ROLL HARDNESS MEASUREMENTS

-TOOL FOR QUALITY AND PROCESS CONTROL

LAHTI UNIVERSITY
OF APPLIED SCIENCES
Plastics engineering
Bachelor’s thesis
Autumn 2007
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FOREWORD

I would like to thank all the people who instructed me and were willing to share their knowledge with me, which helped me to complete this thesis. También quiero dar las gracias al personal de Wipak Iberica. Si volvemos a encontrarnos en el futuro espero que pueda hablar mejor castellano que antes con vosotros. Muchas gracias por todo.

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Bachelor's thesis in plastics engineering, 36 pages, 6 appendices

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ABSTRACT

The object of this thesis was to investigate the measuring of roll hardness and whether it could be implemented as a part of quality or process control. The thesis was commissioned by Wipak Iberica from Spain, and it was started during late winter 2007. The measurements were taken using two roll hardness devices. The other device was Tapio RQP manufactured by Tapio technologies, and the other was PARotester II manufactured by Proseq. The measurements were made mainly at the factory of Iberica, but a few check measurements were taken in Wipak Nastola factory.

The beginning of the thesis includes chapters of terminology used in plastics industry; the production methods of plastic film and the concept of roll hardness are explained. Both basic and converting film production methods are dealt with. From the basic methods coextrusion is explained, the converting methods cover printing, slitting and lamination. In the second section the focus is on the hardness measurements devices, and on the measurements. Also, the analysis of the results and the issues, which have to be taken into consideration when implementing the device are discussed.

As a result of this thesis one can say that roll hardness measurements will give information about the process conditions and the quality of the roll if they are correctly utilised. But this requires a basic database of measuring results, which cannot be retrieved anywhere. Once the database is created, it will help to lower the costs and enchance the process quality.

Keywords: Plastic film, Roll hardness, Quality improvement, Test procedures

Lahden ammattikorkeakoulu
Muovitekniikan koulutusohjelma

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Rullakovuusmittaukset
Työkalu prosessin- ja laadunvalvontaan

Muovitekniikan opinnäytetyö, 36 sivua, 6 liitesivua

Syksy 2007

TIIVISTELMÄ

Tässä opinnäytetyössä tutkitaan rullakovuuden mittaamista ja sen soveltuvuutta tuotantokäyttöön osana laadun tai prosessin valvontaa. Työn tilaajana oli Wipak Iberica Espanjasta ja se aloitettiin kevättalvella 2007. Mittaukset suoritettiin käyttämällä kahta eri rullankovuusmittaukseen tarkoitettua laitetta. Toisena laitteena oli Tapio Technologiesin valmistama Tapio RQP, ja toinen laite oli Proseq:in valmistama PAROtester II. Mittaukset suoritettiin pääasiallisesti Iberican tehtailla, mutta muutama tarkistusmittaus suoritettiin Wipak Nastolan tehtaalla.

Työn alkuosa sisältää muovikalvoteollisuudessa käytettävää terminologiaa, muovikalvon tuotantomentelmiä, sekä rullakovuuden käsitteen. Tuotantomenetelmistä käydään läpi sekä perustuotantomenetelmiä kuten coekstruusio, että myöskin jalostusmenetelmiä kuten paino, leikkaus ja laminointi. Tutkimusosassa keskitytään laitteisiin, niiden avulla suoritettuihin mittauksia ja analysointiin, sekä luodaan pohjaa laitteen käyttöönotolle.

Työn tuloksena voidaan sanoa että rullakovuusmittaukset oikein hyödynnettynä antavat osviittaa prosessin tilasta ja rullan laadusta. Tämä vaatii kuitenkin mittaustulospohjan, jota ei ole mistään valmiina saatavissa. Mutta kun tulospohja on kerran luotu auttaa se alentamaan kustannuksia ja parantamaan prosessin laatua.

Avainsanat: Muovikalvo, Rullakovuus, Laadun parantaminen, Testausmenetelmät

CONTENTS

1 INTRODUCTION

The development of packaging machines has set up high demands for the runnability of the packaging materials, in this case the customer rolls. The high web speeds of the packaging machines will quickly reveal badly winded rolls, which will telescope. Telescoping always causes problems; at least it will lead to a situation where the machine web speed is lower than it could be. In the worst cases one pallet of badly winded rolls can cause severe production losses for the customer, who then surely makes a complaint about it.

Also, if the roll has been winded too tight the cores may collapse, or the roll will not unwind properly i.e. the roll is blocking. Too tight rolls may also degrade the mechanical properties of the film, which is winded if the roll is not immediately consumed. This is due to the time dependant stress relaxation, which is a common characteristic to almost any plastic material. In this process the amount of force needed to keep the same elongation will degrade when the plastic is held under force for long periods of time.

Weak runnability does not always mean poor winding, for example high deviation in thickness profile can also cause problems, if the roll has a so-called floppy edge. This floppy edge can, for example “jump off” from the transporting claws of a packaging machine. The equality of the thickness profile is also vital to the producers of plastic film, because it will decrease costs.

In Wipak Iberica the need for eliminating loose or not properly running rolls was evident as it would be for any film producer. The loose rolls cause losses in quality, money and, in the worst case, customers.

2 WIPAK

Wipak group together with its American daughter company Winpak group forms the packaging division of the Finnish, family owned multi-industry company Wihuri. Wipak itself is divided into Food, Medical, Covexx and Walothen marketing areas. Wipak group has 1 700 employees and its 12 plants are located in seven different countries in Europe. The biggest units by employees are Nastola (FI), and Walsrode (GER). (www.wipak.com.)

Wipak produces flexible and semi-rigid films for food and medical as well as to technical applications. One of the most well known trademarks for Wipak is the Steriking product family, which are used in the sterilisation of medical instruments, although the food sector is the biggest business area by turnover. Wipak is considered as the technological leader in multilayer barrier films. (www.wipak.com; & Wipak 2006.)

3 WIPAK IBERICA

Wipak Iberica is a company started as a result of Wipak group purchasing the converting business from Flexible Packaging S.A in October 2004. The Iberica unit is focused on converting films and aluminium foils. The converting services cover printing, lamination and slitting. Iberica also serves as a logistics centre for the Southern European market. Wipak raw material films come either from another Wipak factory or from an external supplier. (www.wipak.com.)

4 TERMINOLOGY

Because this thesis uses terms that are mainly used in paper, foil and film industry it is necessary to clarify the meanings of these terms. It is also common that some terms are used to describe different meanings depending from the source, and this chapter will also eliminate the possibility of misunderstandings.

Flexible packaging – Normally flexible packaging is used to describe the whole chain, which a polymer granule will go through until it is in a form of a package in a market. In this context the chain of flexible packaging is limited to the point when the product leaves Wipak in the form of a roll.

Customer roll - A roll, which is sent to a customer. It is slit from a masterroll. The slitter lines usually produce the customer rolls, but sometimes the slitting can be done in a production line online. See also masterroll.

Machine direction - Direction of the material flow through a machine, abbreviated MD.

Masterroll - Masterroll is a semi-finished roll, which acts as raw material for the converting methods such as printing, laminating or slitting. The masterroll will hold its status as long as it is inside the factory. For example, if a roll is produced in the cast line it is a masterroll, if it is then laminated or printed the masterroll status still remains. When it is slit to customer rolls the name changes accordingly. If the masterroll is sold to another company, it is referred to as a motherroll. See also customer roll.

Print design – An illustration or picture, which is printed on the film.

Rewinding - A process or a phase of a process, where flat film is rolled around a core or similar, resulting as a roll.

Telescoping - A situation in a roll unwinding process, where part of the roll travels laterally even though the core/mandrel of the roll is tightly fastened. This causes severe problems for converters. One of the main causes of telescoping is the internal slippage of the film wraps. Telescoping may also occur during handling, for example if the roll is lifted from its core. See figure 1. Telescoping is also referred to as roll shooting. See also telescoped roll.

Thickness profile - A graph, which is formed from a series of sequential thickness measurement values in TD direction. These thickness measurements are usually presented in the form of a graph, where a flat line would be the optimal situation, but in real-life the graph has always some variation. Thickness profile is sometimes also referred to as gauge profile.

Transversal Direction - Width-wise direction in the roll. Also referred to as cross machine direction. Abbreviated respectively TD or CD.

Unwinding - A process where plastic film is unrolled from a roll. Normally the mother roll is unwinded in the other end of the in a slitter machine and the customer rolls are rewinded simultaneously in the other end. See also rewinding.

Web break – In web break the continuous web such as paper or film, is broken down unexpectedly and/or unintentionally in the production or converting line. In plastic films this kind of situation can occur when the melt strength of the polymer is too low.

