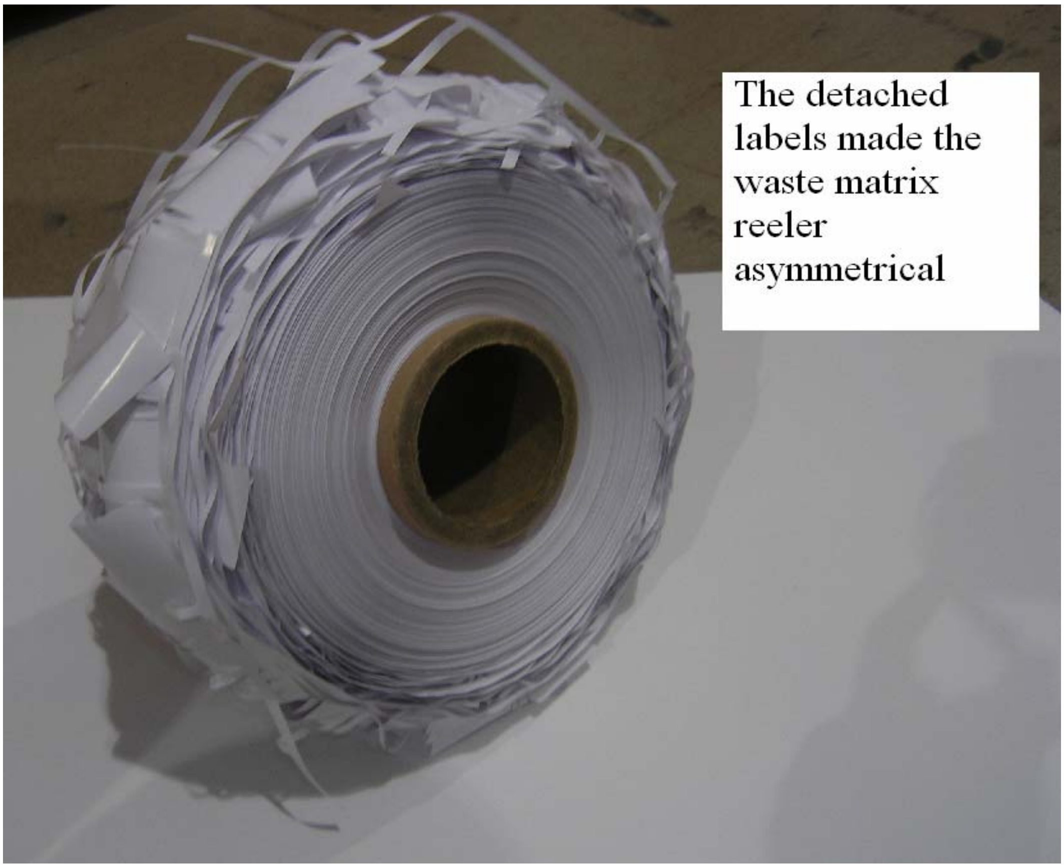


Figure 47 The waste matrix rewinding unit after the label detachments

Asymmetrical roll (**figure 47**) causes pulsating tension to the waste matrix web which occurs as a break at the take-up roller.

Table 15 The number (grades 0-5) of detached labels in different web speeds in the second Gallus trial run arranged by the two different web widths before and after the cooling treatment (bolded figure)

[m/min (0-5)]	135 mm	155 mm
RL-RR-Rmod20	2, **-**	**-, 1**
RC-RR-Rmod20	4, **2**	**-**
RB-RR-Rmod20	1, **2**	1, **1**
RL-RR-Rmod0	2, **-**	1, **-**
RC-RR-Rmod0	5, **5**	4, **2**
RB-RR-Rmod0	1, **5**	-, **1**

The results after the second Gallus run are collected in the **table 15**. The results got from the first attempt are marked down as normal figures and the results after the cooling treatment are shown as bolded figures. Graphs were not useful to draw as the amount of loosened labels was so high.

12 CONCLUSIONS

Conclusions are made according to the results got from the experimental part combined with the known theory concerning the self adhesive laminates. It is worth noticing that the data amount is relatively concise in order to make any exact and final conclusions concerning the trials.

Factors which influenced the measurements, Gallus test trials and the performances of the trials were the same for every laminate. Exception was the cooling treatment done for the second Gallus run laminates.

The maximum speed of the Gallus R160 converting machine is about 160 m/min. Some laminates could have been run faster than that but the machine was setting the speed limit.

12.1 The first converting run laminates

When examining the results of the first Gallus run (**table 16**), it is shown that the laminates which had a lower release value ran better in the Gallus R160 converting machine than the laminates with lower release values. This is logical. The face matrix stands better as the force which is needed to separate the layers in the laminate is smaller. The higher the release force, the bigger is the stress on the matrix edges and the face paper in the matrix has to stand higher forces.

Table 16 The converting speeds of the first Gallus R160 run six laminate combinations with web widths 135 mm and 155 mm

[m/min]	135 mm	155 mm
RL-RP-Rmod0	150	130
RC-RP-Rmod0	130	100
RB-RP-Rmod0	159	162
RL-RP-Rmod20	110	40
RC-RP-Rmod20	120	50
RB-RP-Rmod20	162	130

The green pile in the maximum speeds of the laminates in the **figure 43** shows that the laminates with **RC-RP-Rmod0** did not run as fast as the other laminates. The release value of the laminate was a bit higher than with the other laminates and together with the lowest fracture toughness and low tearing resistance it was decreasing the converting speeds of the laminates. Other reason for the lower converting speed of the **RC-RR-Rmod0** laminates was that the labels started to loose in an early stage of the converting process with that laminate. The reason for that is not found. Normally labels are detached when the release force is too small. This might have something to do with the stiffness values of the face paper.

The labels started to loose from the release paper at the take-up roller. As the speed increased, more labels were detached from the release paper but they were still attached to the waste matrix. After the waste matrix tension control rollers, the labels either loosened or continued to the rewinding station of the waste matrix. This led to the situation where the rewinding of the waste matrix became discontinuous as the labels on the reeler made the roll asymmetrical (**figure 47**). This led also to an uneven tension on the waste matrix web which led finally to breaks. This lowered the maximum converting speeds. The effect of the label detachments is difficult to compute because despite the label detachments, some laminates could be run well in the Gallus R160. Estimation for the effect of the label detachments on the maximum converting speed of the laminates is somewhere between 20-40 m/min

The high strength values of the face paper RB are easily seen in the high converting speeds of the laminates where the face paper RB was used. The maximum speeds with the laminates with the face papers RB were with the both modifier levels at a higher level than with the other laminates. The laminates with the face paper RL run well compared to laminates with RC and with the modifier Rmod20 they run even better. The strength values of the RL face papers are relatively high even thou it is the lightest face paper in the test. The strength indexes are also showing that the RL paper is relatively strong. The fracture toughness and the tearing resistance of the RL are nearly the same than what they are in the case of RC face paper. As seen in the **figure 48** and in the **figure 49** the maximum converting speeds acted as a function of the tensile strength of the face papers in the both web widths.

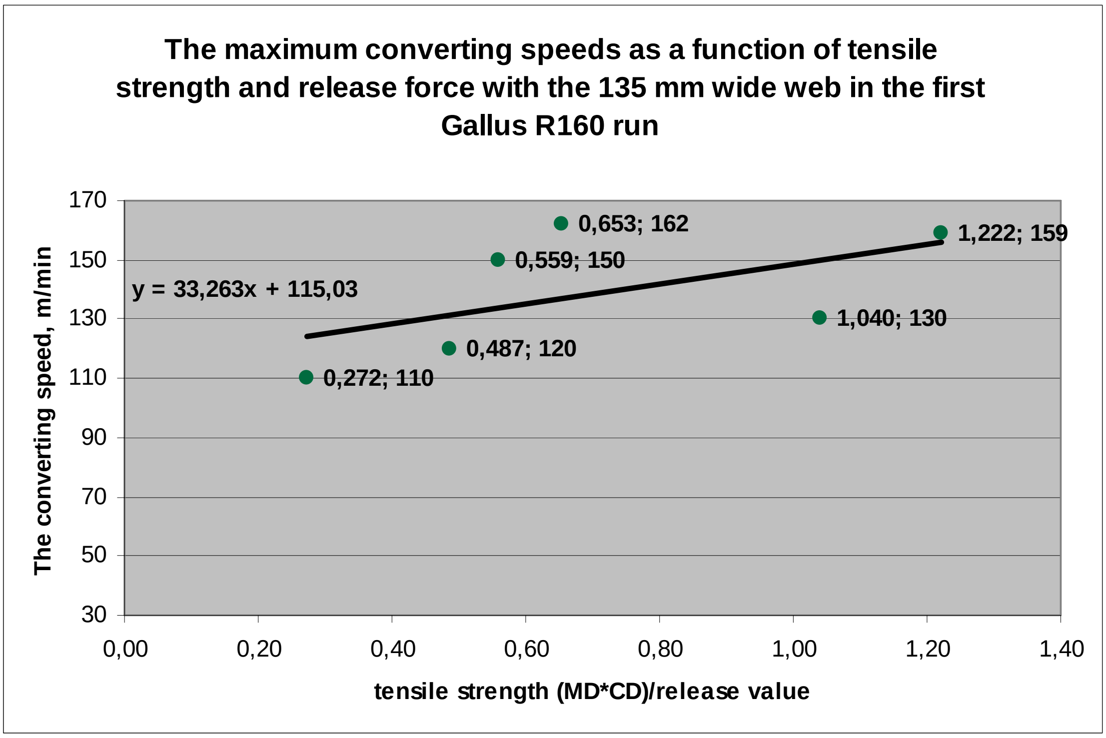


Figure 48 The converting speeds as a function of tensile strength and release force with 135 mm wide laminates

The meaning of the face paper strength characteristics was emphasized with the wider 155 mm laminate (**figure 49**) web because the waste matrix was not so stable and did not tolerate defects as well as the 135 mm wide web. The same kinds of results are seen in all the face papers with both web widths and in all the strength characteristics. The significance of the strength properties in the 135 mm was not as high as with the 155 mm wide web (**figure 49**).

