Tampere University of Applied Sciences

IMPLEMENTING A HARDNESS PROFILE MEASUREMENT TO A CONVERTING MILL

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BACHELOR'S THESIS
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ABSTRACT

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Roll hardness profile is good indication for possible runnability problems that can be caused by several reasons from paper properties to winder settings. A mill had made an investment decision to replace the old Parotester measurement with a modern RoQ measurement for more accurate results. The aim of this work was to implement the new device to the mill and determine possible causes affecting the results.

Data was collected from base paper rolls delivered from two suppliers by using test method based on manufacturers user instructions. This data was analysed with Minitab program to compare suppliers. Trials were run at customer's premises to understand where the problem starts. Metallising process was also studied to determine if it had any impact on the hardness profile.

The metallising process did have an impact to the hardness profile. The most noticeable difference was uneven drop in the mean values across the width. Trial showed that problems start after COV% value go over 6%. Differences were spotted between suppliers in both analysed values, mean and COV%.

Appendices has been removed from public version as classified.

Key words: converting, hardness profile, paper

CONTENTS

ABBREVIATIONS AND TERMS

COV	Coefficient variation of hardness
g	Deceleration, $9{,}81\ m/s^2$ used as unit of hardness
SAL	Self-Adhesive Label

1 INTRODUCTION

This thesis work was done to Glatfelter Caerphilly Ltd. The company is investing in a new ACA RoQ roll hardness measurement device to identify and control runnability problems caused by rolls with bad profiles. These problems can be caused from various sources in base paper properties and converting process. The aim of the work is to successfully implement roll hardness testing to production and to ensure it is done as efficiently as possible. The goal is also to provide the technical team framework that can be utilized if hardness testing is seen necessary to be implemented to another product or production line.

In the theory part of this workcritical basic paper properties and how they can affect the hardness profile are discussed. Measurement principle and the basics of the test method and data collection is also explained. In the experimental part of this work the effect of these paper properties and how the converting process itself affects the hardness profile was studied. In this part the differences in suppliers, and the trials carried out with customers to determine suitable limit for hardness. Runnability were also talked about.

2 GLATFELTER

Glatfelter is a global special paper making company with eleven production sites all around the world. Products ranging from Composite laminates to metalized products and food and beverage products. The company has approximately 2600 employees worldwide and has seen rapid growth over the years after it was founded by Philip H. Glatfelter in 1864. (Glatfelter, a. 2019)

Caerphilly mill produces metallized paper for self-adhesive labels, wet glue labels and gift wrap paper. The mill has two lacquering machines one being 2,2 meters and the other one being 1,65 meters and two vacuum metallizers with corresponding widths. (Glatfelter, b. 2017)

Production process includes pre-lacquering stages where lacquer is applied with one or two rotogravure coating stations with typical coat weight of 0,8-1,6 g/m^2. This provides smoothness required to achieve product appearance and adhesion for aluminium layer. Paper is then metalized in a vacuum to produce a very thin metallized surface to achieve good appearance with minimal consumption of aluminium. Typical top coat of approximately 1 g/m^2 is applied to the metallized surface to provide a suitable surface for printing. Top coat is applied with one coating unit and the other unit is used to remoisten the paper by applying water to the back side. (Glatfelter, b. 2017)

3 BASIC PAPER PROPERTIES RELATED TO STUDIED PROBLEM

This chapter discusses about basic paper properties and how they affect the roll hardness profile and possible to runnability problems such as baggy edges.

3.1 Basis weight

Basis weight describes the weight of single sheet of paper or board in square meter. Most common unit used to describe the basis weight is g/m^2 and it is preferred over the official SI unit which is kg/m^2. Almost all other basic properties are proportional for changes to the basis weight as a result to the changes in fiber and filler amount. (Knowpap 2019)

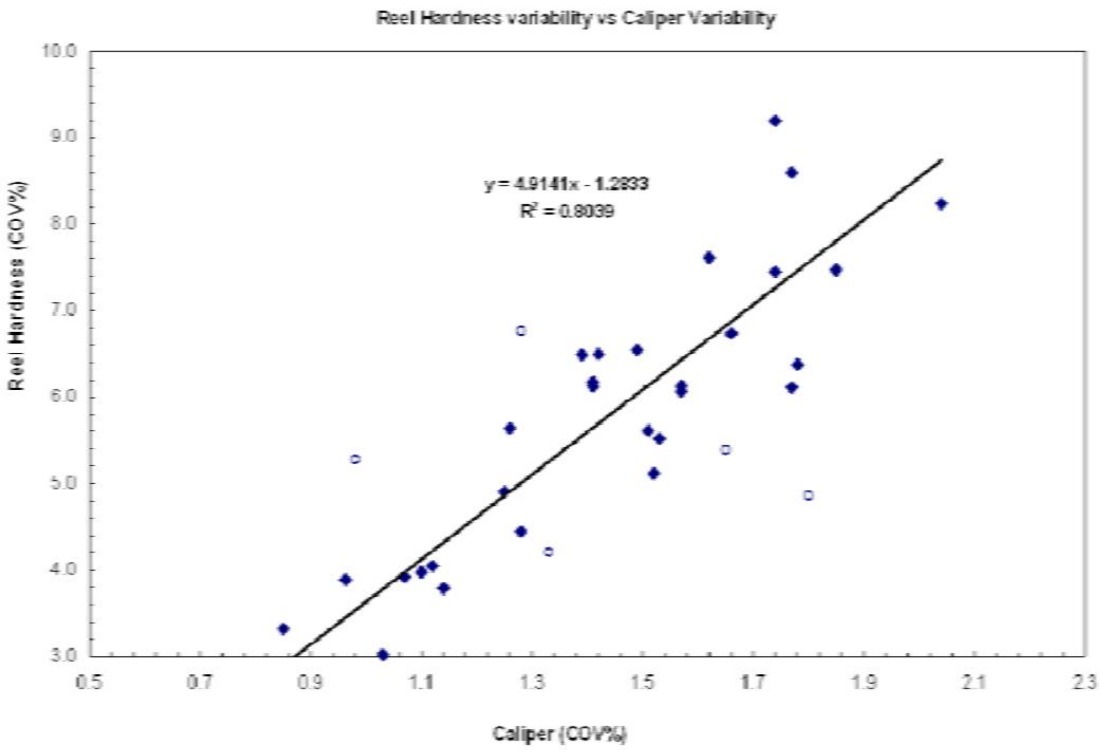
One important property related to basis weight is formation can simply be described as small-scale basis weight variation in paper. Formation also has a big influence on other measured properties, so it is important to be able to measure and determine the variation in it. There are two parameters which can be used to determine formation values, overall intensity value, which describes total grammage variation and one scale value, which describes distribution between flock size. Characterisation of macro-scale variation measured at paper machines makes the coefficient of variation, which is standard deviation divided by mean value is kept as a suitable way to measure total variability. (Knowpap. a, 2019; Norman 2008, 227)

3.2 Caliper profile

Caliper profile is a property that is related to the basis weight profile and it can also be influenced by the amount and type of calendaring method used in the manufacturing process.