5 ROLL DEFECTS

In this chapter the defects, which deserve clarification, are explained. The most thorough list of the defects can be found from a book called Roll and Web Defect Terminology, 2nd Ed. by R. Duane Smith distributed by Tappi press.

Telescoped roll - A defected roll whose edges are misaligned, during handling or unwinding of the roll (see figure 1). Visually it may look like a collapsible telescope, and it is caused by internal slippage of the wraps in a roll. One of the most typical reasons for telescoping is insufficient winding tension.

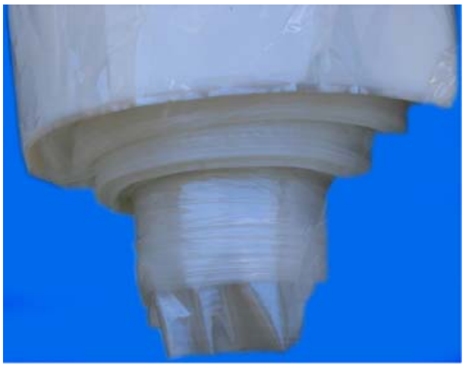

FIGURE 1. Telescoped roll

Body damage - A roll defect, which normally occurs on the surface of the roll. Damage by forklift load forks and incautious handling of the roll are the most typical reasons for body damages. Figure 2 illustrates a typical damage caused by a forklift.

FIGURE 2. Body damage

Collapsed core - Core, which has lost its round shape as in figure 3. The most typical situation for core collapsing happens when a roll is accidentally dropped on the floor. The core can also collapse due to in excessive tensions inside the roll; this can happen in plastic films if the winding tension has been high.

FIGURE 3. Collapsed core

Buckles – Buckles refer to a defect on a roll, which is caused by excessive tension differences between the inner and outer layers of the roll. An example of buckles can be seen in figure 4. Buckles have a wave type form, and they can easily be detected from the ends of the roll. Buckles are for example formed if rewinding is started with too little tension, and the tension is then raised during the process. Buckles can also cause starring.

FIGURE 4. Roll end with buckles.

Ridge - A deformation on a roll, which is usually caused by an unequal thickness profile or a baggy film. This creates a ridge to the roll, which can be seen in figure 5. Usually cast film has these kinds of problems more often than blown film. This is because in blowing oscillation divides the thicker section equally to the whole roll. Ridges are also referred to as bands or rings.

FIGURE 5. A masterroll with a ridge

6 PRODUCTION METHODS

Thermo plastics can be processed in various ways; the most typical basic production principles are extrusion and moulding. Extrusion can be divided into several sub categories such as film blowing, casting, wire coating, coating and pipe extrusion. Moulding can roughly be divided into injection moulding, blow moulding and rotational moulding. Also combinations of the above-mentioned methods exist. (Kurri, Malén, Sandell & Virtanen 2002, 7-8) This chapter will introduce the methods, which are vital for this thesis, and widely used in flexible packaging industry.

6.1. Film blowing

In film blowing the plastic melt is fed from the extruder to the die. The die will shape the melt to a tubular form. When the melt is pulled up and air is simultaneously blown inside the tube, a continuous tube is formed. This is often referred to as the bubble. The bubble is pulled up to the nip rollers. Cooling air is applied to the bubble and the plastic will become solid on the way to the nip rollers. The nip rollers will flatten the bubble and the flat tube is then led to several other rollers before it reaches the edge-cutting unit where it is usually cut open resulting in two film tracks, which are rewinded into two rolls. The production line usually also includes a treatment station where the surface energy of the films is raised with the help of corona treatment. Appendix 1 illustrates a schematic picture of a film blowing line and it also includes a picture of a nip oscillation station, which is a typical way of reducing the defects of unequal thickness profile. (Kurri, Malén, Sandell & Virtanen 2002, 102-104.)

The film blowing line has several parameters, which are used for controlling the process: nip speed, winding tension, extruder temperatures, blow ratio, push-pull ratio, the amount of air and cooling operations. This is why modern film blowing line has a process CPU, which measures and controls the process parameters according to the set up parameters given by the operator. This will enhance the quality and productivity of a film blowing line. (Kurri, Malén, Sandell & Virtanen 2002, 103-106.)

A production line may have several extruders. In such a case the process is called coextrusion. Coextrusion is also possible in casting lines. The melts of the extruders are combined in the die or just outside of the die. It is also possible to divide a melt of one extruder to several layers. The extruder amount of these kinds of production lines varies from 2 up to 10. The controlling of this kind of a process is challenging and the materials have to be carefully picked. The advantages of co-extrusion are the multiplayer films, which combine e.g. the good seal ability of low-density polyethylene PE-LD with the good barrier properties of ethylene-vinyl alcohol (EVOH). (Kurri & co 2002, 107-108.)

6.2. Winding

Winding itself is not a production method, but all the film production lines must have winders or winding stations. In flexible packaging industry there are three major winder types: a Centre winder, a centre wind with lay-on roller and a centre-surface winder (Good & Roisum 2007, 12). In flexible packaging industry the centre winder is the most typical winder type. The only method where it is not used is the slitters.

A winder is the part of the machine, which has a remarkable impact on roll hardness, but it is also dependent from the processes before it. This means that it cannot be totally controlled entirely independently. The winders are controlled via TNTs, which is an acronym for Tension, Nip, Torque and speed. The most versatile winders have all the controls available, while the simplest ones have only speed control, which acts as a tension control at the same time.

Tension can be measured with load cells, dancer roller(s) or from motor readings. The load cells will display a tension value, which the web will generate to it. The dancer roller does not give any numeric value, instead it works relatively. So if the tension is high the roller is pulled up, and if the tension is low the roller will go down. The dancer roller will also warn about the tension variations, which occur during unwinding. (Good & Roisum 2007, 5; Roisum 1998, 56.) The motor reading interpretation is based on the assumption that tension is a by-product of motor torque (Roisum 1996, 22). The tension control is important, because if the tension is too low the roll will eventually telescope and the loose web can roam during the rewind, which will result in a bad roll. On the other hand, if the tension is too high, it will cause several problems, for example in slitters the in-excessive tension can lead to a crushed core and/or stretching of the film (Good & Roisum 2007, 43).

Controlling the nip in this case means controlling of the nip pressure. Nip pressure is generated when the nip is pressed against another roller or the roll itself. Generally the higher the Nip pressure the tighter the roll. The roll may also bounce during the rewinding and increasing the nip pressure naturally reduces this phenomenon. One function of the nip is that it will prevent the air entrainment between the layers of the roll (Good & Roisum 2007, 216-217). The more air there are between the layers, the more likely the roll will telescope due to interlayer slippage (Good & Roisum 2007, 207).

Torque in this case is actually understood as the torque difference between two motors, which are winding the roll. The bigger the difference is the tighter the roll will rewind. In flexible packaging industry the torque differential controlled winders are not so common.

6.3. Film casting

In film casting the polymer is melted in an extruder and it is then led through a die. The die divides the melt equally across TD. The melt is then led with the help of an air lip to a chill roll, which cools the melt so that it can be rewinded to a roll. Normally, after cooling and before the rewinding the edges of the roll are slit away. This is because of the phenomenon of neck-in, which causes that the film edges are thicker than the rest of the film.

In casting process the thickness profile can be adjusted by heating and cooling different sections of the die lip. This is the weakness of this method because despite the fact that the production lines have high accuracy meters, the resolution of the meters can be over 2 microns. This can lead to a roll, with ridges.

6.4. Printing

Printing in plastics film industry usually means flexographic- or rotogravure-printing. For Iberica and the major part of the flexible industries flexoprinting is common. In Flexoprinting the film is driven between a big cylinder called an impression cylinder and a plate cylinder. The function of the plate cylinder is to apply the colour to the film while the function of the impression cylinder is to apply the pressure, so that the transferring of the colour is possible. After this the web usually goes through a drying tunnel where the solvents of the colours are dried out from the web. (Miller 1994, 35-38.) After drying the web is rewinded back to a roll.

6.5. Lamination

Lamination in this case is used to describe a process where two or more webs are combined with the help of an adhesive. Raw material webs are plastic film, aluminium foil and paper. Usually two plastic films or plastic and aluminium are combined; a combination of plastic film and paper is usually done with a sealing process, not in lamination. Lamination is usually performed only once, but in some applications it might be carried out two or three times. The development of multilayer film structures has lowered the need of several lamination cycles, although the need of lamination is still evident in traditional flexible packaging applications. One example would be an application, which needs good sealing properties combined with good barrier properties. This can be possible with a polyethylene-polyamide laminate. Also, the packager might want the printing to be between two films so that the printing inks are neither in touch with the food nor air. This method is often referred to as sandwich printing. (Miller 1994, 107.)