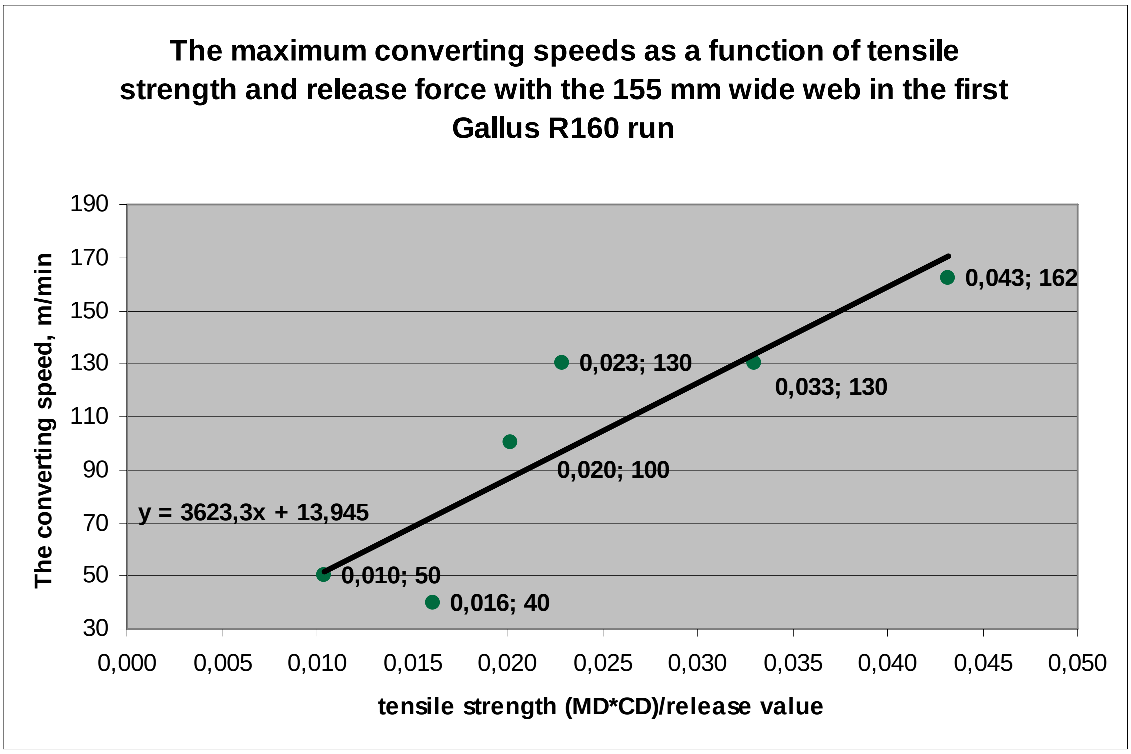


Figure 49 The converting speeds as a function of tensile strength and release force with 155 mm wide laminates

The differences in the trial are easily seen when comparing the web widths. The maximum speeds were clearly higher with the 135 mm wide web than what they were with the 155 mm wide web. This is probably due to the more stable structure of the narrower web. The narrow web tolerates more problems e.g. edge ribbon breaks and label detachments in the converting stage. The tail threading stage was already showing that the narrow web was easier to tail thread on the waste matrix rewinding station as the structure of the matrix was rigid. As the speed of the Gallus R160 increased, the movement in the CD direction of the web increased also. This led to a situation where the widths of the edge ribbons of the matrix were changing. The movement of the web at high speeds was relatively high, approximately ± 1.5 mm. This also disturbed the converting process and caused breaks as the strength of the strip could not tolerate the stress.

The laminates were investigated after the runs and it was noticed that the cutting depth of the die was adjusted right. The die reached just the top of the release liner without harming the silicone layer. This led to the conclusion that the labels did not loose due to the failed die cutting. It is also worth noticing that the die cutting station is vibrating in higher converting speeds. The accuracy of the die cutting is declining as the vibration continues long.

12.2 The laminates in the second test run

The second Gallus R160 run was difficult to perform and the data got from the trial was somewhat scattered. Difficulties are more likely to be caused by the sticky adhesive which led to a bleeding phenomenon.

The second Gallus run laminates ran better with the narrow 135 mm web which is due to the more stable structure than what it is in the 155 mm wide web. The trials with the wider web did not succeed well due to the high amount of labels which were detached from the release paper. It was easier to calculate how many labels were left on the release paper.

Table 17 The converting speeds of the laminates in the second Gallus run

[m/min]	135 mm	155 mm
RL-RR-Rmod20	80	**20**
RC-RR-Rmod20	**154**	**156**
RB-RR-Rmod20	157	65
RL-RR-Rmod0	100	35
RC-RR-Rmod0	-	100
RB-RR-Rmod0	120	**35**

The laminates with higher release values run clearly better than the laminates with lower release values. This is due to the lower amount of loosened labels. The higher release value made the labels to stay better on the release liner as the laminate layers were separated. The lower release force caused the labels to detach from the waste matrix. Compared to the first Gallus R160 run, the second Gallus run matrices seemed to be weaker and more easily breaking. The primer treatment slightly increased the strength properties of the face papers but also lowered the thicknesses of the RLp and RBp papers. This also lowered for its part the stiffness values of the face papers which can be one reason causing the breaks.

The face paper strength characteristics did affect the maximum converting speed values of the both webs. The effect of the strength properties to the converting speeds is easier to see in the 135 mm laminates.

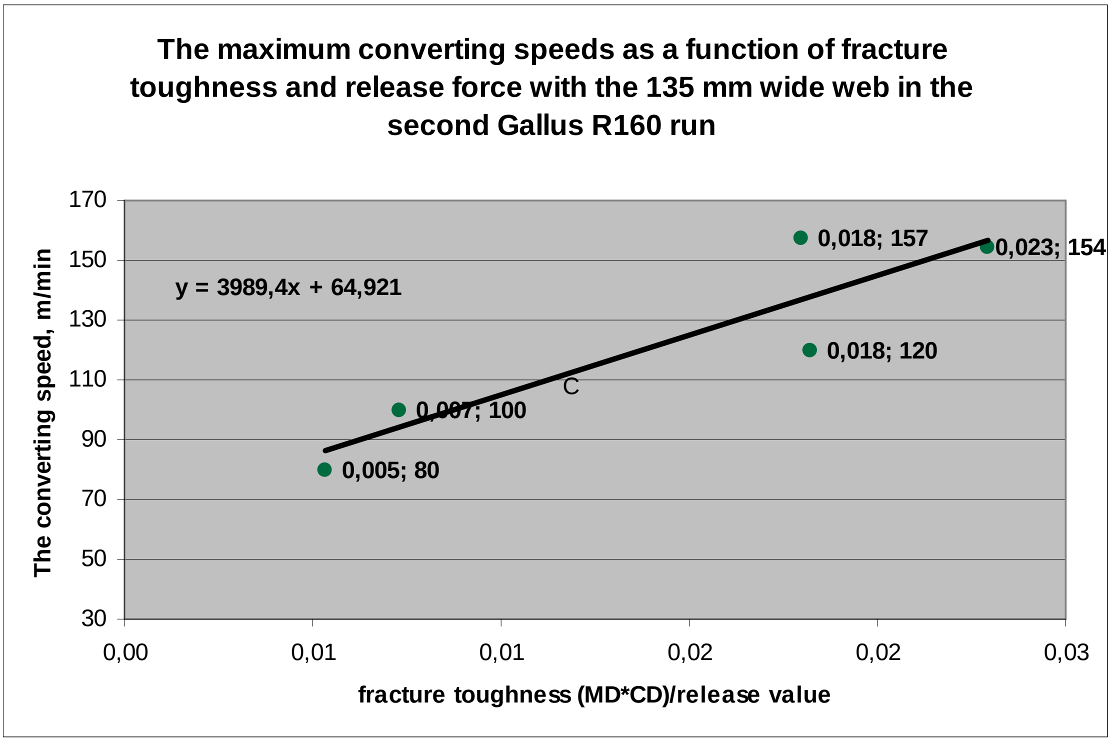


Figure 50 The converting speeds as a function of fracture toughness and release force with 135 mm wide laminates

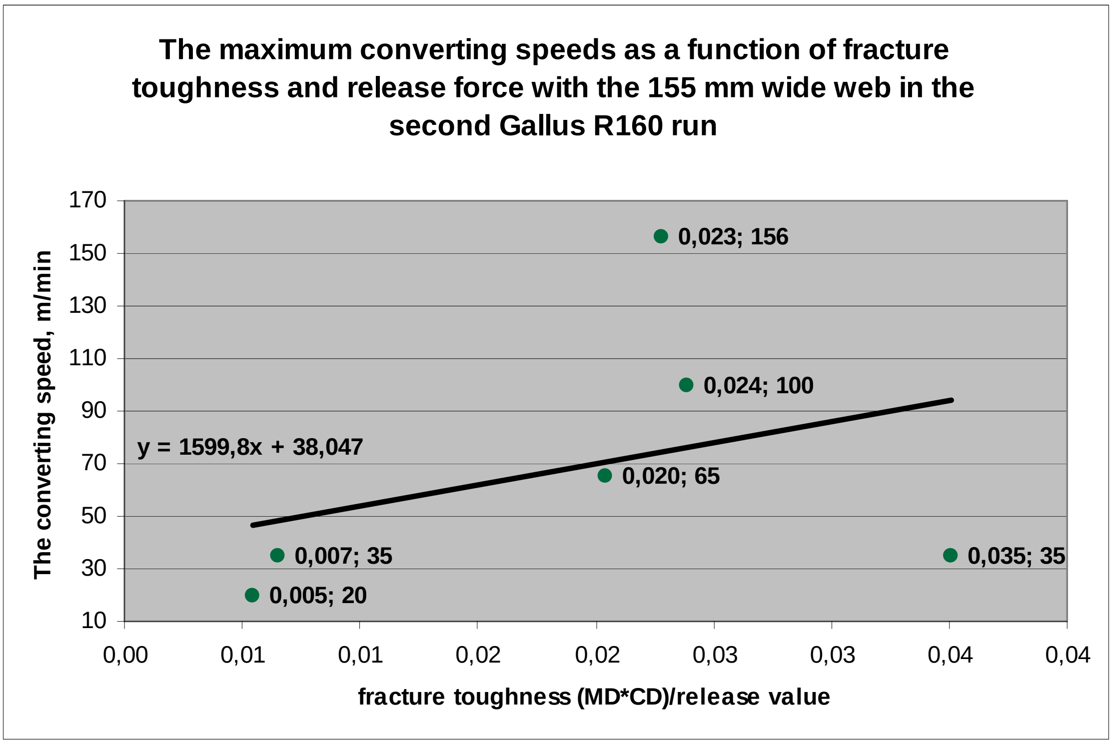


Figure 51 The converting speeds as a function of fracture toughness and release force with 155 mm wide laminates

The results in the figure are differing from the average trend line more than what they did on the first run laminates. But the trend is still growing which is showing that the strength values are in significant role when converting the self adhesive laminates.