According to a study by Wanigaratne, Faltas, Saunders and Virta (2010), investigation of reel hardness profile variation and paper runnability, that basis weight and caliper profile correlation is clearly visible with un-calendared grades and it can also be seen with grades that are soft-nip calendared, but not as clearly. According to study there is no clear relationship between these two in hard calendared grades. (Wanigaratne et al. 2010, 318)

The report also states that in several grades studied during the research show a close correlation between the reel hardness and the caliper profile. Observation was made when studying reel hardness COV% and caliper COV% relationship that when fitted with linear regression, the result was approximately 80%. This can be seen in picture 1. (Wanigaratne et al. 2010, 319)



PICTURE 1. Reel hardness COV% with caliper COV% (Wanigaratne et al. 2010, 319)

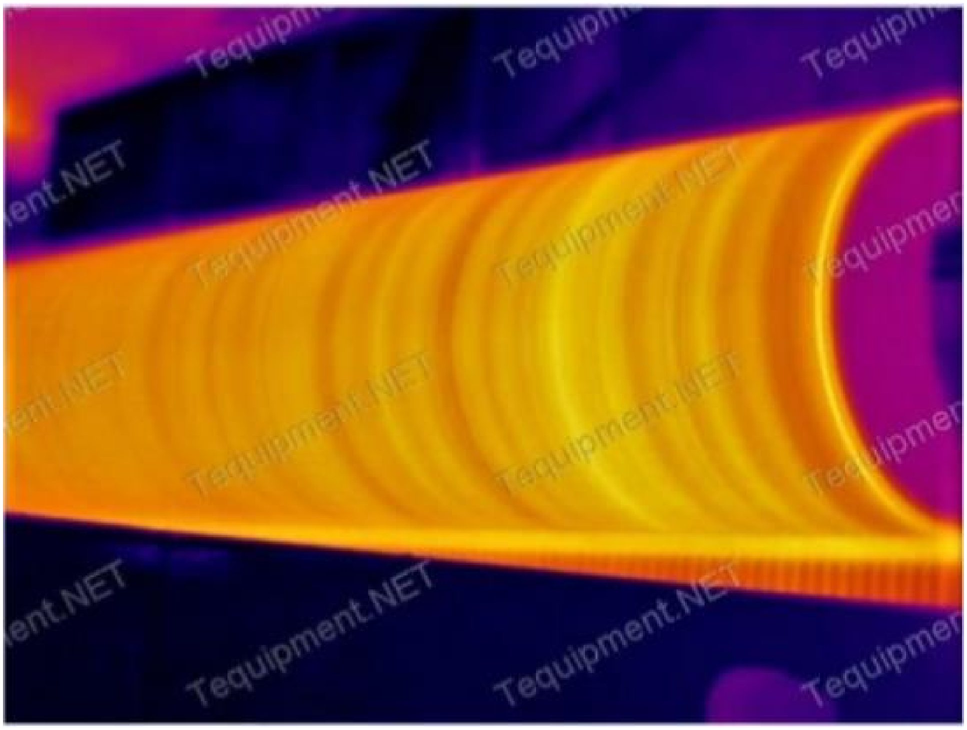
According to the report, if COV value is less than 3,5% it is unlikely to cause problems. Rolls between 3,5-6% should be assessed case by case basis and to take in consideration other factors like grammage, width of the roll and sensitivity of converting or printing press. Rolls above 6% have a high probability to cause problems. (Wanigaratne et al. 2010, 315)

3.3 Moisture profile, Plasticity and Web Tension in Drying

Moisture profile has a big impact on the tension profile of the web as it impacts to elasticity of paper which is dependent on the moisture content. During drying process different thickness layers inside the paper are not drying at the same speed which can be seen in respect to elastic and viscoelastic stresses and strains in the paper. Variating from one drying method to another, the level of paper that dies the slowest is varied. This leads to different development of elastic modulus and shrinkage variation from layer to layer in MD and CD directions. This kind of behaviour can lead to serious problems in the controlling of the behaviour of the final product. (Pakarinen, Kiiskinen, Kekko & Paltakari 2009. 269, 284)

Plasticity and viscoelasticity in paper are coming from the plasticity properties of fibres and other polymers. These materials are different on type of paper that is looked at. Uncoated papers consist mostly of wood polymers such as lignin, hemicellulose and cellulose. Coated paper consists mentioned polymers but additionally either synthetic polymers like styrene butadiene latex or natural polymers like starch. Normally, all polymers are viscoelastic and effected by increases in temperature and/or moisture. (Pakarinen et al. 2009, 243)

Pekka Komulainen (2017) presents in presentation, paper roll quality and hardness, that plasticity of paper effects to calendaring and caliper profile of the paper. He also adds that it has direct impact to roll hardness. The presentation suggests that the best CD profile to compare with roll hardness testing would be thermographic IR camera that could reliable detect small-scale moisture streaks by measuring temperature as seen in picture 2 which is used as an example. He proposes that the root cause for it is represented as dry basis weight linked to moisture detected in IR camera which might be result of variating in caliper profile and seen as a small-scale variation in paper length and in the end at the roll hardness. These kind of moisture streaks can be controlled in some level with the steam box in press section.

