JPMTR 138 | 2010
DOI 10.14622/JPMTR-2010
UDC 676.22:774.56-023.881:024.524|62-56

Case study
Received: 2020-07-07
Accepted: 2020-09-22

Lateral paper web shifting during commercial heat set web offset printing

George Shields[1], Alexandra Pekarovicova[2], Paul D. Fleming[2] and Jan Pekarovic[2]

[1] UPM Kymmene Co.
[2] Center for Printing and Coating Research,
College of Engineering and Applied Science,
Western Michigan 4601 Campus Drive,
A-217 Parkview, Kalamazoo, MI 49008-5462

a.pekarovicova@wmich.edu

Abstract

Paper properties and their role in preventing lateral web movement from cross machine air flows in the drying section during normal heat set web offset litho printing operations were examined. Tensile properties of sheets were measured at various moisture contents and then used to determine the equilibrium stress–strain relationship for papers at moisture contents typical of heat set web offset printing. Air permeability, creep, hygroexpansion, and ultrasonic measurement of tensile stiffness orientation module were evaluated against lateral web movement on heat set web offset litho press. It was found that the only item of interest from these results with respect to the lateral movement performance is the ratio between tensile stiffness orientation modules in the machine direction and cross machine direction, indicating orientation of the fibers in the paper web, and showing that more oriented fibers are less likely to shift on heat set web offset litho printing press. Understanding the effect of water absorption and absorption rate on the stress–strain relationship of paper may yield further understanding of web break tendency during heat set web offset printing.

Keywords: fiber orientation, tensile stiffness index, water absorption, stress–strain in paper, creep, hydroexpansion

1. Introduction and background

The effect of water and heat on the behavior of paper sheets has been studied frequently over many years. Two effects of water, either in liquid or vapor form, on paper sheets are hydro/hygro-expansion (Kajonto and Niskanen, 1998), and softening of the fiber matrix through plasticization (Niskanen and Kärenlampi, 1998). In both cases it appears that water molecules interact with fiber material through a hydrogen bonding mechanism. Swelling of the fiber wall and translation of the swelling to the paper sheet dimensions results in hydro/hygro-expansion. Creep, or at least the increased rate of creep, is the result of fiber plasticization and the corresponding loosening of the fiber matrix (Brezinski, 1956). This occurs because water acts as a softener preferentially bonding with hydroxyl sites in the amorphous cellulose in or between the microfibrils that make up fibers. In commercial printing using the heat set web offset (HSWO) process, water is the largest component of dampening solution, which is applied to the paper surface in conjunction with oil based inks. Part of the water prints and sorbs into the paper (non-image areas), part of the water emulsifies with the ink and prints (image areas) and part of the water evaporates. Hot air floatation dryers are used to evaporate the printed water and a portion of the oils from the ink (Kipphan, 2001).

The purpose of this work is to determine the papermaking reasons for lateral shift of the moving paper web, made on a particular paper machine, on a specific printing press during HSWO litho printing. The lateral movement is seen as a steady state shift to the gear side of the printing press, which can be measured at the exit of the chill section. In upset conditions, such as start up or blanket wash, the web may move so far that it shifts off the paper guiding rollers and/or jams the folder section of the printing press. The lateral shift has been observed on several HSWO printing presses running the subject paper, and attempts to correct the problem have met with little success. The propensity of the web to shift in the extreme during upset conditions has been linked to how the web shifts under steady state printing conditions. For the paper in question made under specific conditions, the amount of water applied during printing appears to govern the magnitude of the lateral shift during steady state conditions.

The hypothesis for why the lateral web shift occurs is related to the air currents within the floatation dryers of HSWO printing presses. The air currents have a machine direction component and a cross machine direction, or, lateral component. Low web tension allows the lateral component of the air flow to move the paper web sideways. Papers with higher web tension will be less impacted by the lateral air flows and therefore will be more centered on the printing press. Moisture addition from printing will reduce the tensile stiffness of the paper and swell the fibers giving rise to hydroexpansion and provide the conditions for increased creep. All of these effects of moisture addition will have the result of reducing web tension. Drying of the paper and ink will cause the fibers to contract and increase tensile stiffness, both of which will increase web tension. The time from water application to drying during HSWO printing is short and it is possible that the rate of tension loss is more important than residual steady state tension.