The release profiles got from the laminates were totally different than what they were with the first pilot run laminates. The release profiles did not act according to the modifier amount but more according to the used face paper in the laminates. As seen in the **figure 41**, the highest release values are gotten with the laminates where the RL face papers were used. The results are way out of the target being at least double what they were with the adhesive RP in the first run laminates. The second largest values were gotten with the laminates where the RB face papers were used. These are probably due to an unsuccessful pilot laminator run where the laminates were left too wet.

The maximum converting speeds are lower with the laminates which had higher release values but on the other hand the laminate RC-RR-Rmod0 with the lowest release value could not be run at all with the narrow web. The laminates with the face paper RC could not be run at all before the cooling treatment. After the cooling treatment, the laminates with face paper RC ran finally the fastest in the trial.

It seems that the high release forces have an effect on the wider web converting speeds. The laminates with high release forces are having smaller converting speeds than the laminates with lower release values. The highest converting speeds are gotten with the laminate RR-RC-Rmod0 with the second lowest release value. But due to the unexpected release values, the data is not so reliable.

Bleeding phenomenon usually occurs with aggressive adhesives. The laminates were examined after the run and it was shown that the die reached the release liner but did not cut the elastic adhesive entirely or the adhesive was flowing back to the cutting mark after the die cutting station. In theory, the delay after the die cutting station and the waste matrix removing unit should be small but in order to do so the web has to be first running. This was impossible as the labels were detached from the release paper.

The adhesive in the second run was removable which needed a primer treatment on the reverse side of the face paper. The adhesive in the ready laminates was extremely sticky and did not act as normal removable adhesive does. This was more likely the reason why the labels were detached so easily from the release paper surface and followed the release paper. The bleeding phenomenon was strong and it made the labels and the waste matrix to be adhered on each others. The assumption was that the increase in the speed would have a positive effect on the bleeding but every time the speed was tried to accelerate, the web was broken by the labels on the rewound unit or on the take-up roller.

The cooling treatment seemed to help to gain some results concerning the 155 mm wide webs. Some laminates could be run after the cooling treatment with the Gallus R160. The temperature most likely decreased the aggressive nature of the adhesive so much that some of the laminates could be run.

12.3 Conclusions

An operating window is drawn according to the results got from the trials and according to the strength measurements. Clearly the most significant factors affecting the converting speeds are the individual strength properties of the face papers, the release force between the layers, the shape of the waste matrix and the converting machine itself.

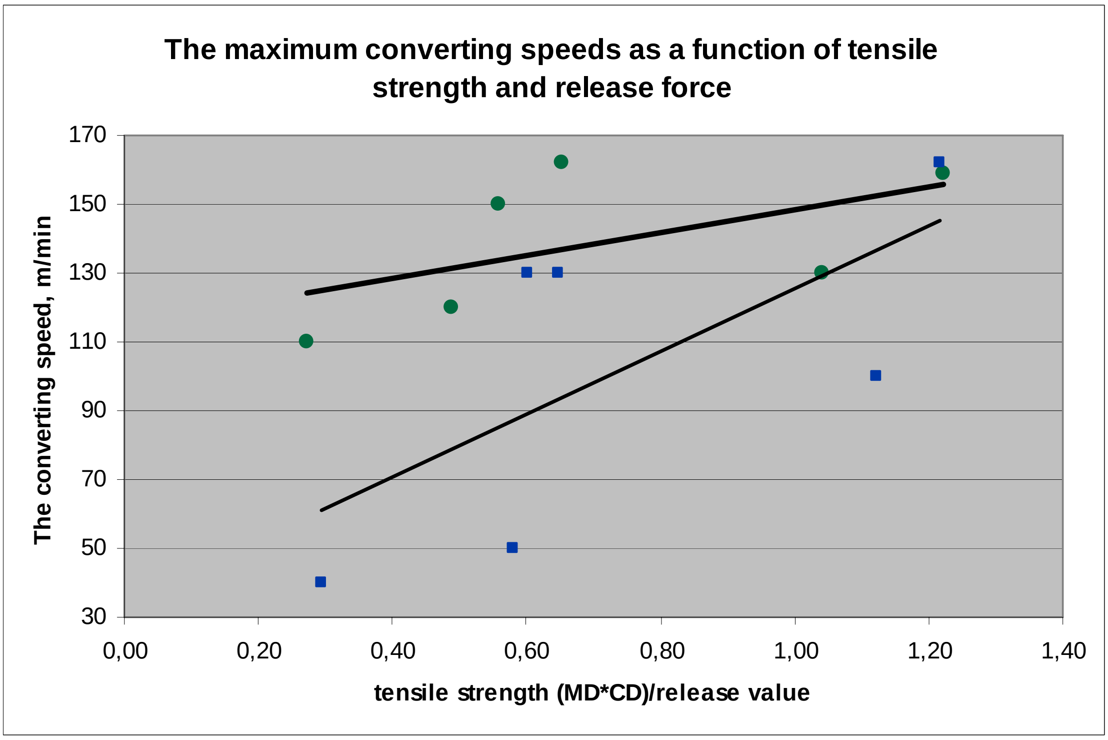


Figure 52 The converting speed of the laminates as a function of the release force and the tensile strength in both web widths.

The converting speeds of the both web widths are drawn in the **figure 52** as a function of the release value and the tensile strength. The upper bolded line describes the 135 mm wide web and the lower the 155 mm wide web. The speed values of the narrower web start from higher levels than with the 155 mm. The converting speeds with the wider web are growing fast as the strength of the face papers increases.

The same kind of development of the converting speed is seen with the fracture toughness (see also **appendices 7-12**). The laminates with face papers with higher fracture toughness ran faster. The effect on the 155 mm web (narrow trend line) was also in this case higher.

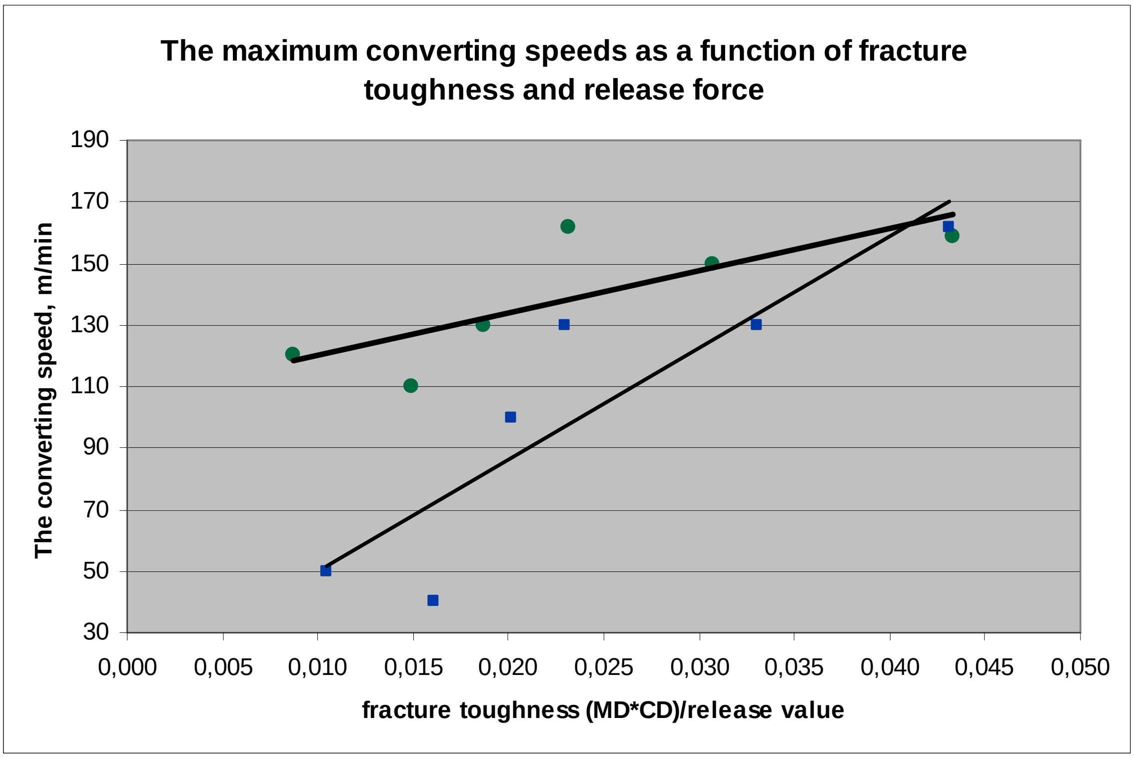


Figure 52 The converting speed as a function of the fracture toughness and the release value in both web widths

When observing the effect tearing resistance and the release value, the results are almost similar to what they are in the **figure 52**. The converting speeds are higher with the papers with higher release values. But as the release value increases as function of the speed, it will in some point decrease the converting speed of the laminate.