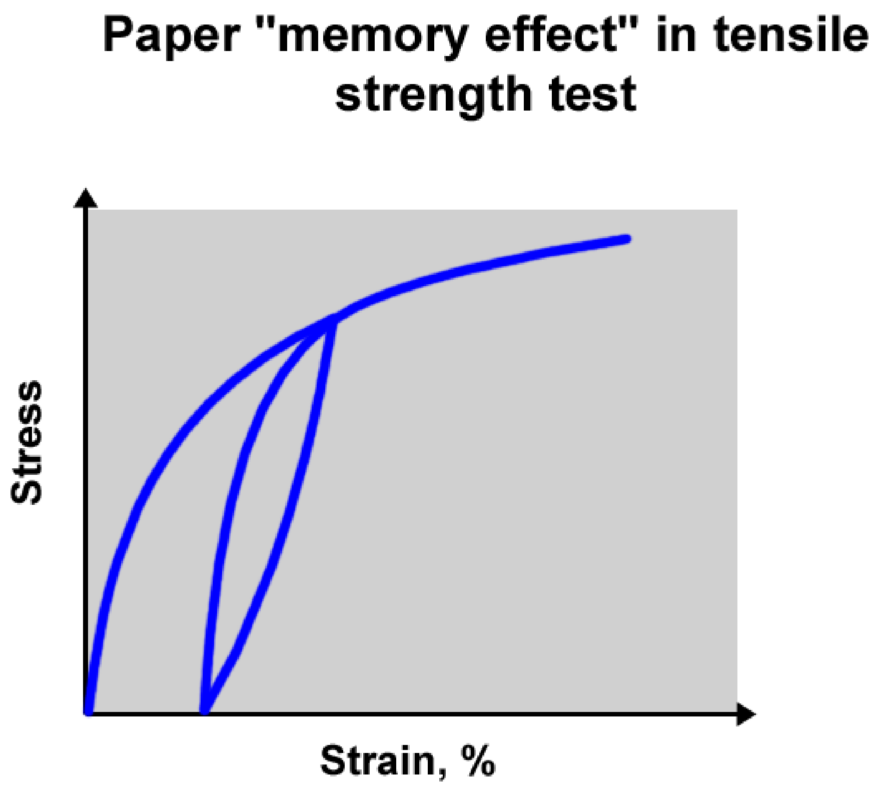


PICTURE 2. Moisture variation in paper web detected by IR camera (Komulainen, P. 2017)

3.4 Elasticity and web length

Last chapter discussed briefly about the viscoelasticity and plasticity of paper. These behaviours can be studied with paper rheology. Rheology studies how material behaves when stress is applied to it. As already mentioned paper is a viscoelastic material and when it is put under load in a tensile strength test but released before breaking point, the deformation can be divided into three categories. Immediately recovered elastic deformation, recovered elastic deformation as time function and unrecovered plastic deformation. (Knowpap, 2019b)

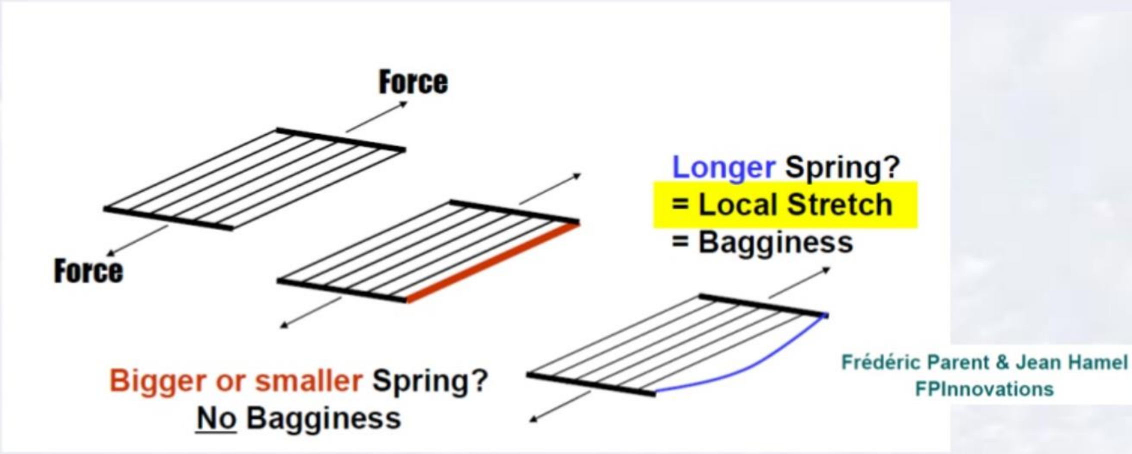
Paper has a so-called “memory effect” which is the result of paper properties and its viscoelastic nature. This effect can be seen in the tensile strength test where sample is put under load but released before the breaking point and followed by other loading with same rate, the stress-strain curve will continue on the path of the original one almost perfectly as seen in picture 3. (Knowpap.2019b) It also shows that paper does not return to its original dimensions after the first test but remains strained. This behaviour needs to be taken to account in the manufacturing process together with the used web tension as every time paper is rewinded it loses some of its elastic capacity. Uneven web tension also causes problems with uneven web length in MD as strain across the web varies in CD direction.



PICTURE 3. Paper memory effect in stress-strain curve. (Knowpap. 2019b)

Because the length of paper reels are usually many kilometres, even small differences in cross machine directional length profile leads to a substantial difference in the end. For example, 0,1% difference after 1000 meters leads to the longer part being 1 meter longer. This is usually compensated with web tension. That's why it is important to consider the CD difference in web tension, strain and original web length. (Komulainen, P. 2017)

Komulainen P (2017) uses picture 4 that we can see below from Frederic Parent & Jean Hamel to visualize how elasticity and sheet length can affect to the roll hardness and bagginess. Also noting that even if the caliper profile is good, variation in web length can cause problems with roll quality such as soft rolls or bagginess



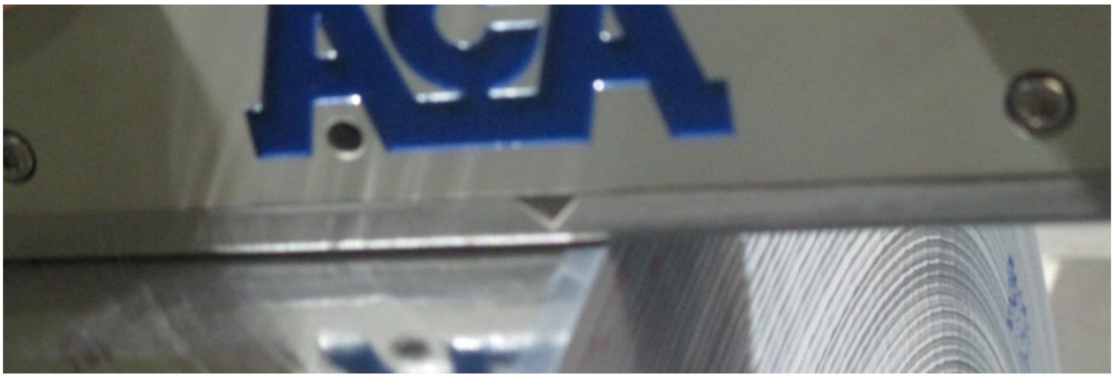
PICTURE 4. How web length and elasticity effects to roll quality. (Komulainen P. 2017)

3.5 Measurement principle and test method

ACA RoQ (picture 5) roll hardness profiler measures the hardness by hitting the surface of the roll with a small hammer with a typical frequency of 35 times per second and a maximum of 50 times per second. The device also has an implemented distance meter with a resolution of 1 mm. Force is generated by a solenoid with two coils and no springs are used. As the hammer hits the surface the device measures deceleration of the hammer and calculates the hardness which is represented as g value where 1g is 9,81 m/s^2. (ACA Oy, a. 2019)

PICTURE 5. RoQ roll hardness profiler (ACA Oy, b. 2019)

Measurements were conducted by operators and the author following the test method (appendix 1) principle. Measurements were always conducted from tending side to drive side. Measurement was done for base rolls just after they had been opened from packaging to limit possible changes from the surrounding moisture and temperature. Device was aligned with roll using the arrow in the device (picture 6.)