Lamination in flexible packaging has two major techniques, dry and wet laminating. The difference between these two techniques is that in dry lamination the film goes first to an adhesive spreading station, which is followed by a drying tunnel. After this it is combined with the other film or foil. In wet lamination the drying tunnel does not exist. In other words, in wet lamination the film gets the adhesive and it is joined with another film, which is the rewinded to a roll. (Miller 1994, 108-112.)

Adhesives, which are used in the lamination of flexible packaging, are usually two component glues. One component is the adhesive and the other one hardener. The glues are normally divided into solventbase and solventless groups. The latter may use water as solvent. Usually it doesn’t use solvent at all. In solventbase adhesives the most common solvent is ethylasetate. One of the major differences between solventbase and solventless glues is the curing time. It is common that solventbase glues will cure quicker than solventless glues. Another difference is the processing temperature. Solventless glues have so called low temperature grades, which can be processed in 40-60 °C.

Plastic-plastic, plastic-aluminium and plastic-aluminium-plastic laminates are done in Wipak Iberica, where one of the lamination lines is strictly used only for aluminium laminates. In Iberica the solventless glues are the only glues, which are used.

6.6. Slitting

Slitting is the last process before packing, which the roll goes through before it leaves the factory. In this context slitting is not the same as edge trimming in casting or tube slitting in blowing. Here slitting is understood as a production method, which produces customer rolls. Typically, slitting is performed in a separate slitting machine, but it is also possible to slit the rolls online in the end of another production line, such as casting. Online slitting is naturally a more cost-efficient method than slitting as a separate production phase. Traditional online slitting in a casting line is more demanding, because one has to control the rewinding of two tracks around the same core.

There are three different slitting methods for plastic films: razor cutting, crush (score) slitting and shear slitting. All the schematic figures of these three methods are shown in appendix 2. In razor slitting the film is pulled past a stationary blade. The blade generates lateral tensile stress at the blade tip, which will "slice" the web. It is the cheapest of these methods, but the blade-wore in this method is the fastest, increasing the frequency of down times. Also, a question of safety has to be taken into consideration, because in razor slitting the blades are always exposed and so they can cause wounds and accidents to the machine operators. (CEMA 1998, 1, 3, 7.)

Crush (score) slitting method is a common method for separating the web. It includes a hardened envil roll and a slitting wheel. The slitting is made when the film enters the crushing nip of these two components. The components generate compressive stress to the film, forcing it to slit. It has the poorest edge quality of all of the slitting methods and it also produces lot of dust. Changing the widths in this method is relatively easy, because the anvil roll is fixed and only the place of the slitting wheel has to be changed. (CEMA 1998, 1-2, 6.)

Shear slitting is the most versatile method when looking at the variety of materials, which can be used in the process. Shear slitting produces true shear stress with two rotating disks, which are overlapped with each other. Disks or blades are often referred to as the upper blade and the counter blade or the anvil ring. The film can pass the blades tangentially or the path can be wrapped via the anvil ring. The productivity with this method is high, although the changing of the width is a time-consuming process because the rings have to be aligned carefully. Shear slitting has also more variables to change than the other slitting methods. These facts will increase the importance of operator skills and knife holder design. Of course automation in this case will decrease the variation caused by different skill levels of operators. (CEMA 1998, 2,7.)

Slitting personal have great responsibility in customer satisfaction, because they are the last persons who can spot the film defects and prevent them to leave the factory. It is obvious that a good slitter person never leaves the workstation when the machine is on.

7 THE PROPERTIES OF A GOOD ROLL

Before discussing the quality of a roll and the control of it, a definition of a good roll has to be made. A good roll has at least the following properties:

- Correct shape, the length and the width of the roll are correct and between tolerances.

- The geometry of a roll is correct. The roll is in the form of a cylinder, and the core is placed in the middle of the end of the roll.

- Correct consistency, the roll is not too soft nor too hard
- The roll is free from defects such as buckles and telescoping

(Smith, 2007, 2.)

From these requirements width is the only property, which does not have a huge impact on the total roll quality when talking about customer rolls. All the others may have impact on other characteristics, or are the result of some other one. For example, if the core is out-of-round the roll itself is usually also out-of-round. If the roll is out-of-round it will cause that the mass of the roll is unequally distributed. This means that it will create tension variations in unwinding, which will force the unwinding operator to reduce the line speed in order to avoid problems, such as web breaks or vibration. (Good & Roisum 2007, 52.)

Most of the above mentioned properties can be achieved or lost during the last winding before the roll is sent to a customer, normally during slitting. This does not mean that the reason for a non-quality roll is always in slitting. For example, gauge variations may cause the roll to be impossible to wind without forming ridges. One reason for customer rejection can be weak lamination strength. In this situation, the hands of the slitter operator are completely tied.

8 ROLL HARDNESS

Roll hardness is a feature, which indicates something about the equality of the thickness profile and the tensions in a roll. Also a connection between roll hardness and roll density sometimes exists. The denser roll the higher hardness value it normally has. The hardness measurements are used widely in paper and in plastics industry as well. In the paper industry roll tightness and roll hardness usually have the same meaning. Basically, almost every material, which can be rolled, can also be measured for roll hardness. The materials, which are not candidates for roll hardness measurement, are too soft, such as tissue paper, or too hard such as metal.

The oldest roll hardness-measuring device, which is still in use, is no more complicated than a stick. The operator hits the roll with the stick, and listens to the sound, which the stick generates, the harder the roll the higher sound it will generate. This device of course does not give any numerical data and it is impossible to have an accurate hardness profile. But in the hands of a skilled operator, the stick can be very useful. On the other hand, stick measuring suffers from the issue that the results are highly dependent on the operator. Nowadays, the researchers do not scarify so much resource to roll hardness measurements. The pressure type methods are now be the interest of more researchers. Two of the most known pressure type methods are called pull-tab test and Smith's needle. But these measurements are not always suitable for industrial use, due to their complexity and to the time the measurement itself will take. (Good & Roisum 2007, 301-303.)

It is also more accurate to indicate the equality of film thickness with hardness measurements, than with the thickness profile measurement devices themselves. This can be explained by the fact that thickness measurement devices measure only one wrap of the film, where as the roll hardness meters evaluate the total hundreds or thousands of wraps. Also, even the best online-thickness measurement devices have an accuracy of ±1 micron. This is relatively high for example in a film where the total thickness is 25 microns and the ±1 micron accuracy, is an 8% relative accuracy (Good & Roisum 2007, 174). The hardness value itself is impossible to transform into the thickness value, but the hardness and thickness profile shapes have usually the same formations, which means that the peaks and valleys can be found from the same position from both profiles. Also, it is possible to convert the hardness values, which have been measured with different devices. However, this requires a lot of experiments, and it is usually grade dependent. (Good & Roisum 2007, 297-298.)

9 HARDNESS MEASUREMENT DEVICES

All roll hardness measuring devices work with the principle of impact. But the values are not usually compatible with each other. The simplest one of these was mentioned earlier in the text, and because it is neither a standardized method nor accurate it is left out of this chapter.

9.1. Selecting devices

Two facts were taken into consideration when the searches for the testing machines began. First, the device had to be applicable also for plastics. The second principle was that it must be possible to transfer the data electronically to an archive and/or post process the measuring data easily. Two devices were found that fulfilled both criteria: the PAROtester II and Tapio roll quality profiler. Both of them use the same kind of measuring method. The principle of the method is that an impact body is launched towards the roll, and the hardness value is calculated via the changes of the speed of the impact body.

9.2. PAROtester II

PAROtester II is a roll hardness measurement device, which was originally designed for paper rolls. The basic set includes the impact head with a 1,5 meter cable, a display device with a carrying strap and a cable to connect the device to a CPU, for the data post processing and archiving. Printer, charger cables and a calibration/test block can be obtained as accessories. The basic set is illustrated in figure 6.

FIGURE 6. PAROtester II basic measuring kit

In the measuring phase an impact body is launched by spring force perpendicularly to the examined roll. The direction of the measurement can be chosen depending on the situation. Normally, a vertical direction is used, because this causes less incorrect measurements. During the measurement the inductive sensors record the impact and rebound velocities and the display unit calculates the hardness value “L”. The L value vas introduced in 1978, and it is calculated with the following formula:

$$L = 1000 * \frac{B}{A}$$

Where

A = the maximum velocity of the measuring head before the impact
B= the maximum velocity of the measuring head after the impact

The results of the measurements can be archived for example according to roll number, and they can be transferred to a PC (PAROtester II user manual).