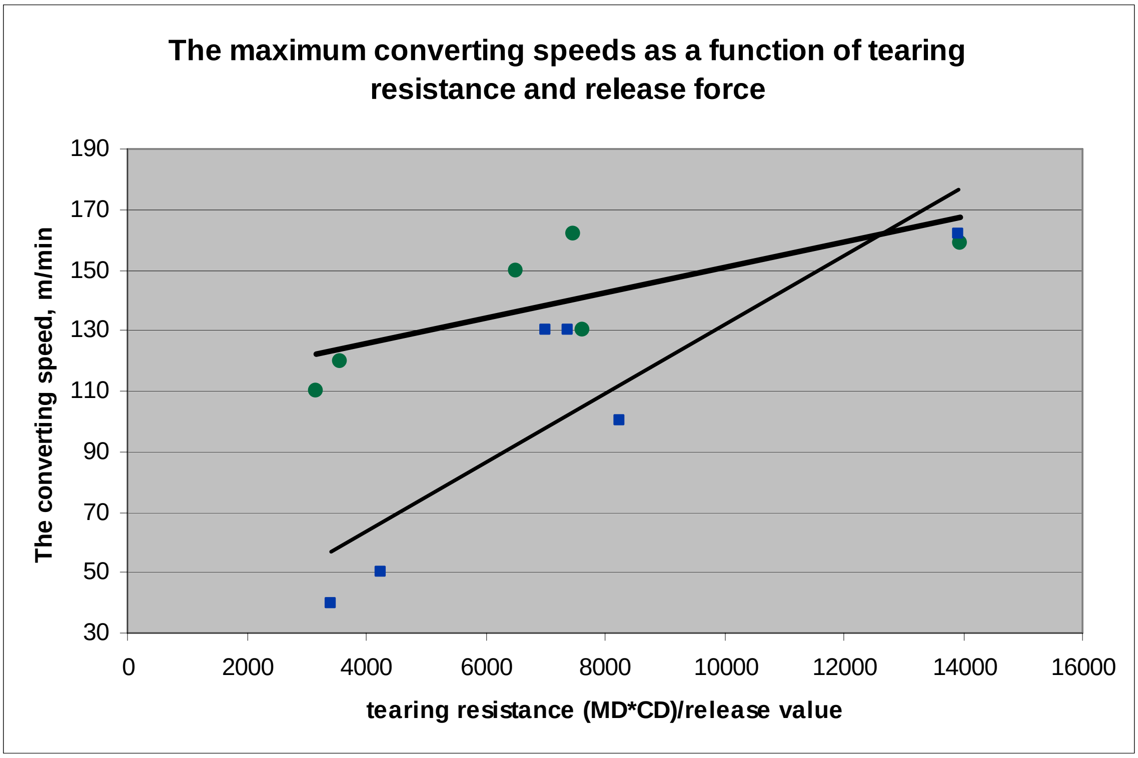


Figure 53 The converting speed as a function of the tearing resistance and the release value in both web widths

According to the **figures 51-53** an elucidations of the possible working window for the laminates are drawn in the **figure 54-55**.

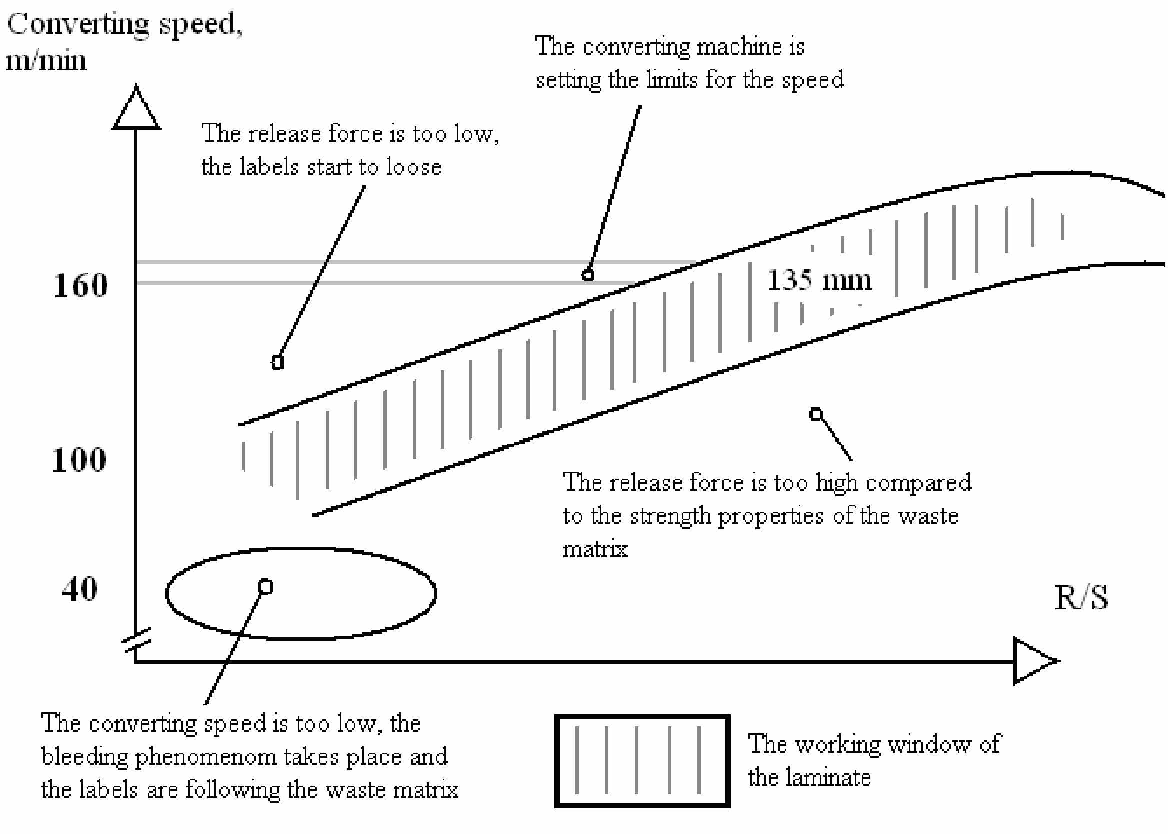


Figure 54 The operating window for the 135 mm wide web where the R/S is the release force divided by the strength of the paper

First the converting speeds are increasing because the laminate tolerates the stresses caused by the converting. The speed growth of the 135 mm wide laminate as a function of the ratio of release force between the strength properties of the face papers in the **figure 54** is moderate. As the release force grows as a function of speed the converting speed of the laminate decreases. The first break occurs as the release value passes the strength properties of the face matrix. It was also seen that the low converting speeds are causing the labels to detach from the release liner. This is due to the bleeding phenomenon. Too low release force causes the labels to detach and eventually it leads to a break.

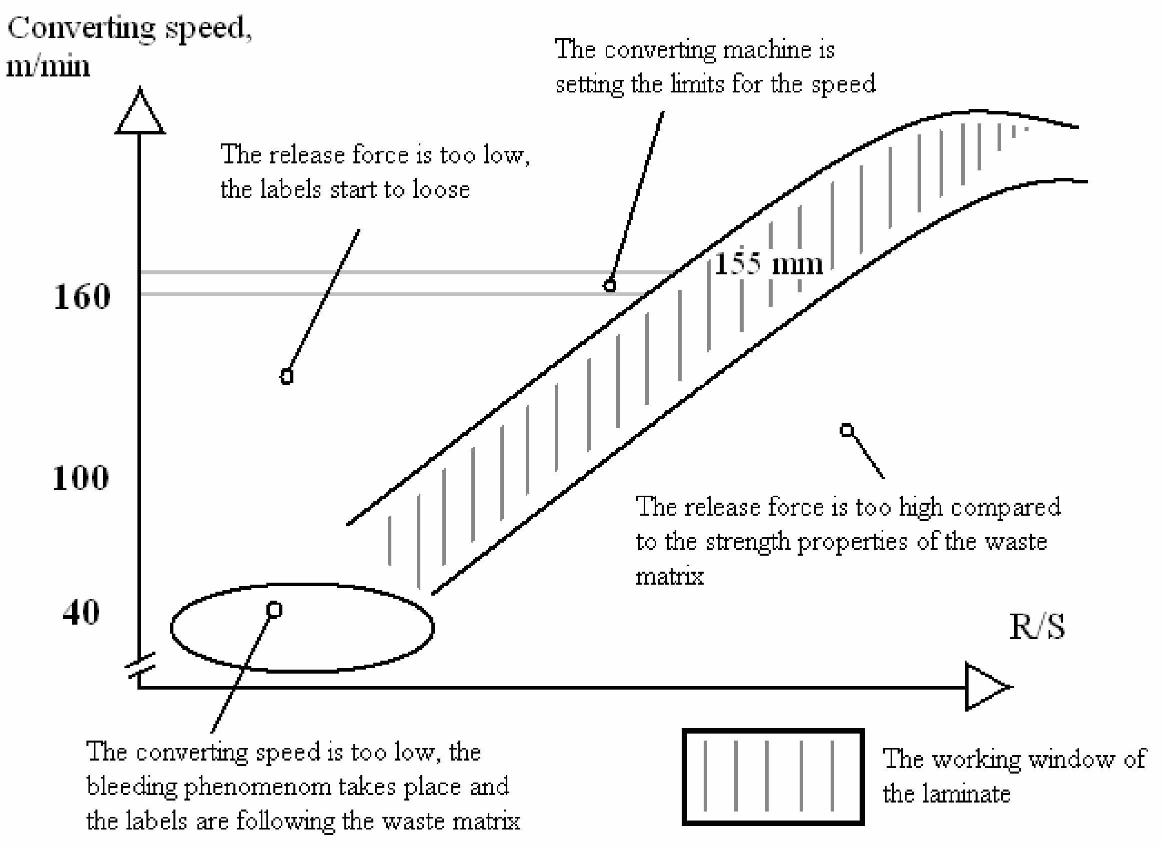


Figure 54 The operating window for the 155 mm wide web where the R/S is the release force divided by the strength of the paper

The converting speed of the 155 mm wide laminate in the **figure 54** was growing steeply as a function of the ratio between the release force and the strength properties of face papers. The laminates with higher release values did not run as good as the ones with Rmod0.

The other constraining factors for the converting are the label detachments when the release force is too low and the machine vibrations and other disturbances the converting machine causes such as the web movement in CD direction. The area which is lined is the working window for the laminate.

REFERENCES

Printed references

1 Citius imaging C10 camera. User`s manual.
2 Henttonen, Heikki. Stanssausyksikön käyttöönotto ja testaaminen. Insinöörityö. Tampere 2001. 29 p.
3 Karhuketo, Hannu; Seppälä, Markku J. Kemiallinen metsäteollisuus 2; Paperin ja kartongin jalostus (2. uudistettu painos). 2004.
4 Norontaus, Markus. Tarralaminaatin stanssaus. Teknikkotyö. Tampere 1998. 25 p.
5 Patrakka, Pekka. Rotary die cutting of pressure sensitive laminate. Diplomityö. Espoo, 1995. 49 p.
6 Pynnönen, Toni. Tarralaminaatin releasearvon muuttuminen. Insinöörityö. Tampere.
7 Räntilä, Pekka. Mikrokreppaus. Insinöörityö. Tampere 2006. 54 p.
8 Scandinavian pulp. Paper and board committee. Scan-p 11:96, tearing resistance.
9 UPM Raflatac. Adhesive coating specifications. Version 49/09.06.2004.
10 UPM Raflatac. Labelstock products. 27 p.