PICTURE 6. Aligning the device with the roll.

After the device was aligned with the roll it was pressed against the surface (picture 6) which started the measurement sequence. The device was moved against the surface in constant speed indicated in the screen with three colours (blue, green and red). If the user went slow a blue arrow was displayed. If speed was in target speed area, a green arrow was displayed. If the user went too fast a red arrow was displayed. Small speed variations were possible, and accuracy was deemed acceptable if the speed remained in the blue and greens arrows. Measurement was conducted three times to get the average values which were then used as the data was analysed. This data was then saved to a device and later downloaded to a computer (appendix 2), where it can be more closely analysed in the purposely built excel provided by the manufacturer.

4 EXPERIMENTAL PART

This chapter presents the results and the implementation process of the measurement to production. In this work hardness measurement was introduced to wider 2,2-meter machine with the focus being in SAL products. This decision was determined by studying customer feedback and observations from production.

4.1 Methods and data collection

All the data was collected with ACA RoQ roll hardness profiler. Measurements were conducted during period between February and April 2019. The test method was put together by using machine supplier manuals and test measurements to ensure reliability and fitting to production. Test method is included as appendix 1.

Base paper was delivered by two different suppliers that are named supplier A & supplier B in this part of the work. Combined amount of base paper rolls measured for this work were169 rolls. Divided between suppliers A being 90 rolls and supplier B being 79. This data was collected to an excel where data between suppliers were stored separately. The changes to the profile were also monitored by measuring rolls between each process, and how it changes through out the process. Comparison was also made between finished rolls and their corresponding base rolls.

4.2 Results

The data from base paper was collected to an excel where it was stored containing roll id, mean hardness, standard deviation, coefficient variation and range. It was determined from literature that coefficient variation or COV% is good indication of problems to runnability. Minitab was used to analyse data and to compare results between the two suppliers. When comparing mean values of the two supplier it was noted that supplier B has more consistent hardness than supplier A and it can be seen in the figure below.

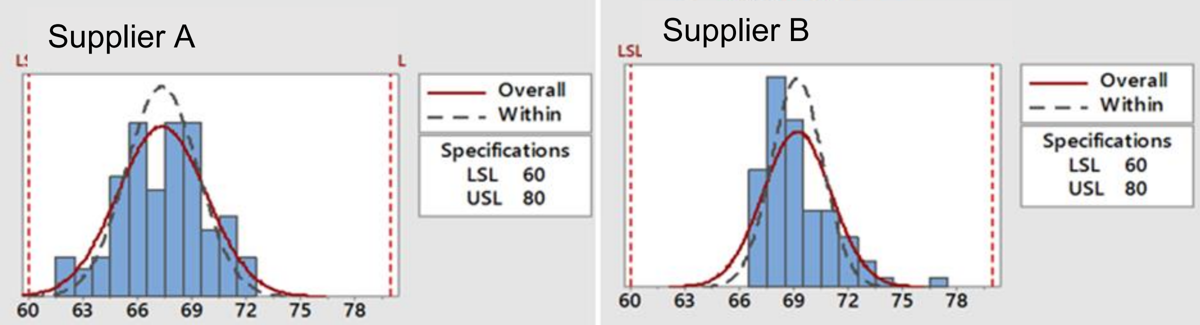


FIGURE 1. Mean hardness comparison between suppliers. In the x-axis is the mean hardness value distribution between 60-80 g, and in y-axis is the amount of results that has corresponded to that x-axis value.

Although the absolute value for hardness does not have that much effect on this application, it is a sign of consistency on what supplier can supply. COV% values were also analysed, and it was noted that supplier A has wider distribution than supplier B. This is visible in the figure 2 below. Specification was set to 1-5 as it was seen at the customer visit that it was possible to effectively run rolls full speed up to COV% value of 6.

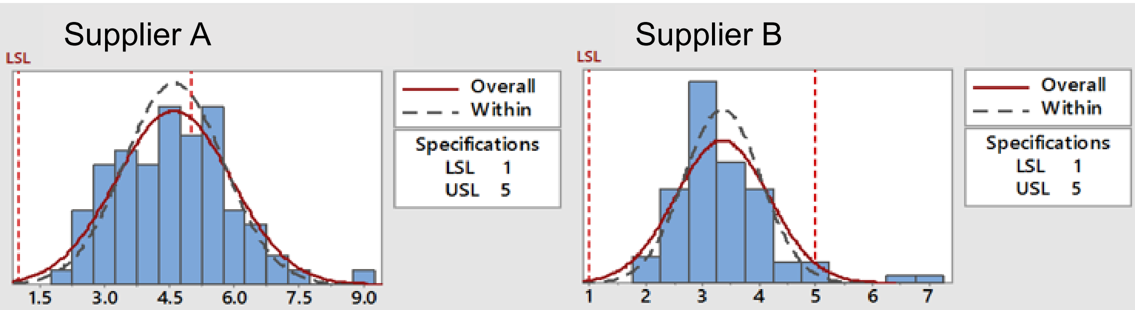
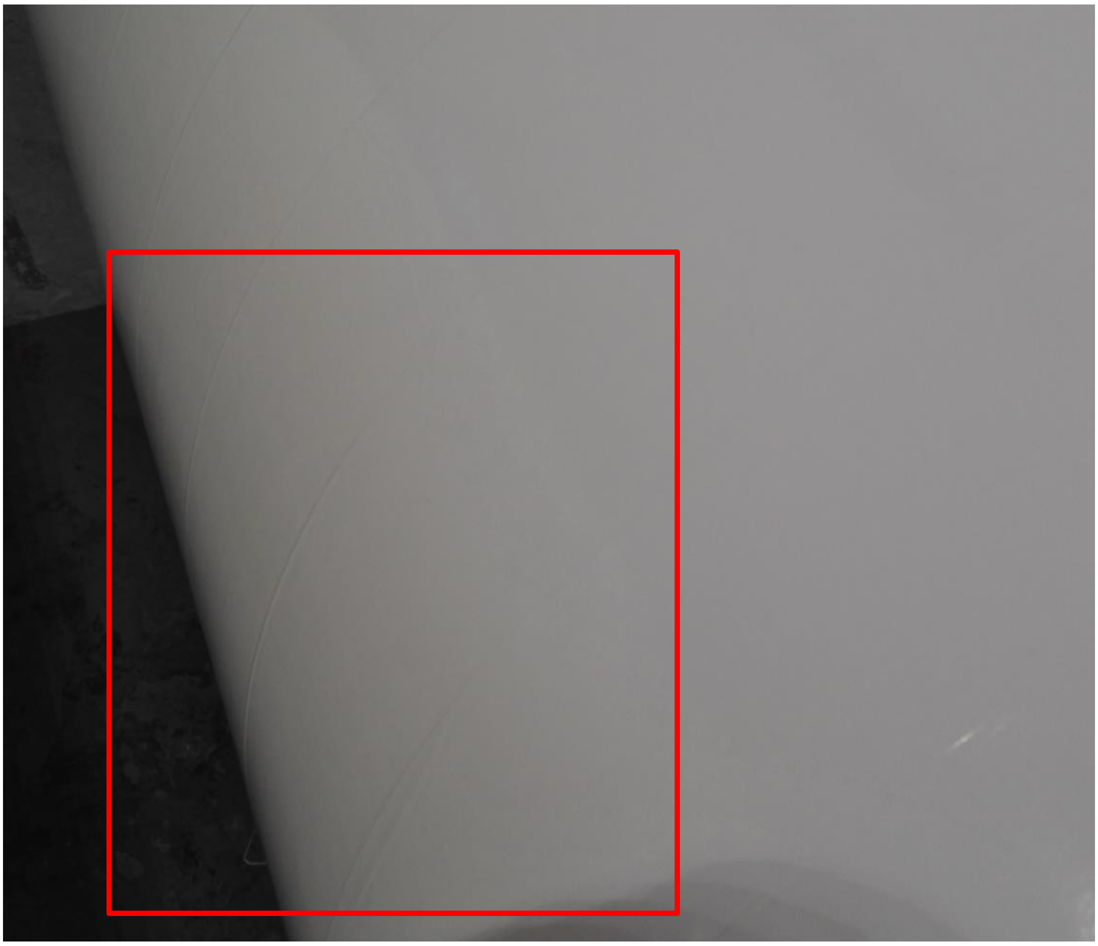


