Investigation of reel hardness profile variation and paper runnability

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ABSTRACT

The reel hardness measurements were carried out on various paper grades using a Tapio Reel Quality Profiler (RQP). The grammage and caliper profiles of the same samples were also measured using a high resolution Tapio offline paper profiler. Based on this work it was identified that a clear correlation exits between caliper and hardness profiles in cross direction (CD). The data further suggested that nearly 80% of hardness variations can be explained by the variations in caliper in CD. It was apparent that small caliper variation can be amplified to give a significant hardness variation. Caliper variations can be originated from both grammage variations and non-uniform calendering.

Further, it was apparent from this work that reel hardness profile in a parent roll does not change in corresponding customer rolls, even as there is an increase in hardness after winding. Combination of these two features (consistent harness profile in parent and customer rolls and relation between caliper and hardness profiles) can be used as a guide to fine tune the settings of a paper machine, especially at the early stages, before making tonnes of reels with “poor” profiles.

The hardness data and information collected in last five years suggested that if a hardness profile lies within ±5% of mean hardness, then the reel is unlikely to cause a runnability issue, provided that the profile does not show a distinct gradient in CD.

If the variation in reel hardness (COV %) is less than 3.5%, then that reel is unlikely to cause any hardness of level related runnability issue. In contrast, if the hardness variation is approximately greater than 6.0%, then there is a high possibility that reel can cause runnability problems. The reels with harness variation in between 3.5% and 6.0% should be assessed with other factors to determine its potential to cause issues. Some other factors that should be taken into considerations include presence of a gradient in the hardness profile, grammage of the paper grade, reel width and sensitivity of the press or converter for reel hardness variations.

INTRODUCTION

Reel hardness measurement has been traditionally carried out in industries where products are formed into rolls, and so is widely used in the paper industry. Reel hardness measurement is employed to gauge the roll uniformity, so that an experienced operator may be able to judge the quality of the reel in terms of its uniformity, surface unevenness, soft spots/edges etc. Hardness across the reels is gauged either manually by beating the surface with a wooden stick and listening sound or by using a hammer type device (e.g. Schmidt hammer or Parotester (Kompatscher, 2003)). There were also some advances made in online hardness measurements in parent rolls (Nuyan, S, 2008).

Although a significant amount of work had been carried out in understanding baggy webs, wrinkles, creasing and other runnability issues that may experience in daily operations of pressrooms or converting machines (Roisum, 2002, Smith, 1995), reel hardness measurement hasn’t gain its prominence. Measurement techniques and instruments that were employed were at times inferior or did not provide a sufficient resolution to recreate the hardness profile across the reel to conduct a proper analysis. Besides, the test data collected from these measurements have not been clearly linked up with other paper properties to diagnose the root cause. Moreover, being a subjective measure, the evaluation is heavily dependent upon operator’s experience. There is also no objective measure or industry accepted specification for reel hardness measurement.

When a runnability issue is reported by a converter or a printer on a particular paper grade, a number of actions are generally taken by the manufacturer to identify root causes of the issue. The examination of Cross Direction (CD) and Machine Direction (MD) profiles of key properties, such as grammage, caliper and density is typically assessed. The reason for this is to see whether any significant variations in these profiles have contributed to the runnability problem. These measurements are typically very accurate but are time consuming and could also be costly. The paper in question has to be sampled, correctly labelled and sent to a specialty laboratory for offline profile measurements. The advantage of systematic reel hardness measurement is that it can be carried out relatively quickly, at the premises and, it has the potential to identify possible problematic reels that can cause runnability issues. If successful, this can be a win-win for both the paper maker and the converter.

AIM

The aim of this work was to investigate the relationship between the level of hardness profile and its variation, the typical variability in key properties profiles and the extent of the runnability in converting or re-winding operations. In other words, it is aiming to explore the usefulness of the reel hardness as a quality consistency measurement to screen “good” from “bad” reels.

METHOD

Reel hardness measurements were carried out using Tapio® Reel Quality Profiler (RQP). This is a handheld testing device which consists of a hardness measuring head and a distance encorder. The measurement technique is to apply an impact onto the reel surface by a spring loaded head and measuring the deceleration. The deceleration is given in terms of gravitational acceleration (g) and uses it as the unit of reel hardness. The hardness values and distances are recorded in the hard disk of the PC attached to the unit for later analysis.