CD-ROMs, e-mails, learning environments and web pages

11 Fapet. Papermaking science and technology. [CD-ROM].
12 Finat. Finat position release liner. [web page]. [31.03.2008]. http://www.finat.com/files_content/publications/recycling/FINAT%20position%20release%20liner%20FINAL.pdf.
13 Laurikainen, Eliisa. [e-mail]. [01.03.2008].
14 Pirisjoki, Mika. Lisätietoa stanssauksesta. [e-mail]. [04.03.2008].
15 UPM Raflatac. Intranet. [web page]. [17.02.2008]. http://intranet.raflatac.com/europe/ta/RaflatacOy/.
16 UPM Raflatac. KnowTac v. 1.0/2.0. UPM Raflatac. Learning environment.
17 VTT industrial systems. Knowpap version 7.0. Learning environment.

Discussions

18 Pietari, Ismo. Research and development director. Discussion at UPM Raflatac. February 2008.

19 Pirisjoki, Mika. Quality Development Manager. Discussion at UPM Raflatac February 2008.

APPENDICES

1 Basis weights and thicknesses of all the face papers

2 Basis weights and thicknesses of the release papers

3 Tensile strength, fracture toughness and tearing resistance of all the face papers

4 Strength indeces of all the face papers

5 First run label detachments with the 135 mm and 155 mm wide webs

6 Release values of the 1st and the 2nd run laminates

7 The maximum converting speeds as a function of tensile strength and release force with the 135 mm and 155 mm wide webs in the first Gallus R160 run

8 The maximum converting speeds as a function of fracture toughness and release force with the 135 mm and 155 mm wide webs in the first Gallus R160 run

9 The maximum converting speeds as a function of tearing resistance and release force with the 135 mm and 155 mm wide webs in the first Gallus R160 run

10 The maximum converting speeds as a function of tensile strength and release force with the 135 mm and 155 mm wide webs in the second Gallus R160 run

11 The maximum converting speeds as a function of fracture toughness and release force with the 135 mm and 155 mm wide webs in the second Gallus R160 run

12 The maximum converting speeds as a function of fracture toughness and release force with the 135 mm and 155 mm wide webs in the second Gallus R160 run

The basis weights and thicknesses of all the face papers APPENDIX 1.

[g/m^2]	RL	RLp	RC	RCp	RB	RBp
1	59,4	63,7	75,7	79,7	83,7	87,5
2	58,8	63,6	75,9	80,2	84,6	87,1
3	58,8	63,5	76,6	80,5	84,4	87,9
4	60,2	62,8	75,5	81,7	84,0	86,8
5	59,5	63,1	76,5	80,5	85,3	88,8
6	59,7	63,4	75,4	80,7	84,8	88,8
7	59,3	64,2	75,8	79,8	84,8	88,5
8	59,7	63,0	76,0	80,5	84,2	87,6
9	59,3	63,8	75,7	79,7	84,8	88,7
10	59,3	62,9	75,4	81,3	85,5	88,6
11	60,1	63,4	76,0	79,8	86,1	86,2
12	60,1	63,3	76,0	80,5	85,2	86,2
13	59,0	62,6	76,1	79,5	86,0	88,5
14	58,9	63,6	76,9	80,5	85,9	88,4
15	59,0	63,8	76,0	80,6	84,2	87,8
16	59,3	63,7	76,3	80,9	84,4	87,3
17	59,7	64,0	75,6	79,0	85,8	87,7
18	59,5	63,3	76,7	79,9	85,6	86,5
19	58,7	63,7	76,2	80,9	85,8	87,9
20	59,0	63,5	76,5	79,5	85,8	87,9
average	59,4	63,4	76,0	80,3	85,0	87,7
Stdev	0,45	0,41	0,44	0,67	0,75	0,84

[g/m^2]	RL	RLp	RC	RCp	RB	RBp
1	55	58	71	70	70	69
2	52	61	69	68	73	69
3	54	57	72	68	74	68
4	50	56	70	68	73	69
5	51	58	70	67	78	67
6	53	57	71	68	72	70
7	52	57	69	68	75	68
8	53	56	69	69	72	68
9	52	56	71	69	74	65
10	52	58	71	72	75	66
11	52	56	70	68	73	70
12	50	58	70	68	78	72
13	52	54	71	70	74	71
14	55	53	72	68	71	72
15	55	57	70	68	72	72
16	59	58	71	69	71	72
17	55	57	69	68	75	71
18	52	56	70	67	75	69
19	52	53	71	68	75	67
20	51	54	71	68	72	70
average	**52,9**	**56,5**	**70,4**	**68,5**	**73,6**	**69,3**
Stdev	**2,13**	**1,93**	**0,94**	**1,15**	**2,14**	**2,07**

APPENDIX 2.

The basis weight values of the release papers.

[g/m²]	Rmod0	Rmod20
1	58,8	58,9
2	59,0	59,2
3	58,4	58,3
4	59,0	58,5
5	58,2	58,5
6	58,3	59,4
7	58,3	58,7
8	58,5	58,4
9	59,0	59,5
10	59,3	58,6
11	58,9	58,6
12	58,4	59,3
13	58,9	58,8
14	58,4	58,8
15	59,1	59,7
16	58,3	59,5
17	58,5	59,7
18	58,3	58,5
19	58,6	58,7
20	58,3	59,3
average	**58,6**	**58,9**
Stdev	**0,34**	**0,45**

[g/m²]	Rmod0	Rmod20
1	51	52
2	51	52
3	53	51
4	53	49
5	52	53
6	53	54
7	51	52
8	58	52
9	55	53
10	53	56
11	52	53
12	52	51
13	53	51
14	57	53
15	60	56
16	58	51
17	55	50
18	53	51
19	55	49
20	56	52
average	**54,1**	**52,1**
Stdev	**2,61**	**2,20**

APPENDIX 3.

The strength properties of all the face papers.

RL	MD	StDev	CD	StDev	ratio MD/CD
Tensile strength, kN/m	4,21	0,22	1,86	0,10	2,19
Tensile strength index, Nm/g	70,8	3,8	31,4	1,8	2,19
fracture toughness, J/m	0,58	0,10	0,75	0,11	0,77
fracture toughness index, mJ/m/g	9,7	1,7	12,6	1,9	0,77
tearing resistance	292	29	312	38	0,94
RC	**MD**	**StDev**	**CD**	**StDev**	**ratio MD/CD**
Tensile strength, kN/m	6,04	0,30	2,79	0,11	2,16
Tensile strength index, Nm/g	79,5	3,9	36,7	1,5	2,16
fracture toughness, J/m	0,50	0,06	0,61	0,11	0,81
fracture toughness index, mJ/m/g	6,5	0,8	8,0	1,4	0,81
tearing resistance	355	19	348	12	1,02
RB	**MD**	**StDev**	**CD**	**StDev**	**ratio MD/CD**
Tensile strength, kN/m	6,12	0,63	3,03	0,21	2,02
Tensile strength index, Nm/g	72,0	7,4	35,7	2,5	2,02
fracture toughness, J/m	0,76	0,08	0,87	0,15	0,87
fracture toughness index, mJ/m/g	8,9	1,0	10,2	1,8	0,87
tearing resistance	438	29	484	12	0,90

RLp	MD	StDev	CD	StDev	ratio MD/CD
Tensile strength, kN/m	4,31	0,19	2,16	0,14	2,19
Tensile strength index, Nm/g	68,0	2,9	34,1	2,3	2,19
fracture toughness, J/m	0,63	0,07	0,85	0,12	0,74
fracture toughness index, mJ/m/g	9,9	1,1	13,4	1,9	0,74
tearing resistance	284	15	273	9	1,04
RCp	**MD**	**StDev**	**CD**	**StDev**	**ratio MD/CD**
Tensile strength, kN/m	5,68	0,33	2,76	0,16	2,06
Tensile strength index, Nm/g	70,8	4,1	34,4	2,0	2,06
fracture toughness, J/m	0,69	0,01	0,75	0,09	0,93
fracture toughness index, mJ/m/g	8,6	1,1	9,3	1,1	0,93
tearing resistance	364	17	336	10	1,08
RBp	**MD**	**StDev**	**CD**	**StDev**	**ratio MD/CD**
Tensile strength, kN/m	6,94	0,35	3,19	0,12	2,18
Tensile strength index, Nm/g	79,1	4,0	36,4	1,3	2,18
fracture toughness, J/m	0,78	0,07	0,92	0,10	0,85
fracture toughness index, mJ/m/g	8,9	0,9	10,4	1,0	0,85
tearing resistance	430	30	484	26	0,89

APPENDIX 4.

Strength indeces of all the face papers.

tensile strength indeces	MD	CD
RL	70,83	31,39
RC	79,46	36,73
RB	71,96	35,69
fracture toughness indeces	**MD**	**CD**
RL	9,70	12,56
RC	6,51	8,03
RB	8,90	10,23
tearing resistance indeces	**MD**	**CD**
RL	4,92	5,26
RC	4,67	4,58
RB	5,15	5,69

tensile strength indeces	MD	CD
RLp	67,96	34,11
RCp	70,78	34,38
RBp	79,08	36,36
fracture toughness indeces	**MD**	**CD**
RLp	9,9	13,4
RCp	8,61	9,31
RBp	8,92	10,44
tearing resistance indeces	**MD**	**CD**
RLp	4,78	4,60
RCp	4,79	4,42
RBp	5,06	5,69

APPENDIX 5.

First run label detachments with the 135 mm and 155 mm wide webs

135 mm	RL-RP-Rmod20	RC-RP-Rmod20	RB-RP-Rmod20	RL-RP-Rmod0	RC-RP-Rmod0	RB-RP-Rmod0
0,0						
10,0						
20,0						
30,0						
40,0						
50,0						
60,0					14	6
70,0					20	14
80,0					25	14
90,0				14	40	14
100,0			6	25		
110,0			6	30		
120,0				35		
130,0				40		
140,0						
150,0						
160,0						
[m/min]						

155 mm	RL-RP-Rmod20	RC-RP-Rmod20	RB-RP-Rmod20	RL-RP-Rmod0	RC-RP-Rmod0	RB-RP-Rmod0
0,0						
10,0						
20,0						
30,0						
40,0						
50,0					14	
60,0					25	
70,0					40	
80,0						6
90,0						14
100,0			14			14
110,0			14			14
120,0				6		25
130,0				14		25
140,0				25		40
150,0				40		
160,0						
m/min						

APPENDIX 6.