FIGURE 2. COV% comparison between suppliers. X-axis is the COV% values and y-axis is the amount of results achieved.

Predicted defective rates for these grades were surprisingly high according the data, supplier A being 38 % and supplier B being 25 %. Different surface defects caused by handling and storing, or transporting can also cause an impact on these numbers as they can cause measurement errors. Examples of these can be seen in picture 6 below.



PICTURE 6. Surface defects that can cause measurement errors.

If these were all removed broke could be as high as 30 kg per roll. These can be seen in the measurement charts as downward spikes. The device does not have a filter for these kinds of errors but due to the high amount of measurement points (approx. 1000 per 2m roll) the impact to the average result is usually small. This is visible in chart 1 as seen below. If these spikes are affecting to the result, it can be identified by evaluating if the range matches to what is seen in the chart. In these charts x-axis is always the width of the roll and y-axis is the hardness (g) values measured.

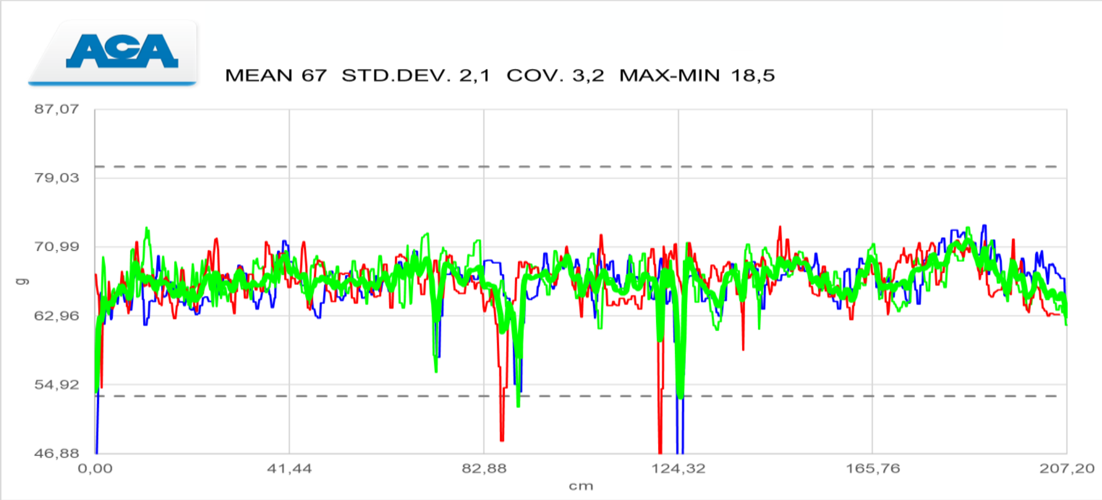


CHART 1. Possible measurement errors. X-axis being the width of the roll and Y-axis being the measured hardness value.

4.3 Process affecting to profile

To study if the process does have an effect to the profile was five rolls were picked randomly and they were measured after each stage and profiles were compared to each other to see possible changes. This is presented in charts 2 & 3 below. Chart 2 presents what the profile of base paper was just after it was opened from wrappers.

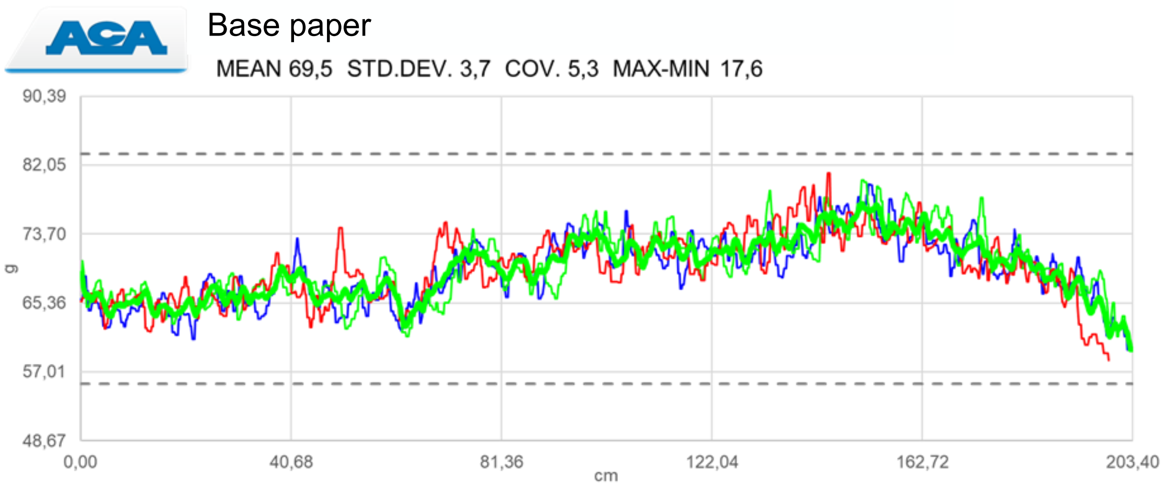


CHART 2. Base paper hardness profile after opening it from wrapping. X-axis being the width of the roll and Y-axis being the measured hardness value.