The grammage and caliper profiles were measured using an offline paper variability analyser (Tapio® PVA) which consists of two beta-gauges for heavy (Kr-85 for 150g/m^2 and above) and for lighter grammage (Pm-147 below 150g/m^2) paper samples. The caliper was measured using a stylus type eddy current sensor. The paper samples that prepared in either in machine direction (MD) or cross machine direction (CD), can be measured using the offline profiler. In the present study, only samples prepared in CD were tested. About 10-15 CD paper deckle strips collected from a certain paper grade were joined together using adhesive tapes (front side attached with back) to form a mini roll. It was important to keep the sides and sequence of the samples in correct order to perform accurate variability analysis. The grammage and caliper of the CD deckles were measured in 0.8mm intervals. The distance sensor attached to the profiler enables the aligning of the position of each caliper measurement with that of grammage. The raw data were filtered with 25mm low pass filter to remove high frequency variations, where this level of variations are generally difficult to control in a typical paper machine and hence is meaningless to include in the data in estimating the variability.

SAMPLES

As part of the study various grades of imported and locally made LWC paper, Fine paper and Packaging grade (carton board, sack, liner) paper were tested. Only selected data are presented in the current paper and the paper grades corresponding to the data are indicated the results section.

RESULTS & DISCUSSION

Relationship between hardness profiles of a parent and customer rolls

Winding is the key process that carries out in a paper mill to convert a parent reel into a roll form for further processing. Figure 1 shows an illustration of a typical winder at a mill, highlighting the main sections.

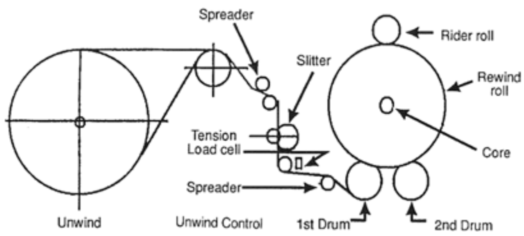

Figure 1 Winder at a finishing section of a mill (Frye, K)

The reels are typically slitted as per customer needs into specified usable widths after trimming the edges of the paper. The roll structure (tightness and uniformity) and web control (keep web without wandering) are some of the important aspect of winding. Uniformity and magnitude of wound-in tension in the reel has been considered as key parameters that maintains a healthy roll structure. The non-uniformity in the cross-web direction of the roll could be resulted from inefficient winding or due to various other reasons such as variations in moisture, caliper, grammage and reel hardness etc. Whilst these are listed as individual factors that affect the roll uniformity; they are not necessarily be fully independent from each other. It is obvious to expect a close relation between moisture and grammage in addition to relation between grammage and caliper particularly in un-calendared grades. Intuition may suggest that reel hardness may be related to other listed properties, yet only little has been reported in the literature.

It is expected that tightness of a re-wound customer roll to increase notably in the process of winding. One may expect that most of the non-uniformities shown in the hardness profile of a parent reel can be removed in the process of winding. The plots and data shown below are comparison of hardness profile in a parent reel and its customer rolls. The aim of this work was to investigate the level of change in cross direction hardness profile from winding process.

Figure 2 shows the conventional labelling of customer rolls cut from a parent reel, front (operator side) to back side (drive side) of the paper machine. Figure 3 & 4 shows the reel hardness profiles of 65g/m^2 LWC and 190g/m^2 packaging grade paper. The reel hardness profile of parent reels and its corresponding customer rolls are showing in each plot. The scale on the right hand side of each plot corresponds to hardness of customer rolls.