FIGURE 7. Measuring with PAROtester II

Measuring with PAROtester II is simple; the measuring head is placed perpendicularly to the roll (See figure 7 left side). Then it is carefully pressed down while the spring gets tensioned. After enough pressure is gained the spring will launch the impact body towards the roll (See figure 7 right side). After this the measuring head is carefully lifted up, a short beep sound will indicate that the machine is ready for new measurement. The L-value of the last hit numeric value is displayed on the screen. Also, the values of the previous measurements are displayed in a form of a histogram, and this histogram represents the hardness profile. The manufacturer recommends that the distance between the two measuring points should be 50-100 mm, depending on the accuracy wanted and on the material measured. (PAROtester II user manual.)

9.3. Tapio roll quality profiler

Tapio roll quality profiler aka Tapio RQP consists of the measuring head, which is connected to a modified tablet PC. The tablet PC can be controlled with a stylus or an external keyboard. Transferring the measuring data to other systems can be done with USB or bluetooth. The equipment is illustrated in figure 8, and an illustration of the measuring head can be found from appendix 3.

The measuring principle of Tapio is quite similar to the PAROtester II, but the measuring resolution is higher and also the measuring head is semiautomatic. At the beginning of the measurement the head is pressed perpendicularly at the roll and the motor of the impact body starts working. After one second the head is moved steadily towards the other end. At the end of the roll the head is lifted up and the impact body stops moving. The head measures the distance and the deacceleration of the impact body simultaneously. The hit frequency of the impact head is 10 hits per second. The resolution of the measurement is determined by the speed of the measuring head. When the speed is high the amount of the impacts is low per metre and when the speed is low the amount of the impacts is increased. The distance meter normally records the distance every 1 cm, this can be changed to 0,5 cm, which will also raise the resolution. Changing the distance meter settings can only be done by the manufacturer of the device. (Tapio RQP Roll Hardness Profiler –Operating Manual; Palosuo & Mustonen, 2007.)

FIGURE 8. The Tapio RQP equipment

10 MEASURING PROCEDURES

When planning the measurements, there was one major issue that affected the planning of the tests. It was the fact that there is no reliable measuring data, results or references to compare the results with, neither from paper nor plastics. One of the major reasons for this situation is that the hardness value is a sum of many factors and this is why one value cannot be directly generalised to all situations. Taking this into consideration it was decided that, as much measurements were taken as possible and reasonable during the testing period. The measurements were taken generally from mother rolls, but also some customer rolls were measured.

The procedures of the two devices were quite similar. Measuring included recording of the investigated material, the measuring itself and digitalization of the results when measuring with PAROtester II. Tapio did the digitalization automatically. After digitalization the results were analysed and compared with possible other graphs using Microsoft Excel. With Tapio the number of scans per roll was five, which was the recommendation of the manufacturer. Proseq, which is the manufacturer of the PAROtester II claims that the device has high accuracy. Also, one measuring cycle takes more time, than with Tapio so the number of scans was chosen to be three. At the beginning of the measurements of PAROtester II, a large deviation was noticed especially in thick films. The reason appeared to be the place of the test points, which has to be exactly same on each scan. This led to a use of a template, which helped in reducing the deviation. The template reduced the amount of the test points, but it had a great impact on reducing the deviation. The template was made so that the distance between measuring points was 55 millimetres. The picture of the template can be found from appendix 4. Appendix 5 represents the measuring graphs before and after the template use.

Because of the semiautomatic measuring nature of Tapio, the five scans were repeated from other direction, if the profile had lot of peak and valleys. In this way the possible errors could be eliminated. When doing this, the latter graph had to be mirrored in order to make the comparison.

If there was a suspicion that the data would be incorrect or corrupted the measuring was re-performed if possible. The measuring was carried out only by one person, which eliminated the possibility of measuring errors, caused by different operators.

11 RESULTS

The measurements were taken during May and June. Almost 80 rolls were tested including over 250 scans. All the measurements are not presented in this chapter. Because some measurements were so noisy that the reliable interpretation of the results was hard or almost impossible. Also, some measurements were taken in order to get a clue from the hardness value and the factors, which can affect the value. Showing and explaining these graphs individually would be rather confusing and hard. The results of these test measurements are discussed in chapter 11.5 “Factors that affect roll hardness”.

11.1. Case 1: Printed rolls

In order to find out whether the printing has effect on the hardness profile, the printed rolls were the first reasonable step in this process. Two of measurements were done with Tapio, and one with PAROtester II. The first measurement (Case

1A) was done to a printed roll, where the similar print designs are printed in side-by-side, resulting two “tracks”. Film was a laminate of aluminium and plastic film, with thickness less than 150 microns. The measuring was done with PARO-tester II.

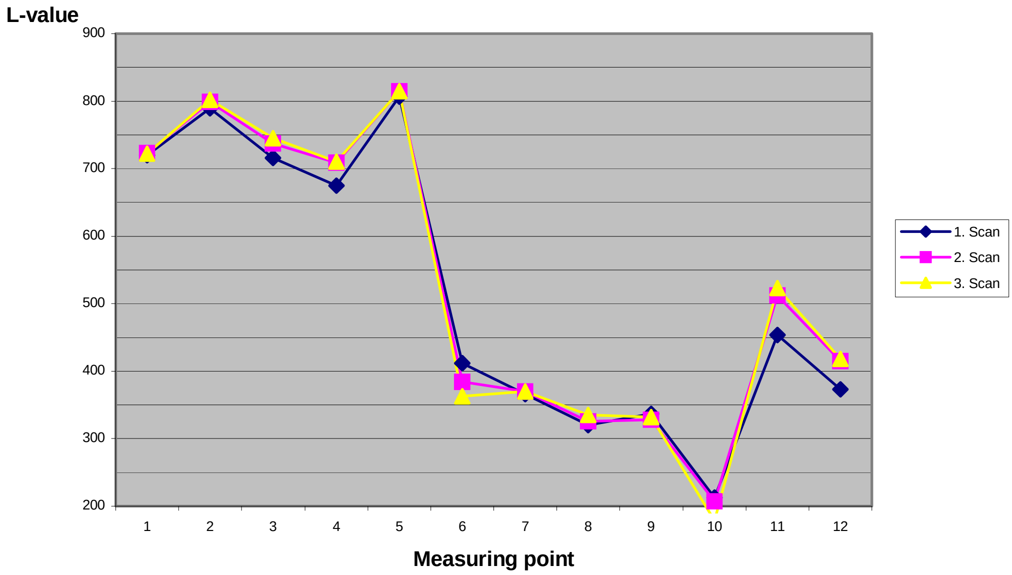

FIGURE 9. Hardness profile for case 1A

In the figure 9 the y-axel represents the hardness value (i.e. L-value) and x-axel represents the number of the order number of the measuring point. The change of the track occurs in the figure 9 at measuring point 6. Shapes of the print designs were 98% equal; only one text part was different in the designs. This can also be verified from the shape of the hardness profile of these tracks. Both of the tracks have one remarkable soft point (points 4 & 10) and one remarkable peak point (points 5 and 11). The interesting feature this hardness profile has, is the fact that it seems that the hardness value will decrease approximately 50% when the track is changed. One explanation to this could be that the designs were printed with different colours. But if this kind of behaviour were found out from equal designs, it would be possible that the colour spreading is not equal on the print machine.

In another case the measuring was done with Tapio and the target was printed film with thickness below 100 microns. The figure 10 represents the hardness profile. The deceleration value is displayed in the y-axis and the x-axis represents the distance in meters.

FIGURE 10. Hardness profile for Case 1B

The print design and colours are totally equal in this case. The design is repeated 9 times in CD. In the profile there are total of 10 soft points. 2 points are in the beginning and the end of the roll. This is typical to the roll hardness profiles, because the edges of the rolls can be much softer or harder than the average of the entire roll. This is fact that also the manufacturer of the Tapio has acknowledged, and the software enables the removal of the start and end sections of the measurement. With PAROtester II one may consider, when taking measurements, that the start and end points must have enough distance to the edges of the roll. The rest 8 soft spots are representing the less printed area between designs. From this figure it can also be seen that the same design has the same shape of hardness profile regardless of the position in the roll.

In order to find out if there is a remarkable difference in the hardness value between the different rolls of the same production lot, a third test was carried out.