Post-lacquer did not have an effect to the hardness profile and slight changes seen in that can be caused by the changes in the profile of the paper during the length of the roll. Winding was however much softer, hardness values dropping from the base papers (chart 2) 69,5 g to 61,3 g with similar profile. Chart 3 presents profile of the same roll after post-lacquer and metallizing processes.

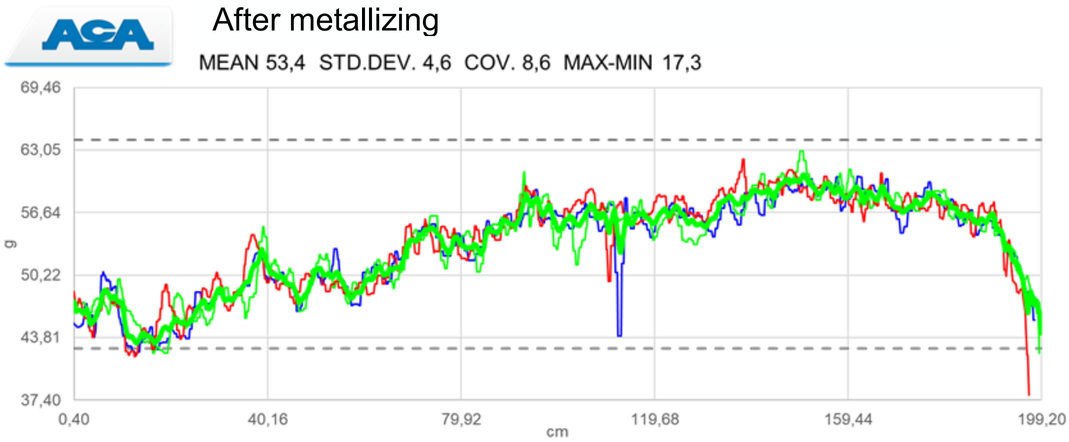


Chart 3. Hardness profile after metalizing. X-axis being the width of the roll and Y-axis being the measured hardness value.

It can be seen from the chart, that mean value is much lover that it was before metalizing but, at the same time, range or standard deviation does not have a big effect. COV value increases because the mean value is lower, but the standard deviation does not change. Winding can be soft in the metallizer because there is no air inside the machine during the process and only controllable parameter is tension.

The most noticeable difference however is the difference in shape. It was seen that the front edge tended to drop more than the back edge even when the base paper profile was flat. This would suggest that there could be something specific to this machine that is causing this, but there was no consistency in this as it was changing from batch to batch. This was noticed later when comparing data from customer order to data from corresponding base paper rolls.

Post-lacquer and remoistening process did have an impact on the profile and it did improve as seen in chart 4. Improvement rate was variating from roll to roll and most severe rolls were still noticeably different and did not recover to the same level as they were before.

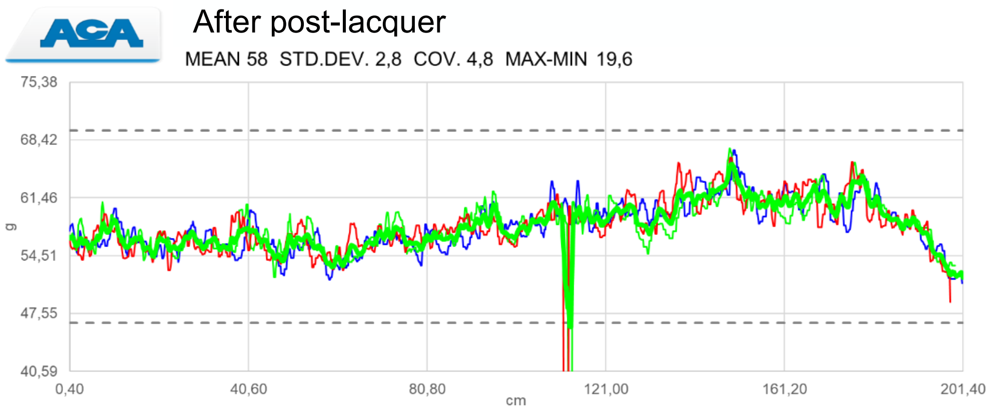


CHART 4. Hardness profile after post-lacquer. X-axis being the width of the roll and Y-axis being the measured hardness value.

4.4 Customer visit

Customer visit was conducted in the end of March as customer had reported increasing amount of runnability issues with specific grades at lamination process. Aim of the visit was to evaluate the starting point for the runnability problems when compared to the hardness profile. Aim was also to determine if storage and transport has any effect to the profile.

The test run contained two parts. The first part was to measure all the rolls that the customer had put on hold based on Parotester data. These were measured and put in order from best to worst to form running order for next day's trial based on COV value and shape of the hardness profile. One roll was also added just base on Parotester data and four rolls were also added from a new order that had been measured before shipping. These were purposely chosen according to the COV values to being the lowest and the highest to detect possible differences in them difference between them.

Table 1 contains the determined running order and results from the RoQ measurement from each roll including mean values, minimum and maximum range and COV% values. SU numbers are for tracability. From the table it can also be seen when the problem starts. White, blue and red coloured rolls run well at full speed and only slight baggy edge was seen in one edge. Roll number 3 was bad at the beginning with COV value of 6,6 but was able to be run at full speed. Rolls highlighted in yellow suffered from extensive baggy edge on the same edge as seen on previous rolls and speed had to be dropped to 80% of the target speed to run them and other parameters had to be adjusted too. Creasing was observed in the beginning of the roll for three rolls highlighted in yellow.

TABLE 1. Results from customer trial. Blue highlighted were picked from new order. No RoQ data was available in red highlighted rolls. Yellow highlighted rolls caused runnability problems.