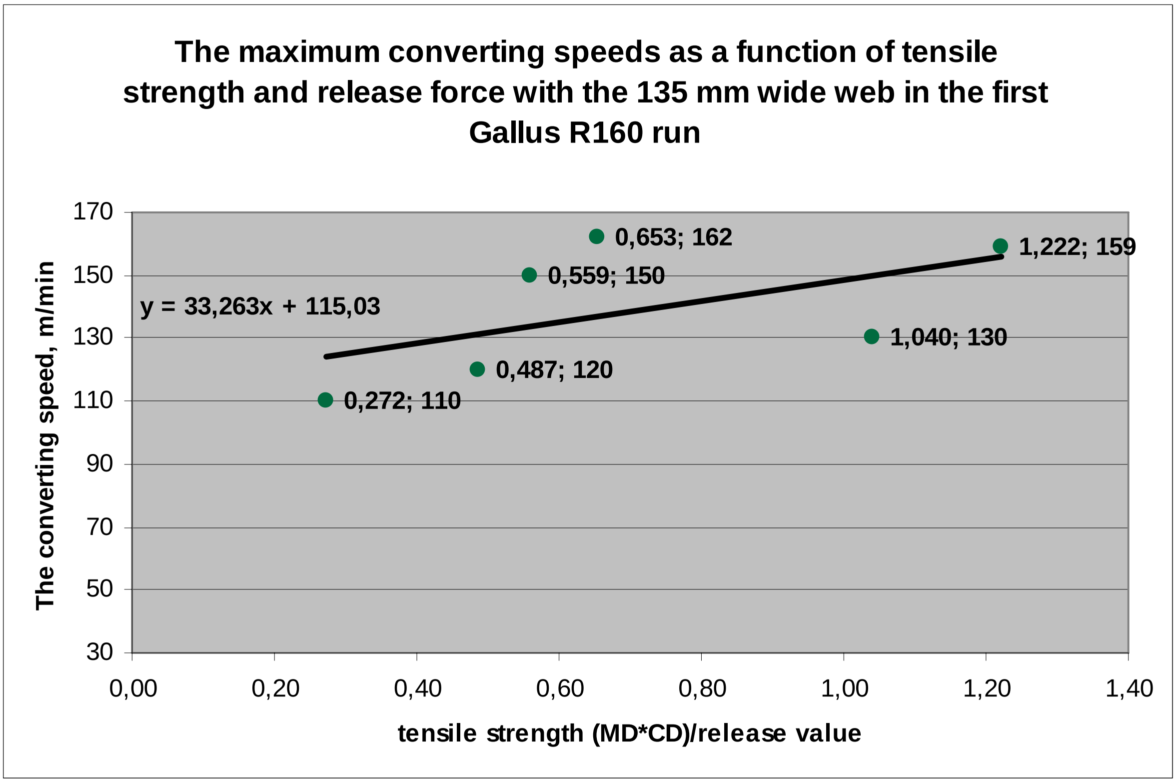
The release values of all the laminates in different speeds.

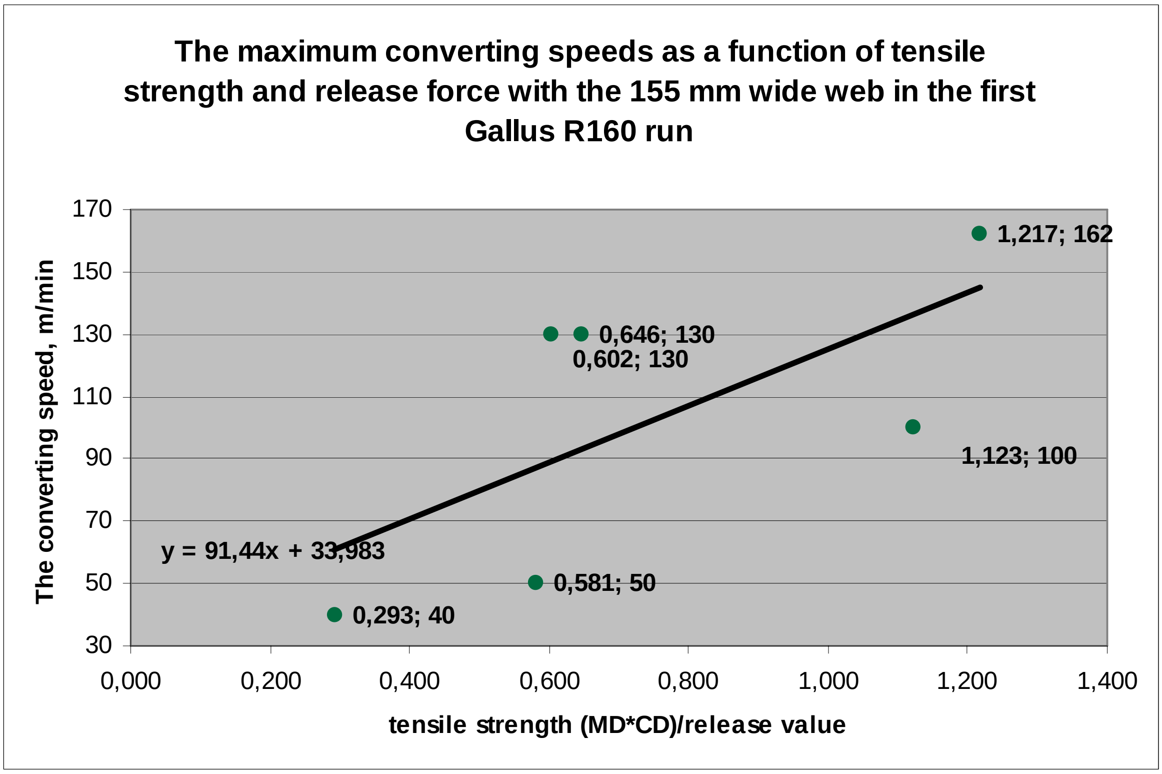
[m/min]	0,3 m/min	10 m/min	30 m/min	100 m/min	150 m/min
RL-RP-Rmod0	4,2	5,7	7,2	11,5	14,0
RC-RP-Rmod0	3,9	6,6	8,1	15,0	17,0
RB-RP-Rmod0	4,0	7,7	8,4	14,0	15,0
RL-RP-Rmod20	12,6	7,7	17,1	28,5	30,0
RC-RP-Rmod20	12,7	6,2	19,3	33,0	37,0
RB-RP-Rmod20	11,1	7,4	16,2	29,0	28,5

[m/min]	0,3 m/min	10 m/min	30 m/min	100 m/min	150 m/min
RLp-RR-Rmod20	14,3	58,5	80,6	80,6	82,0
RCp-RR-Rmod20	2,8	13,5	18,4	20,2	22,4
RBp-RR-Rmod20	6,5	26,7	33,3	36,9	39,1
RLp-RR-Rmod0	7,6	23,0	32,3	58,7	61,9
RCp-RR-Rmod0	2,2	5,9	10,5	21,7	25,5
RBp-RR-Rmod0	4,2	10,1	19,2	36,0	44,2

APPENDIX 7.

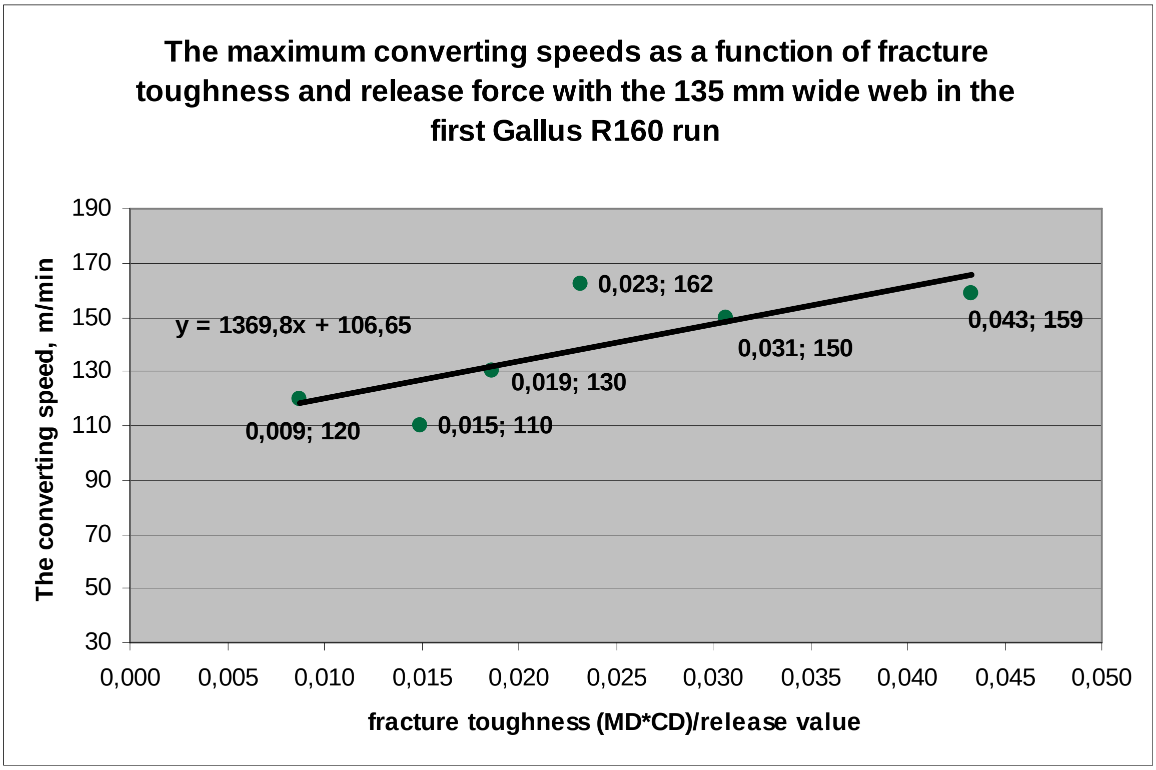
The maximum converting speeds as a function of tensile strength and release force with the 135 mm and 155 mm wide webs in the first Gallus R160 run