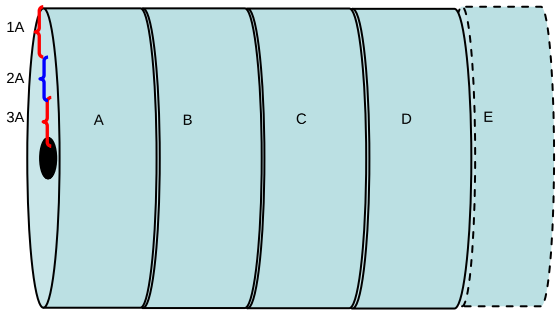

Figure 2. Customer rolls slabs from parent parent reel

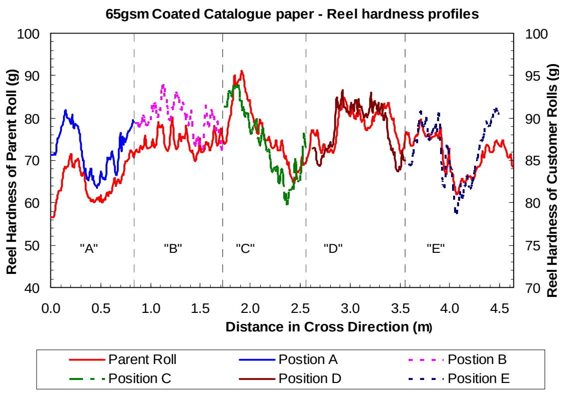

Figure 3 Reel hardness profile of parent and customer rolls (65g/m^2 LWC paper)

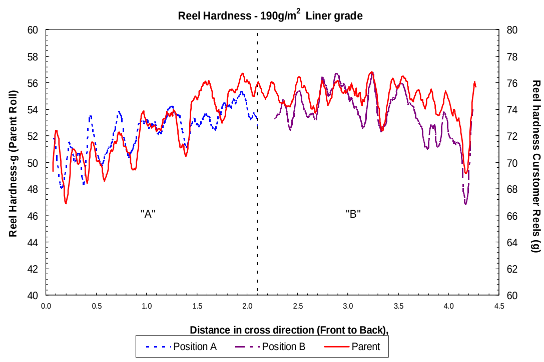

Figure 4 Reel hardness profile of parent and customer rolls (190 g/m^2 white liner)

The plots in Figure 3 & 4 clearly show a close resemblance of the hardness profile of parent reel to its corresponding customer rolls in both grades of paper. A similar observation was made with numerous other grades of paper that were tested during the last five years. The plots also show that reel hardness of customer rolls had increased by an appreciable level after re-winding but at different proportion across the reel.

The reel hardness of each section of the parent reel of 65g/m^2 LWC grade paper compared with respective hardness of customer rolls and percentage change in reel hardness was estimated (see Figure 5). The plot on Figure 5 indicates that increase in reel hardness due to winding varied significantly across the cross direction (depicts in a broken line) from a minimum of 14% to maximum of 33%.

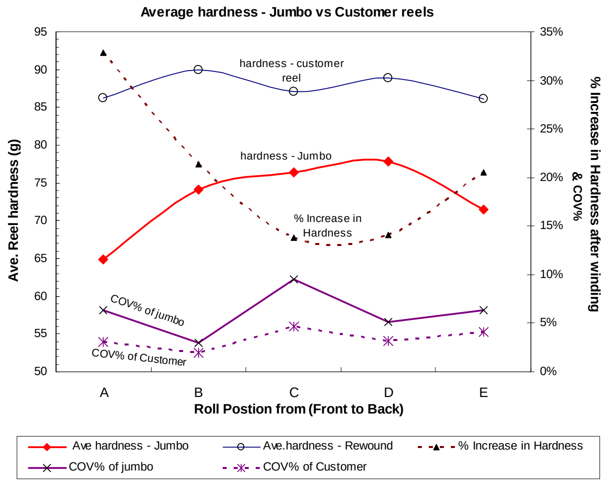

Figure 5 Average hardness of parent roll and customer rolls and % change in hardness from parent to customer rolls. Also coefficient of variation (COV%) of hardness in each location of parent and customer roll is given.

It is apparent that "C" position reel had the lowest increase in hardness after it re-wound. Furthermore, this reel showed a sharp slope in hardness profile across the reel and also had the highest hardness variation (coefficient of variation) COV% of 9.5% in parent and 4.7% in customer roll. This level of variation is obviously a concern as far as runnability of the reel is concerned in a pressroom or other conversion operation. From the hardness profiles obtained from parent reels and respective customer rolls, it can be assumed that there is a close resemblance in the hardness profile of apparent reel to that of its customer rolls especially when there is a significant variation in hardness across the reel.

There are a number of factors that could affect the uniformity of reel hardness across the reel. The tension and nip pressure are two vital variables in re-winding. To be specific, uniform nip pressure and uniform tension are paramount in building a uniform roll structure. Operators in a pressroom or other conversion facility may well know that non-uniformity in the reel hardness can contribute to loose edges, creasing and wrinkles, misregister and other numerous direct and indirect problems. Although non-uniform nip pressure or non-uniform tension across the reel are related to the winder, it may not necessarily be a winder that cause the problem, but could be related to a variability in a basic property in the paper itself. If the variability is grammage or caliper related this could introduce non-uniform nip pressure and tension across the reel. In addition, non-uniformity in caliper could be related to the non-uniformity in grammage or introduced from non-uniform calendaring.