Some of the results of this study were published elsewhere (Shields, 2017; 2018). The work is divided into field and laboratory portions. The field work involved making paper on the target paper machine, using various papermaking treatments to manufacture 11 specific paper rolls. The trial rolls were printed on the target printing press and the lateral position of the web at the exit of the chill section was recorded. The rolls of the paper were ranked by deviation from the center position at the chill section exit. In this way, papermaking factors that impact lateral position were identified. The hygroexpansion and creep of paper under load were tested for an estimate of hygroexpansion and creep potential during printing. Hygroexpansion rather than hydroexpansion is studied due to the ease of conditioning paper to a known moisture content by controlling the relative humidity of the testing environment. Understanding the methods to reduce the lateral web movement may lead to further understanding about the impacts of water on sheet properties during HSWO printing and methods to reduce web break rates for papers made with mechanical pulps.

2. Materials and methods

The paper in question is a grade 4 coated mechanical paper made on a Fourdrinier paper machine in the northern United States, using pressurized groundwood (PGW) mechanical pulp and softwood bleached kraft (SBK) pulp. The paper is coated with a blend of kaolin and ground calcium carbonate pigments, along with starch and latex binders, supercalendered to 64 % gloss and wound into customer rolls on a single drum winder. The subject printing press is a side by side design of two HSWO presses operating at a nominal speed of 8.1 m/s. Each web is fitted with a reel, pre-tensioning section and guiding section prior to four printing units, a 3-zone hot air floatation dryer and a chill section. One of the two presses (left hand press, LHP) follows with a short web lead, displacement guide, silicone emulsion applicator, and slitter section. The second web press (right hand press, RHP) is identical to the LHP through the chill section but differs further along the web path in that the web passes through a long open span, which crosses two 45° air turns before meeting the displacement web guide and slitter section. Both webs come together in the common folder section where the webs are folded and cut into books. A key factor in the design of the target press is the extra distance the web travels between the chill section and web guide on the RHP. The additional distance is 17.4 m. Assuming a nominal press speed of 8.1 m/s the extra travel time before the web guide is 2.15 s. The RHP web behavior is the subject of this work. Lateral shift happening on RHP is schematically illustrated in the Figure 1.

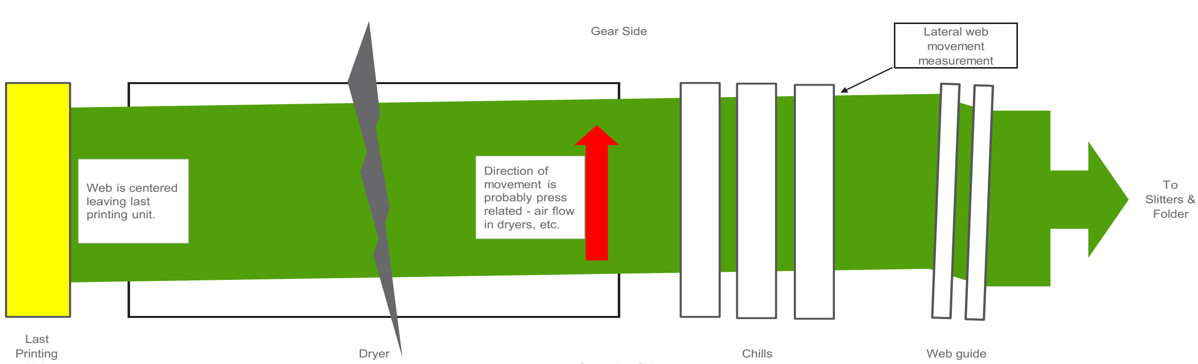


Figure 1: Mechanism of lateral web shift on HSWO printing press (Shields, 2017)

2.1 Laboratory testing

A total of 25 paper samples, including the 11 target paper machine (PM) rolls manufactured for the printing trials (Table 1), and 14 other paper samples, 11 of which are known to not suffer from lateral web movement, were tested in the laboratory conditions. Not all samples were tested for each activity, however all samples that were tested are from this lot of 25 papers.

Table 1: Papers manufactured for the printing trials

1	Standard front edge roll
2	Standard center roll, increased fiber orientation
3	Edge flow closed, increased fiber orientation
4	Increased strain at 20 % solids
5	Reduced ratio of headbox jet velocity to forming fabric velocity (J/W), decreased fiber orientation
6	Softwood bleached kraft (SBK) pulp refining increased
7	The SBK refining decreased
8	Zero pressurized groundwood (PGW) refining
9	Lower wet end starch
10	Higher wet end starch
11	Reduced strain at 90 % solids

The air permeability of all 25 papers was measured using a Technidyne Profile Plus set up for Gurley permeability. Units for the test results are s per 100 ml. Higher Gurley porosity results indicate lower permeability. The procedures, according to TAPPI test method T 460 om-11, section 5.2.1, were followed the standard (TAPPI, 2011). Each paper sample was tested 10 times, 5 on each side. The results reported were the average and standard deviation.