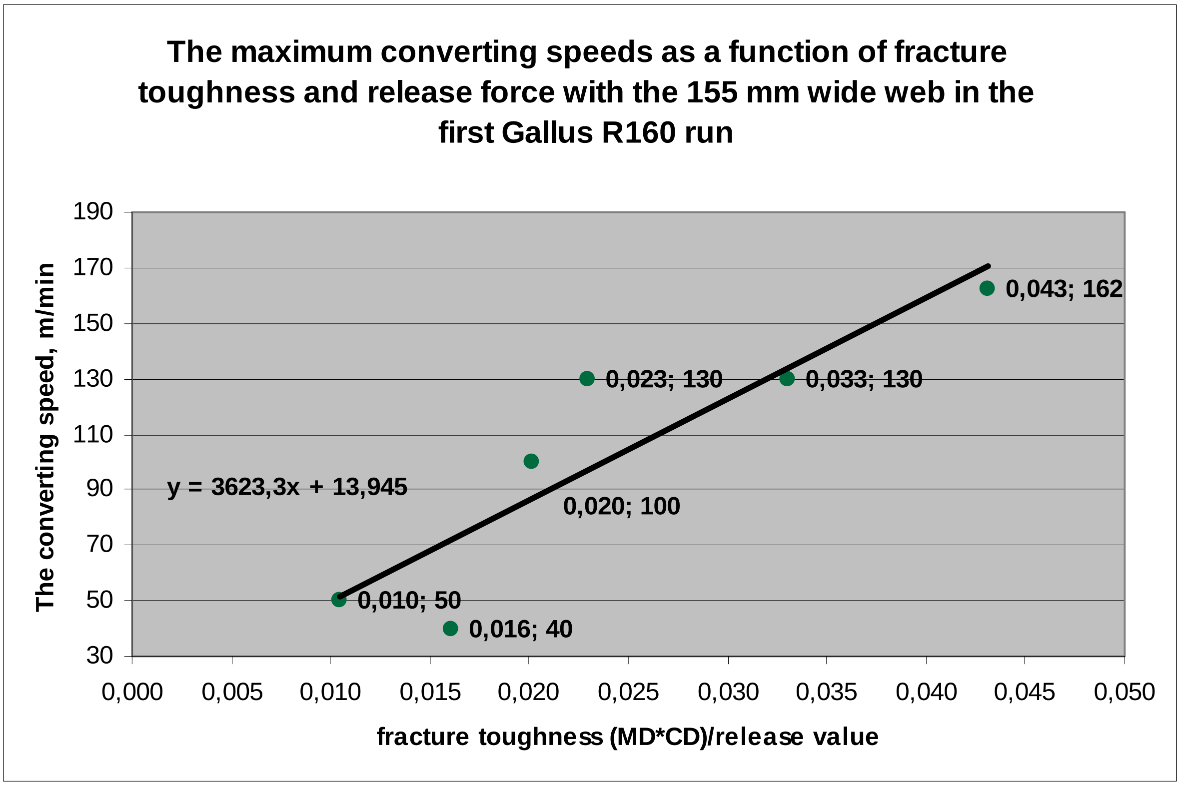




APPENDIX 8.

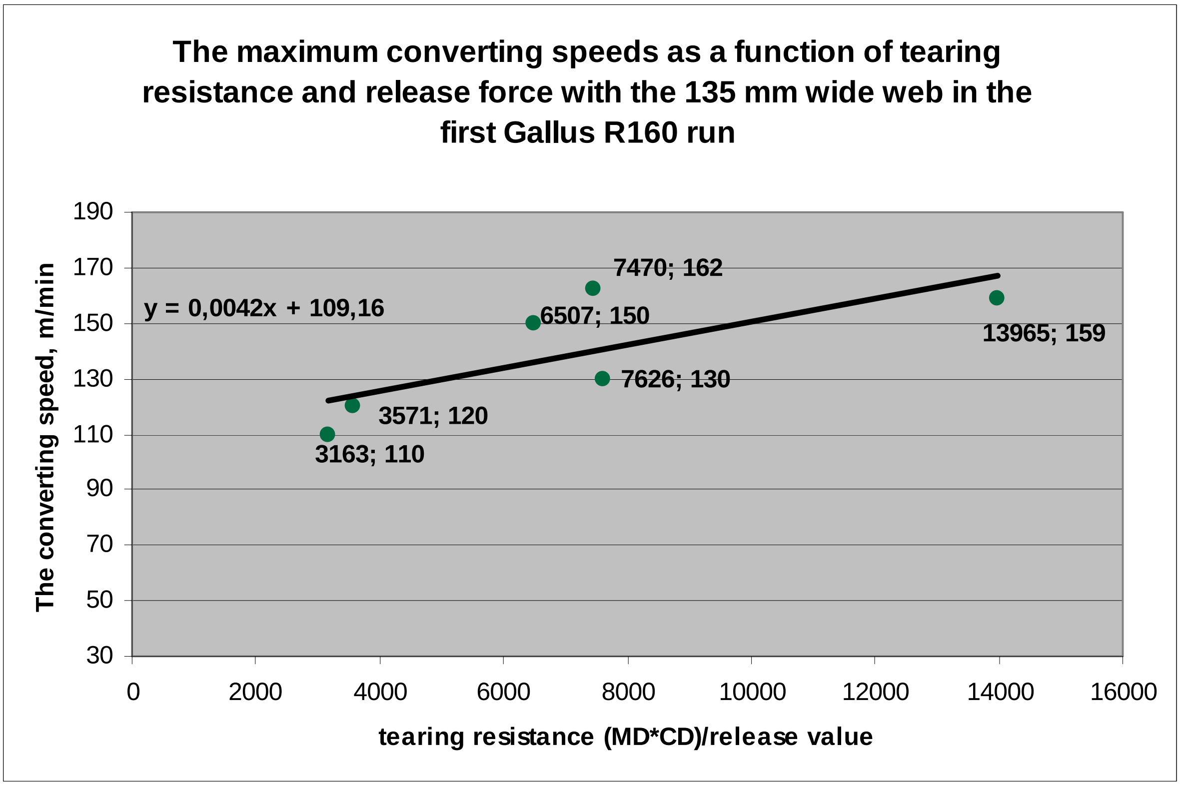
The maximum converting speeds as a function of fracture toughness and release force with the 135 mm and 155 mm wide webs in the first Gallus R160 run

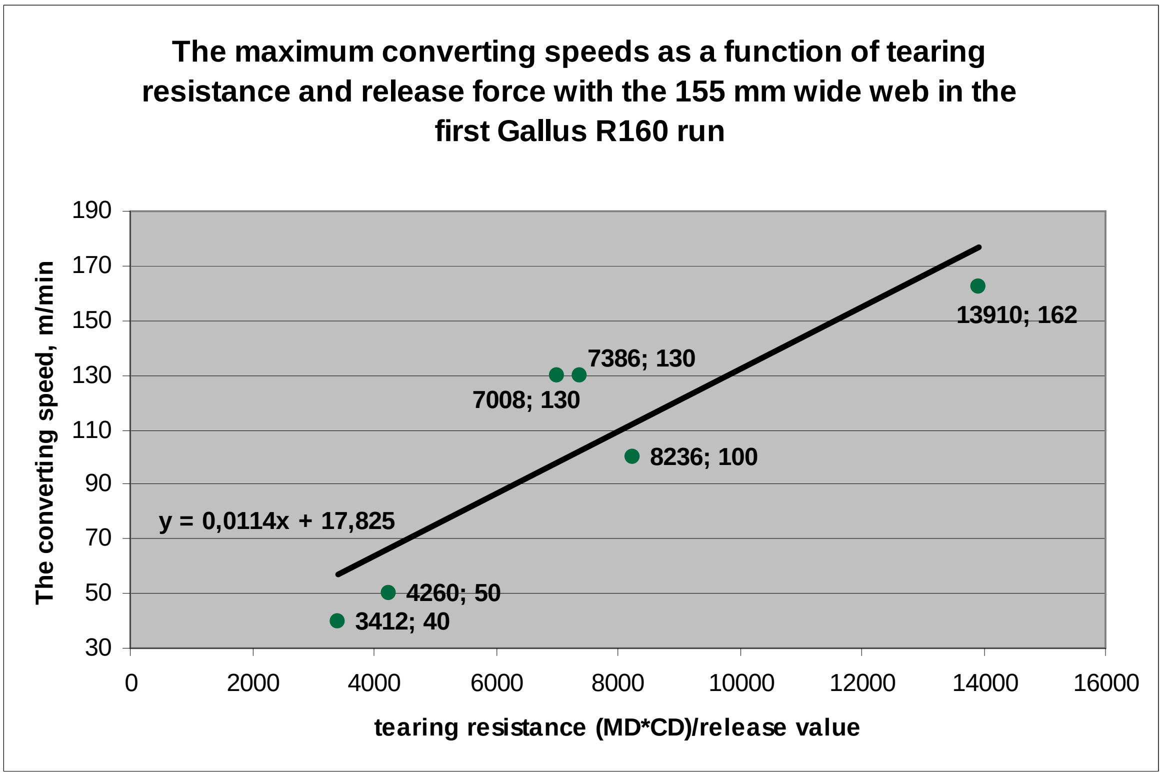




APPENDIX 9.

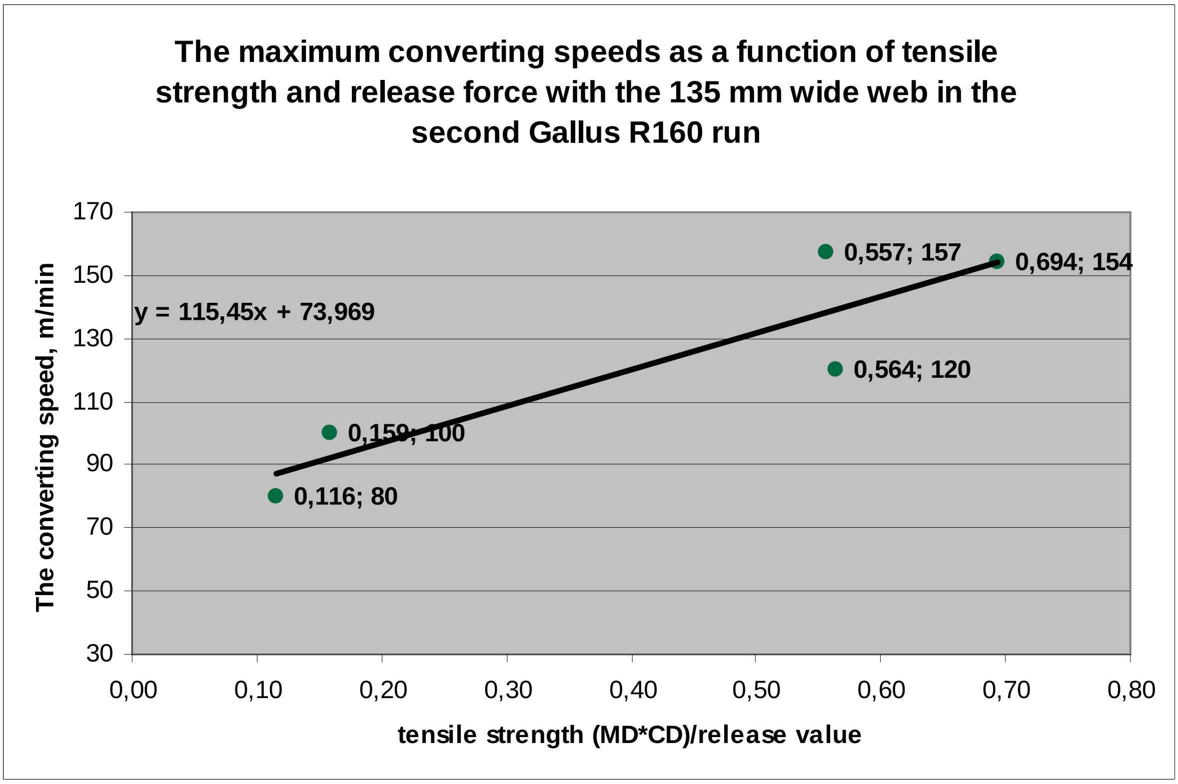
The maximum converting speeds as a function of tearing resistance and release force with the 135 mm and 155 mm wide webs in the first Gallus R160 run