Relationship between Reel hardness profiles and basic paper properties

The caliper and grammage profiles of parent reels and customer rolls of various grades of paper were compared with reel hardness profiles. This was carried out to access the relationship between these properties. Figure 6 & 7 show the grammage and caliper profiles respectively of approximately two meter long customer roll of 205g/m^2 imported packaging paper. These papers had a clay coating on one side and were calendared during the make. However, the type of calendering was unknown.

In general, there is a good relationship between grammage and caliper profilers of un-calendared paper grades and also this relationship can be seen in soft-nip calendared grades, although not as distinct as in un-calendared paper. In most cases, there is no relationship between grammage and caliper in hard calendared paper grades. Figure 8 shows a caliper against grammage plot for 205g/m^2 packaging grade paper. This plot shows a grammage spreads of around 200-212g/m^2 and caliper spread of around 258-268μm in this grade of paper. A close correlation between grammage and caliper is apparent in areas with low grammage and low caliper. Whilst the caliper is levelling in areas with high grammage (~ >207g/m^2) suggesting higher grammage areas may be flattened by calendering. This further indicates the non-uniform calendar nip load across the reel. Nonetheless the relationship between grammage and caliper is weak at higher grammage, the relationship is strong enough at lower end to suggest that nearly 60% of the variation seen in caliper could be explained by grammage variations. Figure 9 shows the plot of caliper and reel hardness. The trends in both profiles clearly point to a close relation suggesting that unevenness in caliper can be contributed to large proportion of the hardness variations. Figure 10 also shows the close correlation between caliper and reel hardness in 52g/m^2 LWC paper. A reel hardness profile across the full deckle width and corresponding caliper profile is shown in Figure 11 for 65g/m^2 LWC paper. There were similar observations on a number of other printing and packaging grades suggesting a close correlation between caliper and reel hardness.

When a runnability issue is raised on a particular grade, it is common to see the denial and blame game between supplier and the converter concerning the responsibility of the issue. This is because there is a real possibility that the problem can be caused by misaligned machine components or uneven tension distribution in the machine and this could cause web to be tighter in one side than the other. However, a fact that cannot be ignored is that, a thicker area, with only a few microns in caliper or grammage in CD in one end, can accumulate into a significantly hard section, while thousands of layers of this paper are wound to form a roll. Reel hardness profiler, in fact has a substantial task in such circumstances to distinguish the cause of the issue, whether it is from poor roll quality or machine misalignment.

It was apparent from the data shown in the previous section that the shape of the reel hardness profile does not changed by the winding process but only increases the hardness level. In addition, the data presented in this section suggest a close correlation between hardness and the caliper profiles. These two features in hardness profile can be combined and utilised as a valuable tool to correct roll profiles at early stages. The measurement of hardness profile of parent roll comes straight out from the machine can be used as a guide to make changes in the settings of the paper machine, before tonnes of paper with significant uneven profiles are made. Based on hardness profiles obtained from the start up parent rolls, subsequent machine settings can possibly be changed to correct the roll profile. Some possible variables that can make a difference are bias in calendar crown (see appendix Figure 17-19), size press pickup profile and in some instances changes to the headbox profile.

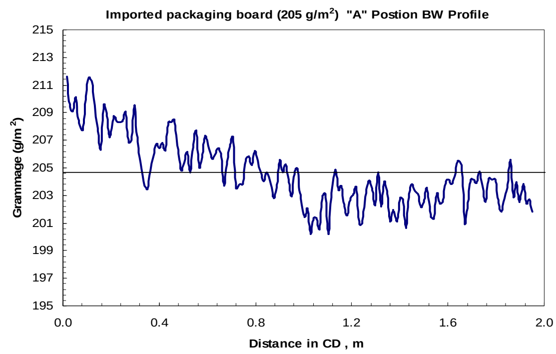

Figure 6. Grammage profile of 205g/m^2 imported packaging board – "A" position reel