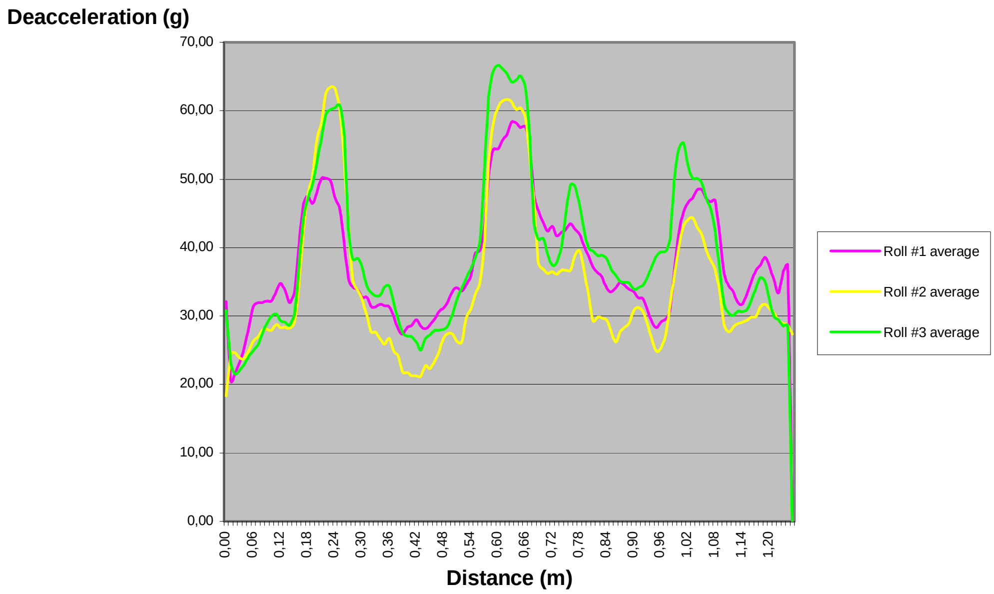

FIGURE 11. Average profile graphs of case 1C

The film was under 100 microns thick printed plastic film. The measurements were taken randomly from three rolls, which were printed in the same production run. The design was printed three times in CD, which can be detected from the figure 11. In this case deviation occurred. The maximum range between minimum and maximum value in the same point is 15 units and the average range was 7,19 with a standard deviation of 3,13. One explanation for these relatively high ranges could be that in this printing design the non-printed and printed areas overlapped. This means that in some points the printed area expanded in CD, and when these areas are piled up on a roll it may give variable results. Another explanation would be that because the rolls were selected randomly, it would be more than highly likely that they were printed to different mother rolls.

11.2. Case 2: Curing of the laminate

In flexible packaging it is generally known, that the laminate will reach its final mechanical properties after curing of the adhesive. If the environmental conditions are steady the time needed for curing will be the same for the same materials. The goal was to find out if the roll hardness is also related to the curing process. In this case the measurements were carried out with PAROtester II. The first three scans (a, b and c) were taken right after lamination, and the three last scans (1, 2 and 3) were taken after the curing was complete. The values and profiles are illustrated in figure 12.

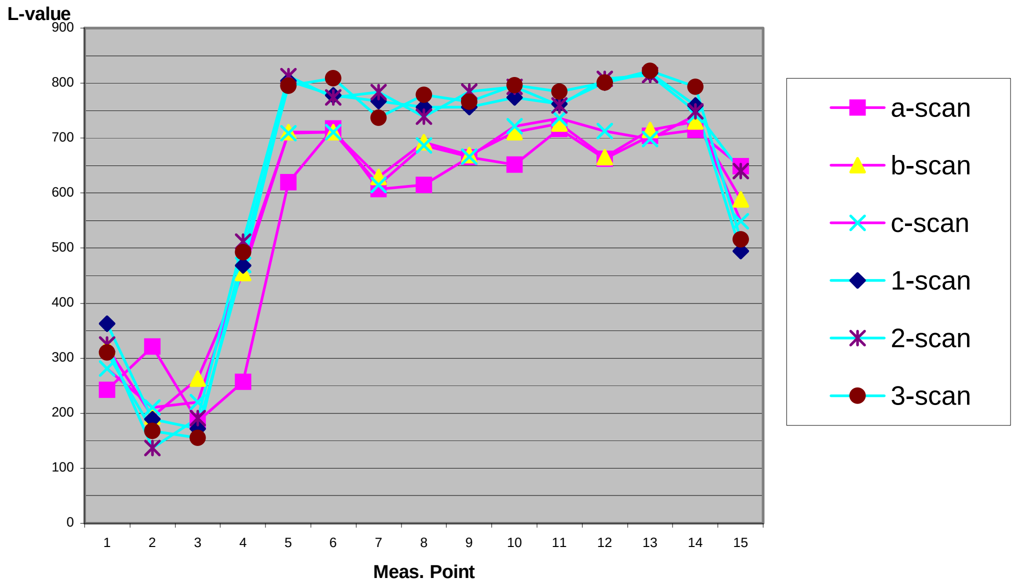

FIGURE 12. Hardness profiles for case 2

As seen in figure 12, the curing process seems to affect the roll hardness so that the roll is slightly harder after the curing is complete. This can be explained by the fact that the cured laminate has better mechanical properties than the laminate, which has just been laminated. And so it may have a higher roll hardness value.

11.3. Case 3: Identifying loose rolls

One of the concerns in flexible packaging is loose rolls. A loose roll is sensitive to telescope. Telescoping will cause handling problems and it causes also problems in all machines, which have unwinding stations. Also, if the roll has a so-called floppy edge it may fall of in the packaging machine or create wrinkles and other problems. It is more than certain that customers will return loose and telescoped rolls back to manufacturer for rewinding. This test case involved both PAROtester II and Tapio. Test results of case 4a are illustrated in figure 13, which represents the average graphs of the rolls.

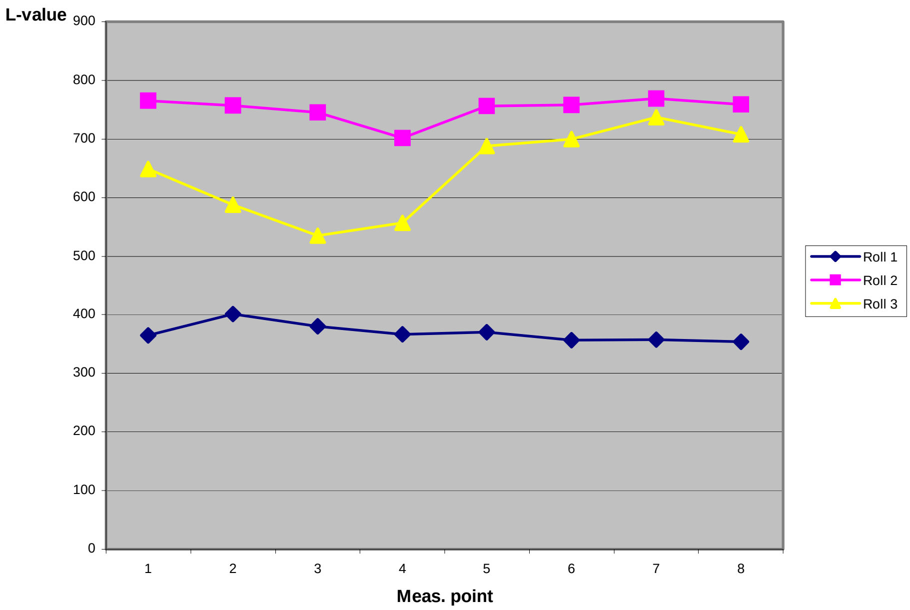

FIGURE 13 Case 4a hardness profiles.

PAROtester II was used in this case. Roll 1 was a loose roll, which was close to telescope and it was waiting for winding operation, which would tighten it up. The other two rolls were tighter ones, which were about to be sent to a customer. The difference in hardness is remarkable and also it could also be heard when measuring the rolls. The tighter rolls developed a higher tone when the impact body struck them. Roll number three is from a different mother roll, which can explain the different curve shapes compared to roll number two.