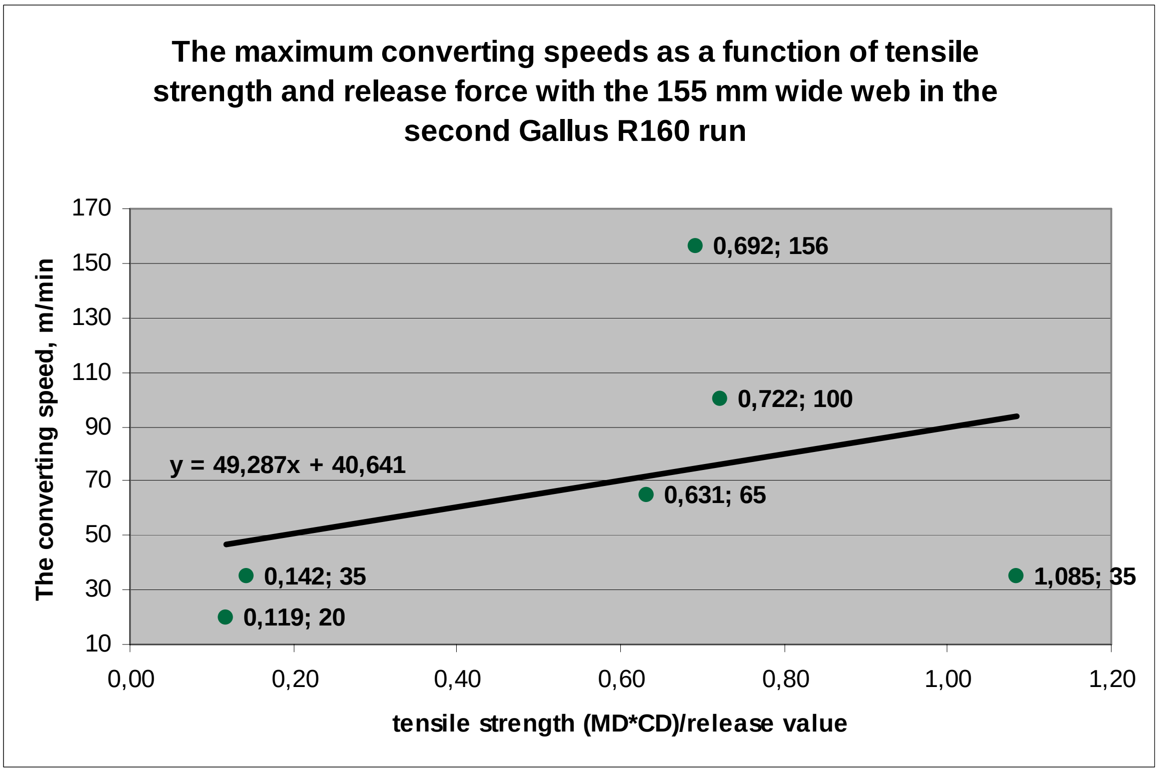




APPENDIX 10.

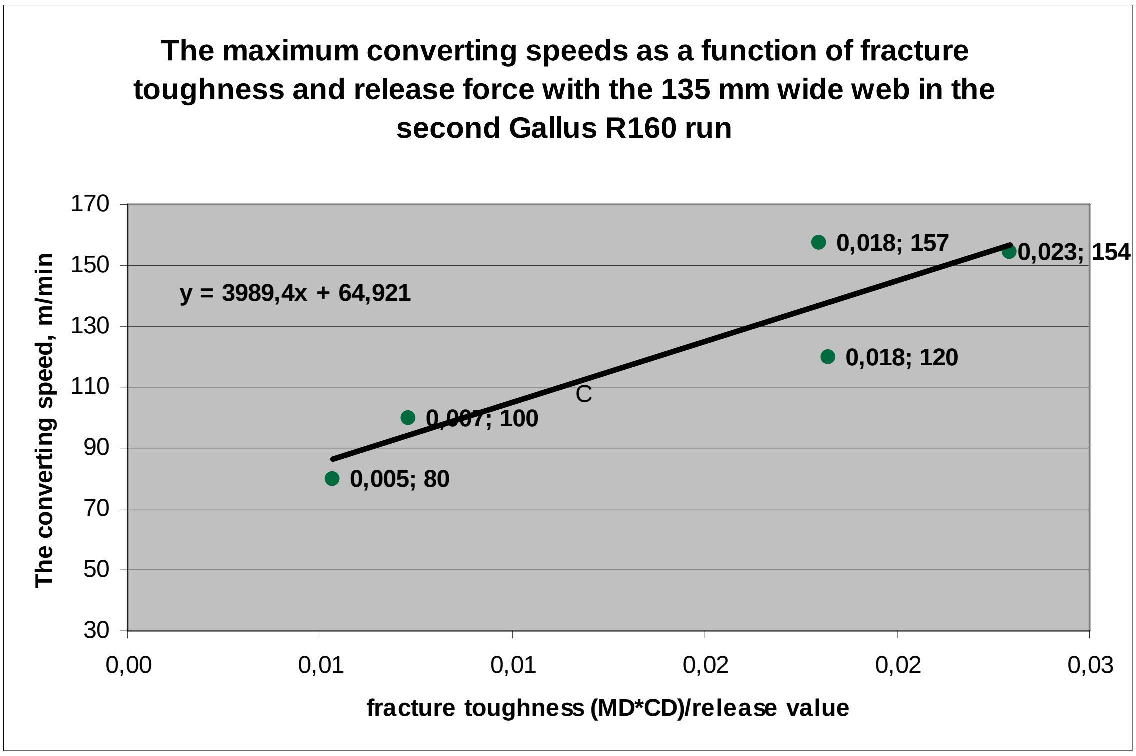
The maximum converting speeds as a function of tensile strength and release force with the 135 mm and 155 mm wide webs in the second Gallus R160 run

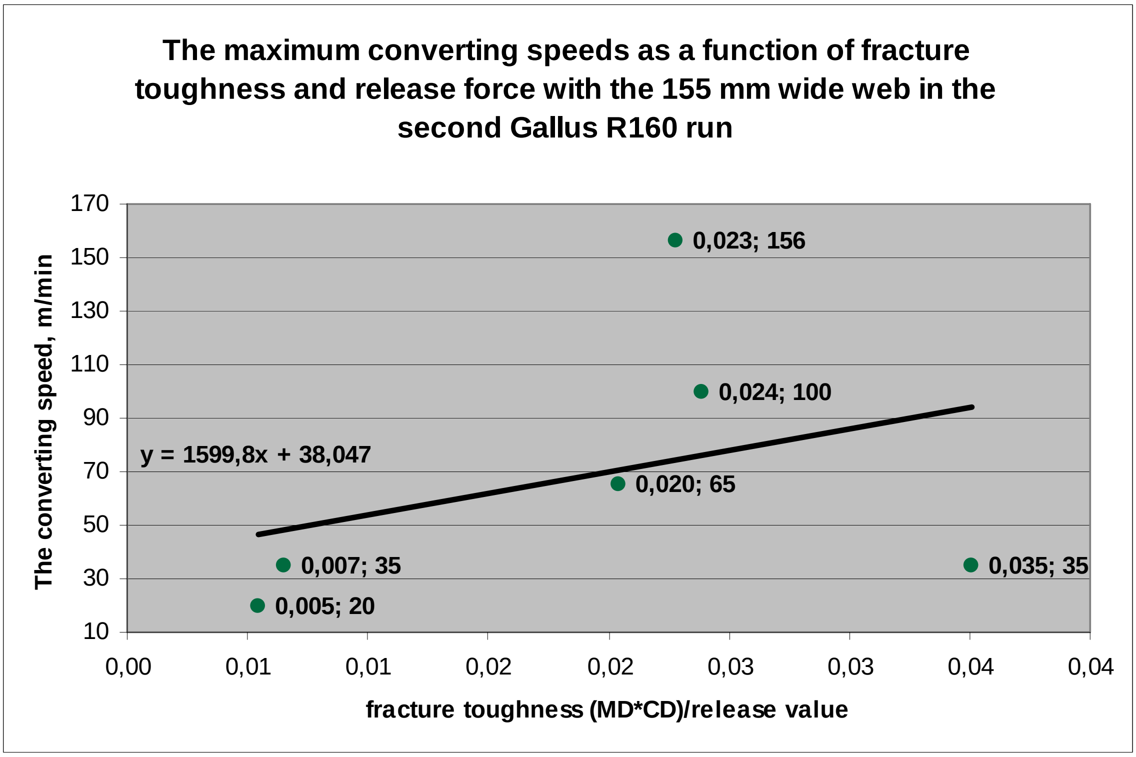




APPENDIX 11.

The maximum converting speeds as a function of fracture toughness and release force with the 135 mm and 155 mm wide webs in the second Gallus R160 run





APPENDIX 12.

The maximum converting speeds as a function of fracture toughness and release force with the 135 mm and 155 mm wide webs in the second Gallus R160 run