No RoQ data available		Runnability problems, settings adjusted		Picked from new order		
Running order	SU	mean hardness (g)	min (g)	max (g)	range(g)	CoV(%)
1	45987636	66,6	57,9	71,8	14	4,3
2	45989286	71,5	63,9	78,9	15	4,8
3	45989454	66	57,4	74,3	16,9	6,6
4	45989127					
5	46041457	70,6	62,5	81,8	19,3	5,8
6	46041294	70,1	63,4	79,2	15,8	5,2
7	46041813	71,9	66,2	78,2	12	3,2
8	46041761	73,2	66	83	17	4,2
9	45934074	73,2	61,5	90,3	28,8	7,5
10	45942966	73,3	61,5	87,3	25,8	8,2
11	45989483	70,5	63,8	77,8	14	4,2
12	45933848	70,1	62	79,5	17,4	4,5
13	45958240	69,5	51,6	79,6	28	8,3
14	45934197	74,9	55,3	90,1	34,8	8,8
15	45989256	68,8	56,3	80,9	24,5	8,9
16	45958839	64,5	50,7	74	23,4	9,1
17	45933802	73	59,8	89,3	29,6	8,3
18	45958135	70,3	42,6	81,5	38,9	10,3
19	45989089	69,3	58,1	82,5	24,4	9,7
20	45990184	66,5	54,4	80,3	26	9,8

These results are in line with earlier studies made by Wanigaratne, Faltas, Saunders & Virta. Where they stated COV values above 6% would cause problems. Considering results from earlier studies and the trial made with customer that in this case rolls with COV value under 5% are very unlikely to cause problems to the customer. When values reached 6-7% it started to be very likely to cause problems.

Shipping had minimal impact to hardness profile on those four rolls that were measured. Measurements were done at factory before packaging and at the customer after packaging and small layer was removed from the surface. This can be seen in increase at mean value, but the shape of the charts stays the same. This can be seen in charts 5 & 6.

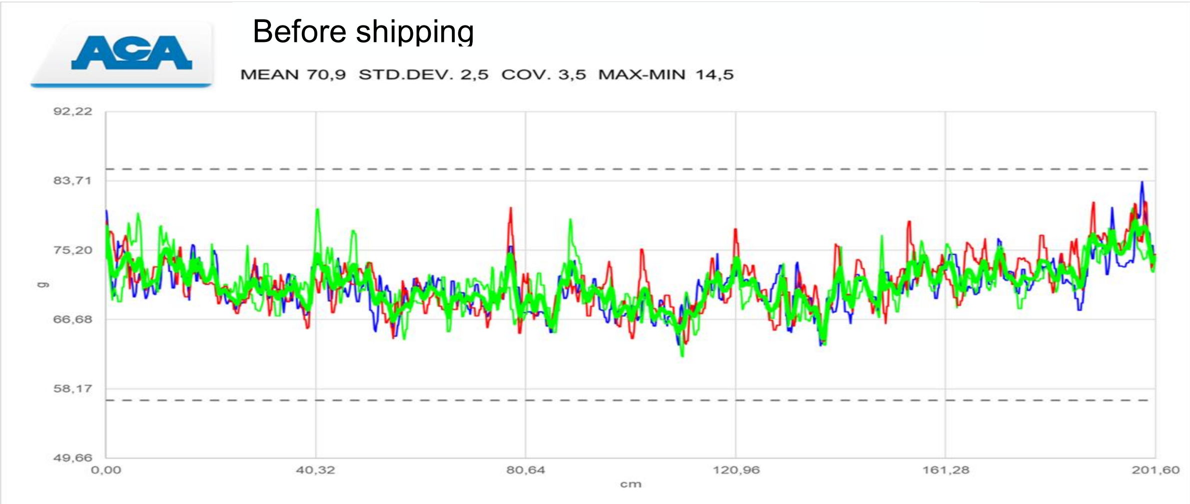


CHART 5. Hardness profile before shipping. X-axis being the width of the roll and Y-axis being the measured hardness value.

Profile is even improving little bit in some cases as seen in chart 6.

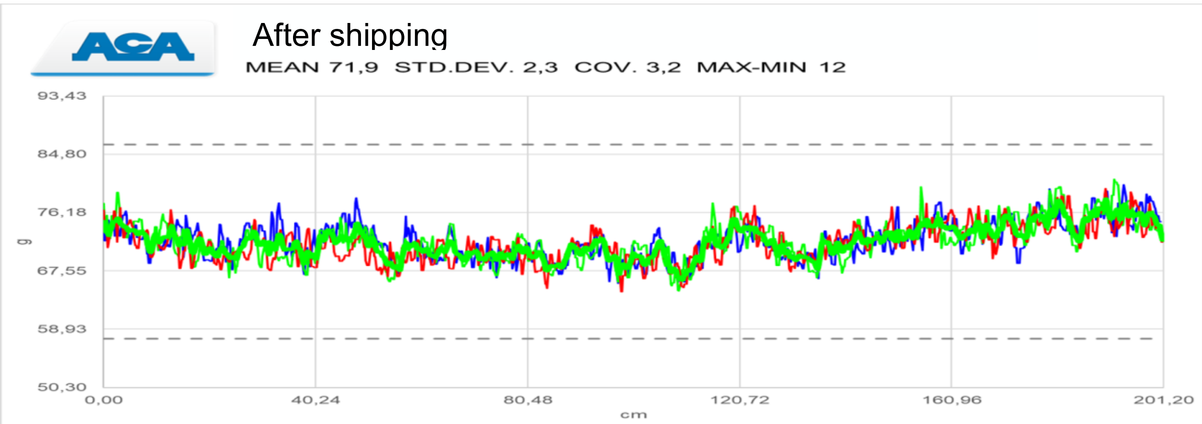


CHART 6. Hardness profile after shipping. X-axis being the width of the roll and Y-axis being the measured hardness value.

4.5 Base paper profiles compared to hardness profile

Three rolls from both suppliers were measured and profiles were compared to the hardness profile. Measured properties were moisture, grammage and thickness. On 2050mm roll 15 measurements were done across the width.

Moisture was measured with PM4 moisture meter and it was variating between rolls at 4-4,5% moisture. Maximum variation across the width was 0,6%. Grammage profiles variation was very minimal being maximum of 2,3 g/m^2 across the width. No correlation between caliper and grammage was found, which can be seen in chart 7.