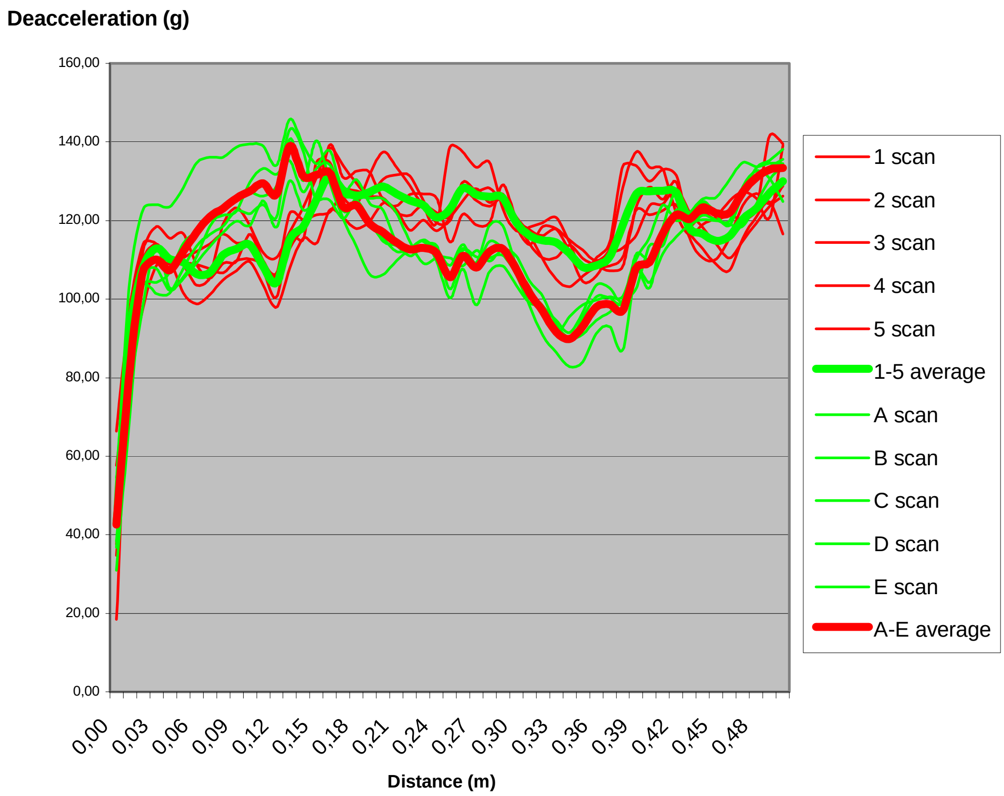

FIGURE 14 Case 4b hardness profiles

Test case 4b involved rolls, which were loose at the beginning of the test. After hardness measuring with Tapio the rolls were winded with more tension resulting a roll, which was tight enough. Another measurement was made after winding. The example profiles, which are illustrated in figure 14, have been taken from a 300 microns thick film. One remarkable fact in this case was that the film was printed, which naturally gives an unequal curve. Scans A to E illustrate the measurements before the winding in figure 14 and the scans 1 to 5 are measurements after the winding. The effect of winding can be seen in the middle of the graph. There the increased wound-in tension has increased the average roll hardness as well. The inconsistent feature in this case is that the left and right sections seem to be less hard after the winding operation. This can be a result of different winding machine or little misalignment of the core in the winder. Also, the print design can explain this, because the printed areas have generally the higher hardness values. This means that the rewinding has highlighted the printed areas, and the opposite phenomenon has happened to unprinted areas.

11.4. Case 4: The problem of repeating length

During this case one strong relationship between roll hardness and shrinking of the film was discovered. The films involved were under 100 microns thick films, which were printed in Iberica. The problem was that the film shrinked independently and uncontrolled. The shrinking was detected if a sample of a film was cut. The cut sample was drawn two lines. The distance of those lines from each other was measured. After a couple of hours the distance was measured again and it nearly always had a smaller value than in the beginning. It vas also noticed that the changes in the distance was not equal in all parts of the film. Shrinking would not have been so big issue if the film would have not been printed, but because of printing an issue of repeating length arose. Rolls were measured with Tapio and the average hardness value was depending of the roll between 100 and 110. A normal slit roll of this thickness has a hardness value maximum of 80.

11.5. Factors that affect roll hardness (Case 5)

The results and experiences from the results are gathered up in this case. In figure 15, these factors are summed up among with the results of previous cases. This fish-bone diagram shows all the factors that will affect the roll hardness value.

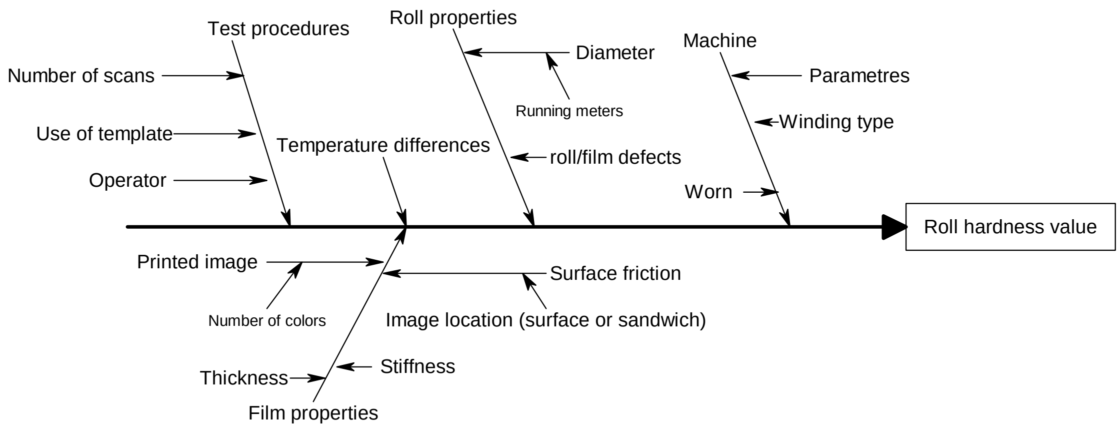

FIGURE 15. Roll hardness fish-bone diagram

There is one factor in the diagram, which does not directly cause variation to roll hardness value, but it has to be taken into consideration when roll hardness level has to be defined. This factor is the surface friction. If we would have two similar films with the same properties, for except the friction, the roll hardness should be higher if we are trying to wind as loose as possible. This can be explained simply by the fact that telescoping occurs when the friction force between the film wraps is too low to maintain the lateral position of the two wraps. The pressure, on the other hand, increases the friction force, and when the interlayer pressure is increased so is the roll hardness value.

One problematic factor is the thickness, or actually the manufacturing process of thick films. Thickness causes variation to the hardness curves, and it is also a factor, which is determined by the end application. Thick films (over 150 microns) are normally made with the casting method, because it is not wise to manufacture these films with the blowing method. Also, the tolerances are normally larger in cast thick films, because it is not so economical to maintain a tolerance of 1 to 5 microns in a 250-micron film thickness, as it would be for a blown film of 80-micron thickness. The bigger tolerances reflects to the hardness profile as a larger deviation.

Another factor, which may have a wide effect, is the temperature variations. In Iberica the temperature can rise greatly during summertime, and this can cause the rolls thermal expansion. If the expansion is not equal throughout the roll, tensions may occur and the hardness value can rise. An example would be that the value is measured during midday and high temperatures resulting in a lower value than if the measurements were performed during the evening. This temperature variation requires more investigation, and it might be that the variance should be very high so that it would truly affect the hardness value.

12 IMPLEMENTATION OF THE DEVICE

Implementation of the roll hardness meter can be divided into five phases:

1) Choosing inspection products
2) Defining the test procedures
3) Collecting the basic data
4) Analysis of the basic data
    a. Defining the acceptance and control limits
    b. Selecting correcting actions
5) Start up of full-scale production measurements

Implementation phases should be carefully planned, so that the implementation could be a success. It could be wise to start the measurements with only a few products, and when the experience rises, expand the range of products via repeating the phases. The following chapters will handle the implementation of the PAROtester II from the view of using the device on slitters, where the goal is to eliminate the loose customer rolls. Other useful implementation areas for Iberica could be that it would work as a part of the acceptance inspection of purchased rolls outside the factory, or in the observation of printing or laminating process.

12.1. Choosing inspection products

Based on the experiences of earlier measurements it would be wise to start the implementation with non-cast and non-printed products, which have the lowest measuring noise levels. When we have limited the selection to these grades, if necessary, we can narrow it down more by selecting the grades, which are the most problematic ones. One example could be flexible film grade with low friction. The winding of this kind of a product to a customer roll can be very problematic, if it is winded too loose it will telescope but if it is winded too hard it can unwind poorly or the core may collapse due to excessive tensions. One way of choosing the materials would be claim-based selections. In this method the measurements are targeted to those materials or product families, which have the highest amount of claims.

12.2. Defining the test procedures

When we have selected the test grades, we can start to think about the test procedures. One issue here is the amount of test points and the amount of scans. Normally in thin grades one scan is enough, because the variation is low. The number of test points could be related to the customer roll width. In a normal situation three points should be enough for thin grades, but if the roll width is more than 600 mm the number of the test points should be raised to four even to five points. Also, if the diameter-width ratio is high, it would be proper to increase the amount of the test points. The ratio is high if we have narrow customer rolls, which are winded to large rolls with big diameter. This leads to a situation, where the mass is also relatively high compared to the width. This combination might cause the roll to be sensitive to telescope. Sensitivity is due to reason that the friction between film layers is smaller compared to the mass it has to prevent from telescoping.