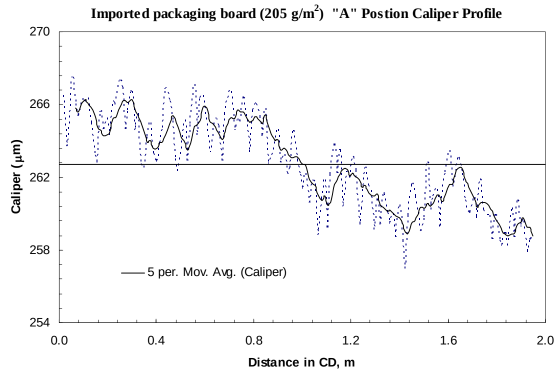

Figure 7. Caliper profile of 205g/m^2 imported packaging paper - "A" position

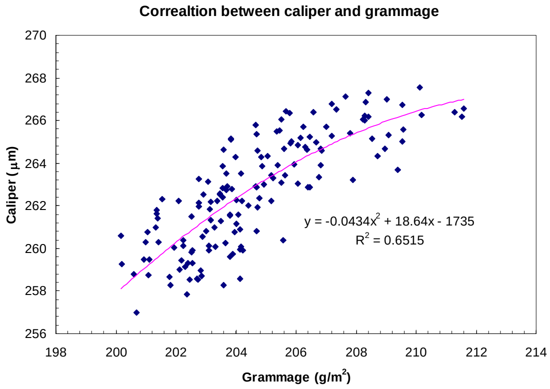

Figure 8. Correlation between caliper and grammage profile of 205g/m^2 packaging board

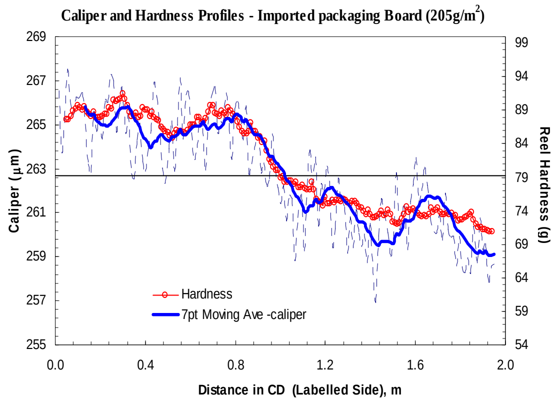

Figure 9. Caliper and reel hardness profiles of 205g/m^2 packaging board

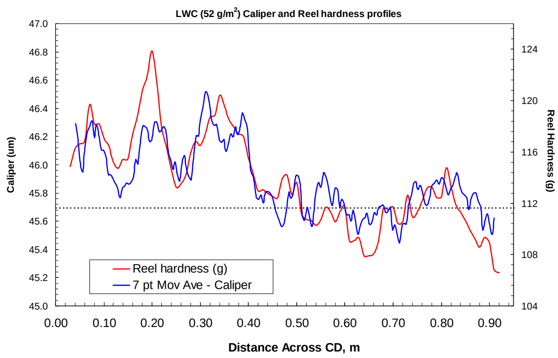

Figure 10. Caliper and reel hardness profiles of 52g/m^2 LWC paper

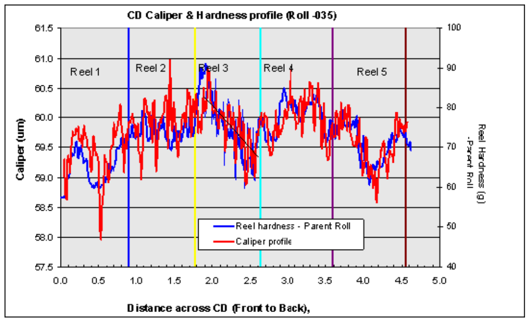

Figure 11. Reel hardness profile of parent roll and full deckle width caliper profile - 65g/m^2 LWC paper

Another interesting observation that was made from the hardness and caliper data analysis was the apparent close correlation between coefficient variation (COV%) of reel hardness and COV% of caliper in CD of the paper reel. The linear regression fitted through data suggested that approximately 80% (R^2=0.80) of hardness variation can be explained by the variation in caliper (see Figure 12). In addition, it appears that, there is nearly a five fold increase in COV% of reel hardness for one unit increase in COV% of caliper.