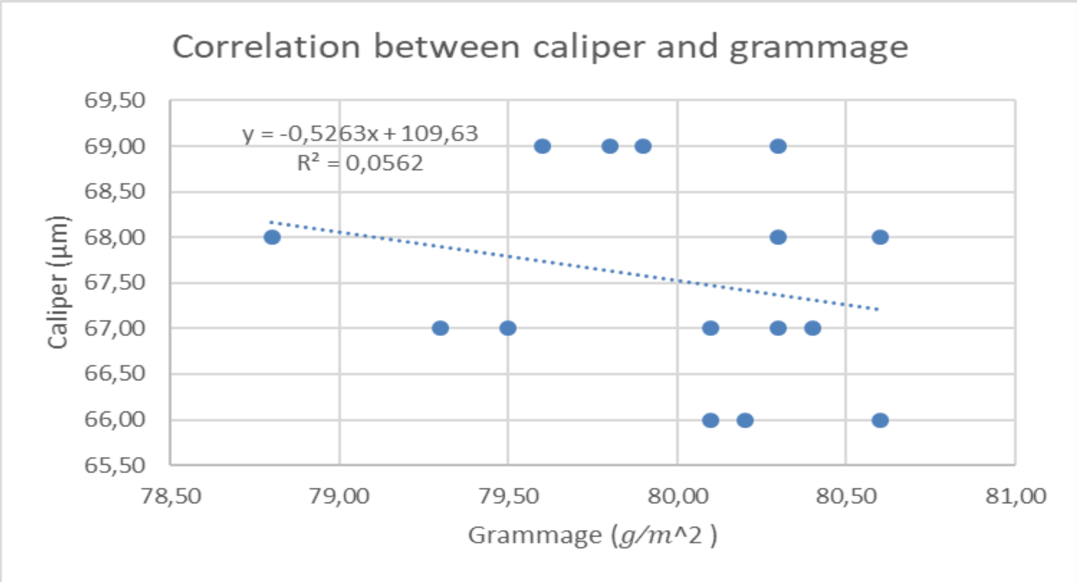


CHART 7. Correlation between caliper and grammage.

Caliper and hardness profiles were compared but no similarities were found. This is visible in chart 8 below. Supplier A did confirm that base paper is supercalandered during production which might even the caliper profile in CD direction.

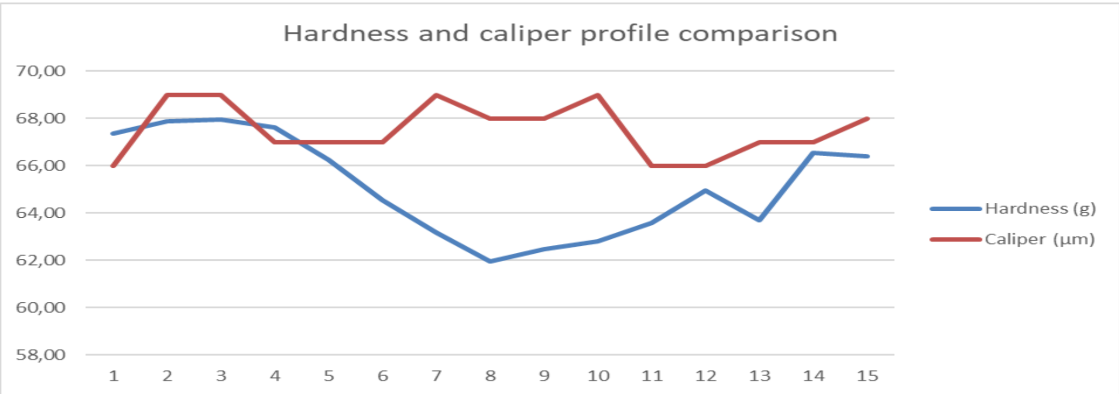


CHART 8. Hardness and caliper profile comparison. In x-axis being 15 measuring points in width and y-axis repesentin hardness and caliper measurement results.

5 CONCLUSIONS AND DISCUSSION

Base paper profile has an impact on how the hardness profile changes during converting process as bad profile is very hard to correct during the converting process. In this case no straight correlation was seen between measured paper properties and hardness profile. This is likely to come from supercalandering as presented in earlier studies that caliper profile is not likely correlate for hardness in heavily calendered grades. Differences could be coming from paper properties, that were not studied like length differences or machinery level like setting at winders. Converting process itself does also impact the profile specially metallizing. Inconsistency was also observed in the results after metallizer where relatively good profiles had radical changes to profile where the front edge was softer than the back edge. This same shape was also seen in trials with customer on the rolls that caused problems. Further studies should be made to determine root causes of the changes in profile. Online moisture profiler could be used after remoistening to ensure even results to the final product.

Trials were successful, and they gave good information where the problems started. If COV% values were over 6% it was very likely to cause problems at this customer. Result of the trial is also in line with the previous studies made regarding the subject where it was noted anything between 3,5-6% can cause problems and variates between machines a lot. This data was then used when collected base paper data was analysed so upper limit could be placed for the specification. Data showed clear difference between consistency of suppliers. Supplier A had much wider distribution in both, mean value and COV% than supplier B and predicted failure rate for set COV% specification limit was much higher than another supplier.

REFERENCES

ACA Oy, a. RoQ Roll Hardness Profiler, Measurement principle 2017. Printed 21.4.2019

ACA Oy, b. ACA RoQ - Roll hardness profiler 2019, Read 23.2.2019 https://www.aca.fi/solutions/aca-roq/

Glatfelter. a, Glatfelter.com/about us, 2019. Read 19.4.2019, http://www.glatfelter.com/about_us/default.aspx

Glatfelter. b, Metalized Paper, 2017. Internal presentation. Printed 11.2.2019

KnowPap. a, version 20.0. 2019. AEL / Proledge Oy. Products and properties. Read 8.2.2019 http://www.knowpap.com.elib.tamk.fi/extranet/english/knowpap_system/user_interfaces/paper_grades/quality.htm. (Restricted access)

KnowPap. b, version 20.0. 2019. AEL / Proledge Oy. Products and properties. Read 20.2.2019 http://www.knowpap.com.elib.tamk.fi/extranet/english/paper_board_properties/4_strength_properties/0_rheology/frame.htm. (Restricted access)

Komulainen P, 2017. Paper roll quality and roll hardness. Read 12.2.2019. Slide show, 9–30. Available at: https://www.slideshare.net/Peeke/paper-roll-quality-and-roll-hardness-1-jan-2018-85460531

Norman, B. 2008. Web forming. In book Paulapuro H. (ed.) Papermaking part 1, 2nd edition, Stock Preparation and Wet End. Helsinki: Paperi ja Puu Oy, 216–288

Pakarinen, P. Kiiskinen, H. Kekko, P. & Paltakari, J 2009. Drying and paper quality. In book Karlson, M. (ed.) Papermaking part 2, 2nd edition, Drying. Helsinki: Paperi ja Puu Oy, 236–295

Wanigaratne, D.M.S. Faltas, R. Saunders, S. Virta, M. 2010. Appita Annual General Conference and Exhibition: Investigation of reel hardness profile variation and paper runnability. [PDF]. Read 11.2.2019. Available at: https://www.tib.eu/en/search/id/tema%3ATEMA20110304112/Investigation-of-reel-hardness-profile-variation/ , 315–321 (Requires purchase)