Ultrasonic measurement method was used for determination of tensile stiffness. For the 11 sample papers plus sheets that are uncoated or have the base paper of the coated sheets available, a 340 mm wide strip of paper spanning the full width of the paper machine was measured every 180 mm. The testing device was a Kajaani Tensile Stiffness Orientation module mounted in a Metso Paperlab paper testing station, where definitions are taken from (Lindblad and Furst, 2001). The following measurements were reported:

- MD Angle – the angle between the machine direction of the paper and the maximum tensile stiffness index,
- TSI MD – the tensile stiffness index (TSI) in the machine direction (MD),
- TSI CD – the tensile stiffness in the cross machine (CD) direction,
- TSI Ratio – the ratio between TSI MD and TSI CD.

An experimental test was attempted with the potential outcome of being able to measure the effects of hygroexpansion and creep. The test device used is shown in Figure 2 and Figure 3. A 25 mm wide strip of paper approximately 350 mm long was clamped at one end to a stationary horizontal bar while the free end passed horizontally over a roller that was free to rotate. The free end of the paper strip was clamped to a free hanging 1 kg weight. The 1 kg weight plus the weight of the clamp represents a load of 0.41 kN/m, quite similar to the web tension on a printing press prior to the print units. In a 50 % relative humidity (RH), and temperature of 23 °C environment, according to TAPPI (2013) conditions, the weight was attached to the strip and a mark placed on the sample at 250 mm from the stationary bar. The sample remained under tension for 30 s when the position of the mark was recorded relative to the initial length. A hand held hot air dryer was used to heat and dry the sample to approximately 125 °C, similar to web temperatures used in HSWO printing. The position of the mark relative to the original position

a) b)

Figure 2: Creep and hygroexpansion test set up: (a) view of apparatus from above, (b) side-view of apparatus from end with 1 kg weights suspended from samples (Shields, 2017)

was recorded. The sample was allowed to cool and condition for 30 s back to TAPPI (2013) conditions and the mark was recorded again. The samples and test set up were relocated to a 90 % RH, 23 °C atmosphere and allowed to acclimatize for 4 h. In the 90 % RH environment, the paper samples were re-clamped to the horizontal bar and the 1 kg weight clamped to the free end. The initial position of the mark was recorded relative to the original position in the 50 % RH environment. The testing procedure followed the protocol from the 50 % RH environment of straining for 30 s, heating to approximately 125 °C, and acclimatizing to the 90 % RH environment. At each step, the position of the mark relative to its original 50 % RH environment was recorded. The test was performed on 3 sample conditions with two tests per condition and the average result was reported. The measurement was done with a steel ruler divided into 0.794 mm (1/32") increments. For results not measuring exactly to 0.794 mm (1/32"), an estimate to the nearest 0.198 mm (1/128") was made. The samples included paper made on the target PM, paper made on a competitive PM with similar basis weight, and a super calandered (SC) grade paper of 45 g/m^2. A schematic of the test set up is shown in Figure 3.

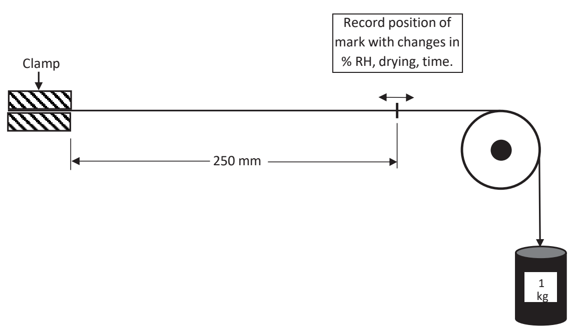


Figure 3: Humidity and creep measurement schematic (Shields, 2017)

3. Results and discussion

3.1 Lateral web shift

During printing, disturbances exist that act in the cross (lateral) direction of the web. Figure 4 illustrates the effect of a cross direction disturbance on the lateral web position as influenced by machine direction web tension.

As web tension increases, the effect of the lateral disturbances decreases, that is, the resulting angle between the machine direction and the path taken by the web is reduced. Examples of lateral disturbances include non-uniform paper properties, machine elements out of alignment, or lateral air flow in the dryer hoods. Therefore, a paper that has more web tension reduction, due to moisture increase during printing, will be more affected by the lateral forces existing in the paper/printing system.