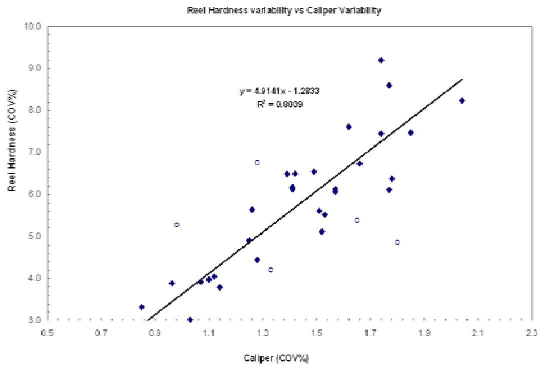

Figure 12 COV% of reel hardness and COV% of caliper in CD of paper reels

Degree of hardness variability on runnability

While it is obvious that variation in reel hardness is detrimental in smooth running of the paper web, it is rather challenging to come up with a definitive value or a limit to declare that all reels with variation above a certain level should be rejected. Generally, each printing machine or converter has its own unique settings. Each machine varies in its level of sensitivity to the hardness variation and hence the tolerance dealing with slack web or sideway movement. For example, a multi-colour printing presses can be naturally lower in tolerance even it has a greater level of web control in comparison to a corrugator or other form of converter. In addition, other factors such as grammage of the paper, reel width etc., can also be decisive factors in determining the sensitivity to hardness changes.

Although it may not be able to be used as a universal rule, the hardness profiles measured in numerous grades in the last five years or so offer a rule of thumb in determining a "good" reel from a "bad". Figures 13-15 show few examples of reel hardness profiles measured in CD of customer rolls. One show a "Z" like profile which has a very high potential to cause runnability problem (Figure 13), another with moderate probability of causing runnability (Figure 14) and one with high prospect of success or no runnability issue (Figure 15).

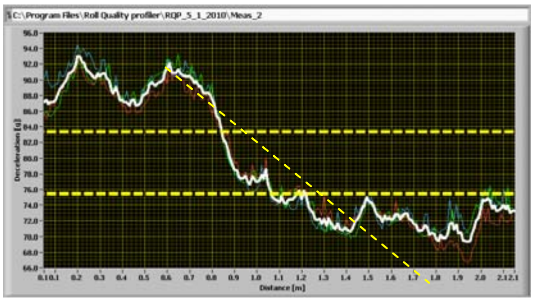

Figure 13. Reel hardness profile of 2100mm wide reel. Horizontal lines indicate the boundary of ± 5% from mean hardness.
(Mean hardness = 79.5g σ=8.1g COV%=10.1%)

Figure 14. Reel hardness profile of 2100mm wide reel. (Mean hardness=81.3g σ=3.4g COV%=4.2%)

Figure 15. Reel hardness profile of 2000mm wide reel (Mean=90.4g σ=2.1g COV%=2.3%)

The horizontal lines shown in the Figure 13-15 represent ± 5% points from the mean hardness. Past experiences on reel hardness measurements suggests that in general if a reel's hardness profile is confined to within a ± 5% boundary, then this will minimise slack edge or runnability issues. However, if there is an obvious slope from one end to the other, then the reel may exhibit slack edges or poor runnability, even the hardness profile is restricted to ± 5% boundary. This could possibly be the case for a reel with profile similar to that shown in Figure 14, where the hardness profile is confined to ± 5% boundary, however, a slope can be seen from about 800mm to the back edge which may cause poor runnability. Further, a reel with COV% in reel hardness greater than 6% or more has a great probability to cause poor runnability. Table 1 & Figure 16 show a general guide to determine a poor reel structure based on reel hardness variation.

Table 1 Rule of thumb in determining poor reel structure

Variation in Reel hardness COV%	**0-3.5%**	**3.5-6.0%**	**>6.0%**
Comment	**Unlikely** to cause runnability	**May** cause poor runnability. Consider other factors	**Highly likely** to cause problems

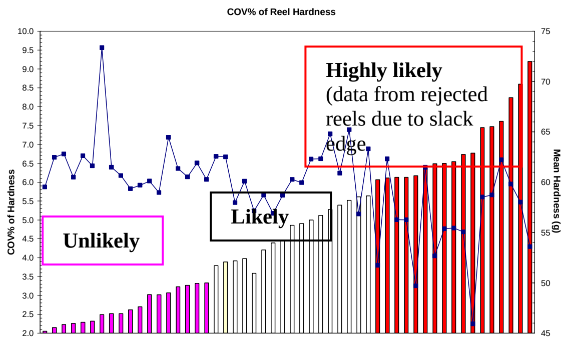

Figure 16. COV% reel hardness and mean hardness

CONCLUSIONS

Based on the measurement of reel hardness profiles on large number of parent and customer paper reels, in various paper grades (packaging, printing and LWC etc), the following conclusions can essentially be made.