It is obvious that instructions for the test procedures are compulsory. Also, an introduction of the machine and the training of the operators are vital. If necessary, a Gage R&R analysis can be performed. The instructions and training will minimize the operator dependent values and possible Gage R&R analysis can give indications if there is a need for improvements to the test procedures. Despite the fact that the PAROtester II is relatively easy to use, the importance of training should not be underestimated. Even a simplest measurement device can give different results if the measurement procedure is different enough. This is one good reason to use Gage R&R. In addition to instruction documents, another important document is a measuring card. It is not compulsory that the card will include the hardness values, because they can be stored to the device memory from where they can be transferred to a computer. An example from the card is presented in appendix 6. The measuring card could be created for example in Microsoft excel, so that it is automatically pre-filled when it is printed for the operators.

During the collection of the basic data it is important not to change all the running parameters at the same time, because this can generate noise to the results, and in the worst case, it can lead to misinterpretations during the analysis of the basic data.

Testing should be carried out always in the same phase of the production. The most economical phase for measuring, in this case, would be immediately after the new cores are placed on the machine and the slitter is running again. In this way the measurement itself would not consume normal production time so much, because the produced rolls are measured during the machine is producing new rolls. This is not necessarily the best phase, because if the rolls are found to be too loose, it is too late to correct the situation. If the beginning of the roll is winded with low tension and the tension is increased during winding too much, it will lead to buckles. On the other hand, a skilful operator can increase the tension so that the roll is still buckle free, even though the tension is raised during the winding. If the measuring is carried out so that the slitter is not started until the measuring and the necessary adjustments to the running parameters are done it leads to fewer loose rolls, but on the other hand, it will increase the idle time of the slitter, which can be costly in some situations. The optimum solution could be in this case that at the collection phase of the basic data the measurement is done in both ways so that the greater amount of tests are done during the slitter is running. This is because the amount of the measurements is greater in the collection phase than it will be when the measurements are done in full-scale production.

In full-scale production the first measurements can be done when the slitter is idle. This will guarantee better start up running parameters. If the first measurements are good, only the control measurements must be made. The control measurements are made when in doubt and when the mother roll is changed.

12.3. Analysis of the basic data

The analysis of the basic data starts with the classification of the data. It should be done at least so that materials with equal thickness are categorised to a same class. Also, if the products with equal thicknesses have different surface friction levels, they must be separated. During the analysis, the analysers should find some strong reason-cause factors. When this happens, the first point is to think that the measured results are correct, and there is no independent and uncontrolled factor, which could cause this situation. If not, then the analysers should think which parameter or parameters cause this behaviour. When the parameter or –meters are found then the next step would be searching for proper levels for them and parameter combinations that will work. This means that minimum and maximum levels are defined for example for slitter web tension.

Another level definition must be made for the roll hardness value itself. There could be adjustment limits and acceptance limits. This means that if the roll hardness exceeds the acceptance limits, then the roll is rejected and it has to be winded again. If the control limits are exceeded, then the roll can be accepted but new measurements should be taken, and maybe slight changes in running parameters need to be done. In the third case, if the value is between acceptance and adjustment limits, then the product can be accepted without questioning. With PARO-tester II the limits are easier to define, because it turned out that the L-value is not so dependent from the grade thickness as the g-value of Tapio. It can turn out that maybe some of the values can be used for different products, which would be positive.

12.4. Start up of full-scale production measurements

The start up of the measurements should be done according to the basic data. If there are doubts that some measurements are incorrect, those products should be left out from the start up. These measurements should be done again, and after the reliability of the measurements has increased, they can be taken into production. At the start up all the operators should have used the roll hardness measurement machine already during the collection of the basic data.

The amount of the measurements in full-scale production is remarkably lower than during the collection phase. In slitters the measurements should be done to the first customer rolls. This will tell if the start-up parameters are correct. After this only control measurements should be carried out when the mother roll changes. All the measurements should be recorded with the information of the order and the number of the roll. Later on, it is helpful if the customer makes a complaint about bad winded rolls.

13 CONCLUSIONS

The goal of this thesis was to investigate the possibilities of the roll hardness measurement devices. One can say that there are several possibilities to utilize roll hardness meter, and most of them can give valuable information. Some of the most remarkable possibilities are found in the fields of goods receival and rewinding processes. The goods receival process is important to Iberica, because all the films are purchased from other facilities, and the variety in quality can be sometimes colourful between different facilities. Also, the rewinding process is important, because if the customer rolls are not winded properly the customer will definitely file a complaint about it.

When thinking about implementing on a roll hardness device it is important to think what we want to investigate with the hardness measurements. If we are satisfied to use the value to check the overall tension level we can choose the PAROtester II, but if we will need more sophisticated data from the roll Tapio would be the reasonable choice.

Another issue in what is important during the implementation is that the hardness profile itself can be very hard to interpret, and if the deviation is high the average value of the measurement is not the key to success. Deviation in the hardness profile is large if the print design of the film is complicated, or it might be true if the roll has been produced using a casting method. Roll hardness value is also not always unambiguous, and in can be a very unique value which depends on the grade, machine etc. Without any reference data from the product or previous experiences from similar products, it is almost impossible to utilize reliably. These issues will require some training of the personnel so they can learn how to interpret the values correctly. In addition to the training of the personnel, the implementation also requires a reference database. If training is done properly and the reference database is established, maybe even linked to statistical analysis methods, roll hardness can become a valuable tool, which will improve the quality and lower the costs.

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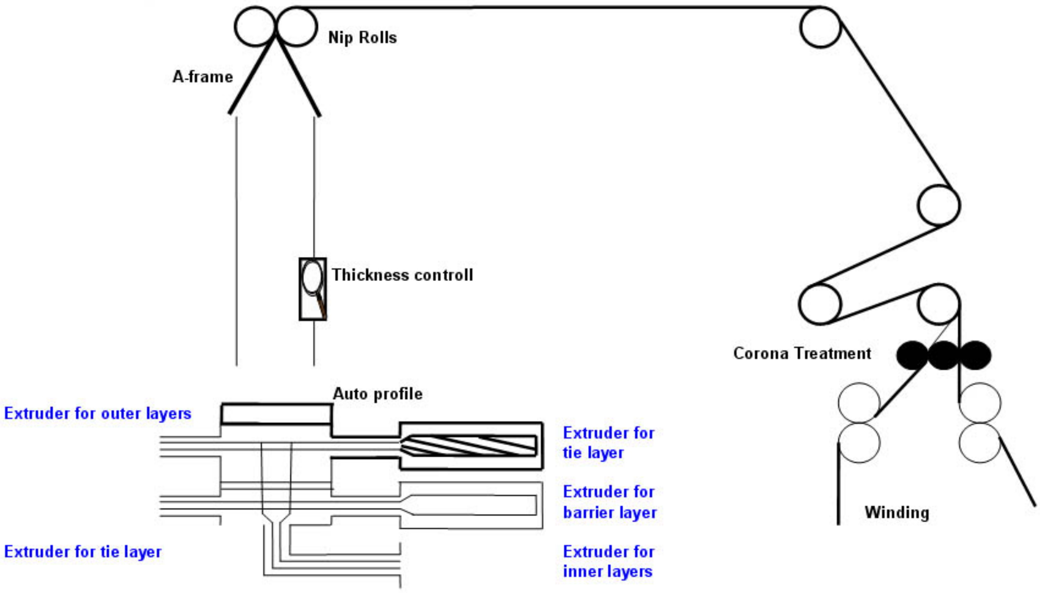
APPENDICES

APPENDIX 1

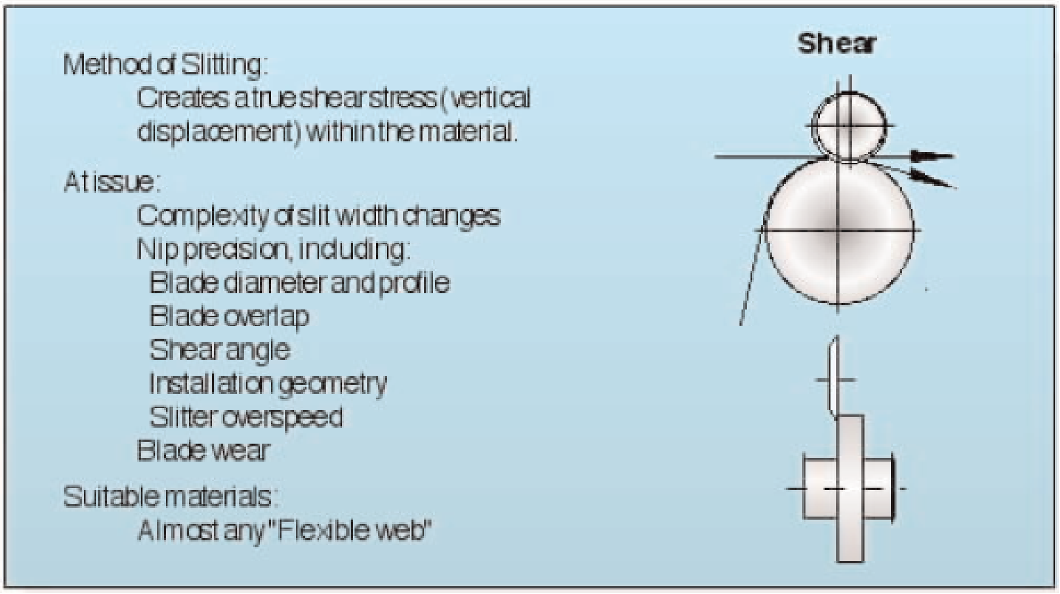
Schematic picture of a conventional coextrusion film blowing line.