The winding process that carried out in converting a parent reel to customer rolls apparently does not change the shape of the hardness profile of the original parent reel in comparison to that of corresponding customer rolls, even though there is an increase in reel hardness from winding process. This feature is highly visible in situations where parent reel had significant hardness variations or in the presence of a distinct slope in the hardness profile. It is also apparent that there is a significant relationship between reel hardness and caliper profiles across the cross direction of the web. It was further suggested that significant proportion of hardness variations can be explained by caliper variations, as such, at times more than 80% of reel hardness variations can be explained by the variations in caliper. In addition, it was apparent that a small thickness variation that wound in to a roll may amplify by the fact that thousands of layers of the defective area pile up layer by layer to give a hard section of the roll. It seems that one point change in caliper variation can cause almost 5 point variation in reel hardness.

The combining the two features observed; i.e. preservation of hardness profile in parent roll in customer rolls and correlation of hardness profile with caliper, can potentially be used as a valuable tool in changing the paper machine setting to correct grammage profile (which may causing the variation in caliper profile) at early stage of the paper make, which will potentially prevent sending tonnes of paper reels into the broke or avoid customer claims.

This work also looked at the possibility of using direct reel hardness measurement as a tool to gauge a reel that potentially causes runnability issues. Although it is rather difficult to come up with a universal rule due to various reasons such as differences in sensitivity of a press or a converter to variation in hardness, width of the paper reel and grammage etc., a general guide can be attained by evaluation of the COV% or the reel hardness. Based on past experiences, it was apparent that a reel with significant slop in cross direction or having a hardness variation in CD in the magnitude of 6.0% or more in COV% highly likely to cause a problem. Further a reel with low COV% in reel hardness (less than 3.5%) unlikely to cause any issues. To determine the runnability of a reel with COV% in the range of 3.5%-6.0%, may require other factors taken into consideration. The level of sensitivity of the machine to hardness variation (historical incidence will be useful), a clear presence of a slope in the profile, reel width (wider reels can cause more problems than narrower reels) and grammage should be considered in determining "good" from a "bad" reel.

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APPENDIX

Different levels of crown biasing in calendar nip to correct thickness profile

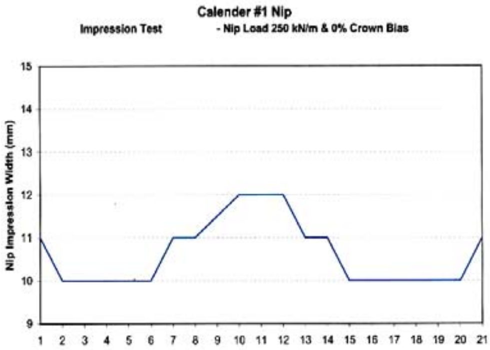

Figure 17 Soft Calender nip crown 0% biased

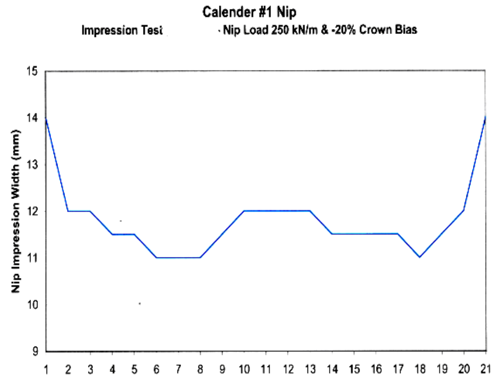

Figure 18 Soft Calender nip crown -20% bias

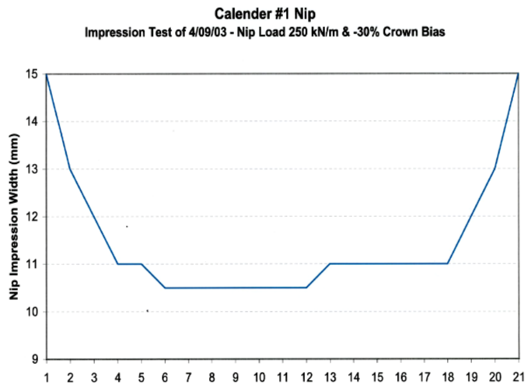

Figure 19 Soft Calender nip crown –30% bias