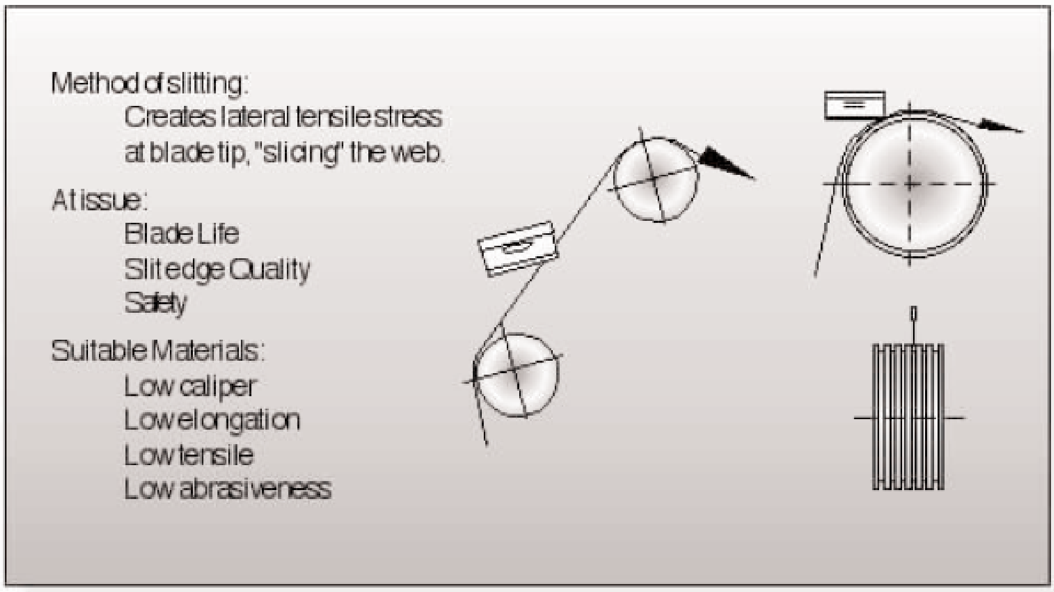
Oscillating nip haul off unit for a film blowing line (Brampton engineering)

APPENDIX 2

Shear slitting.



Razor slitting.

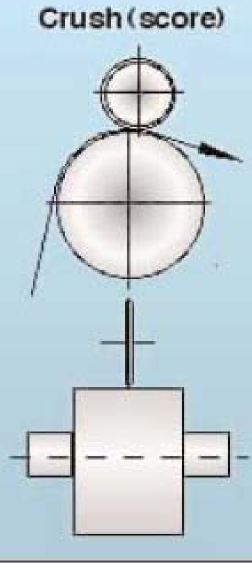


Crush slitting.

Method of slitting:
- Creates compressive stress between the slitter disk and anvil roll.

At issue:
- Blade life
- Slit Quality
- Slitting speed

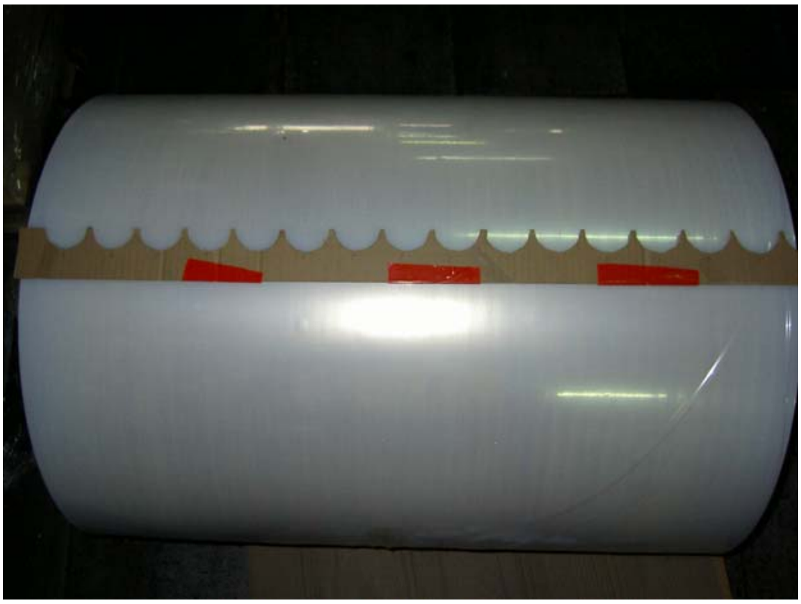
Suitable materials:
- Low Caliper
- Low density
- Low stiffness
- Low tensile
- High elongation
- High abrasiveness
- High compressibility



APPENDIX 3

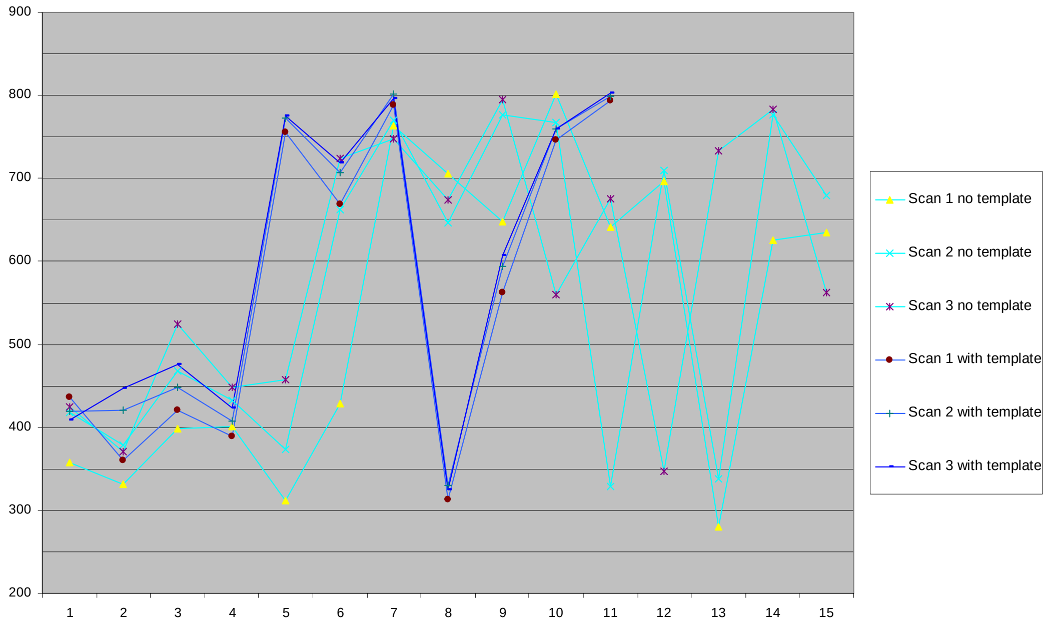
APPENDIX 4

Template for PAROtester II attached to a master roll.



APPENDIX 5

PAROtester II L-values before and after the use of a template.



APPENDIX 6

Date ______________________

Machine ______________________

Operators ______________________

Order # ______________________

Material ____

Width(s)&Times across ______________________

Thickness ________

Printed (yes/no) ______________________

	Brake	Dancer roll	Nip pressure	Web speed	Notes
Roll 1					
Roll 2					
Roll 3					
Roll 4					
Roll 5					
Roll 6					
Roll 7					
Roll 8					
Roll 9					
Roll 10					
Roll 11					
Roll 12					
Roll 13					
Roll 14					
Roll 15					
Roll 16					
Roll 17					
Roll 18					