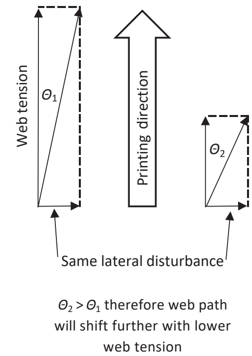


Figure 4: Lateral disturbance on web (Shields, 2017)

Variation in apparent density in the cross direction was considered as a possible contributor to lateral web movement. A variation across the web could conceivably contribute to lateral movement due to: variable water absorption rates, variable permeability, variable in plane tensile properties, etc. Apparent density was calculated as the apparent thickness (caliper) multiplied by the basis weight. In Figure 5a, the CD caliper profile and CD basis weight profile of the target PM is illustrated. The horizontal lines depict the location of individual customer rolls. The blacked out area indicates a roll that was not sent to the target pressroom. The same information was gathered for a competitive sheet that does not experience lateral web movement. A visual inspection of the caliper and basis weight profiles indicates the competitive PM has higher variability across the web than the target PM. The average caliper and basis weight of the paper from target PM and competitive PM are shown in Figures 5a and 5b.

The variation in paper density was calculated as the paper density for a particular roll divided by the average paper density of all customer rolls displayed for the paper machine, and it is illustrated on the Figure 6. The average paper density for the target PM is slightly higher than the competitive PM, likely due to higher coat weight. From previous work (Shield, 2017), it has been determined that the coat weight on the target paper machine sheet has no effect on the lateral web movement.

Figure 6 shows the paper density variation by roll position across the paper machine width. The competitive PM has higher paper density variability than the target PM, however it does not experience lateral web movement. It can be concluded that variation in apparent density does not correspond to increased lateral web movement on the target printing press.

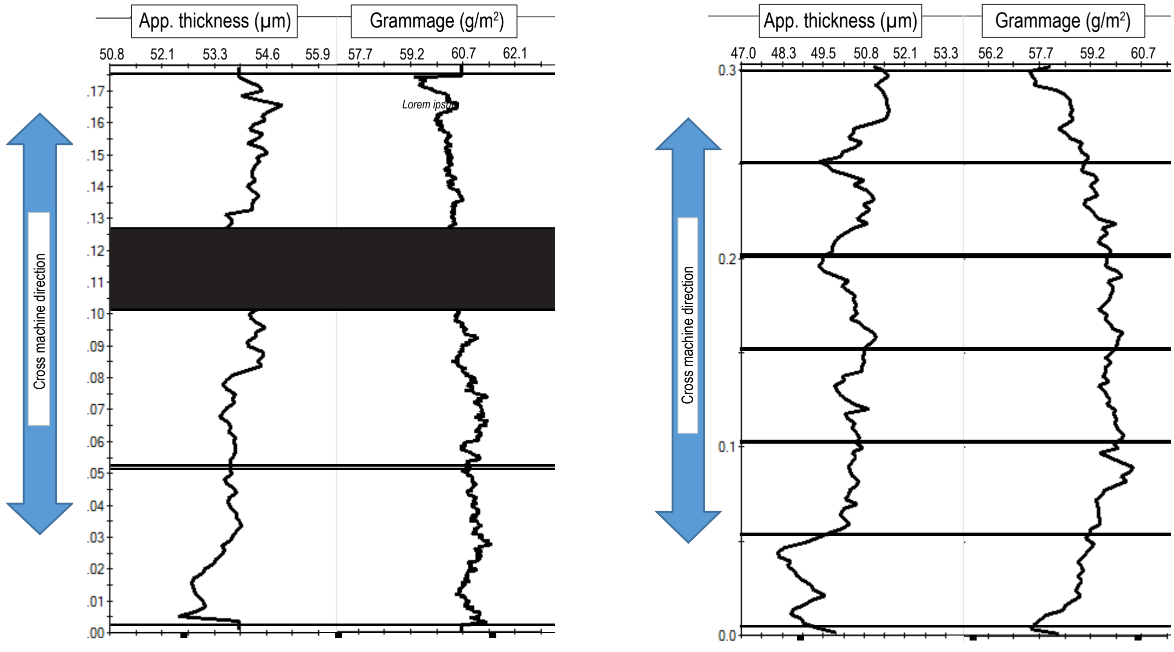


Figure 5: Apparent thickness (μm), and grammage (g/m²) cross direction profiles (a) for the target paper machine, and (b) for a competitive paper machine, adapted from Shields (2017)

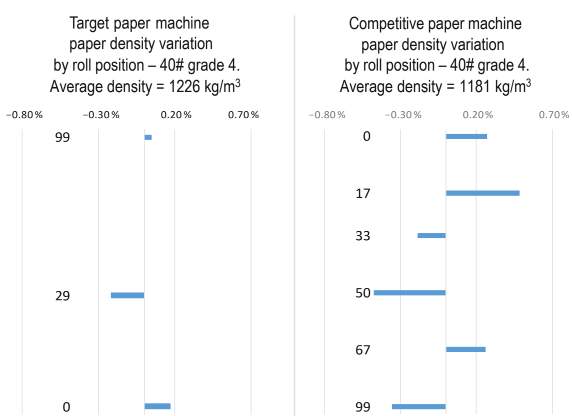
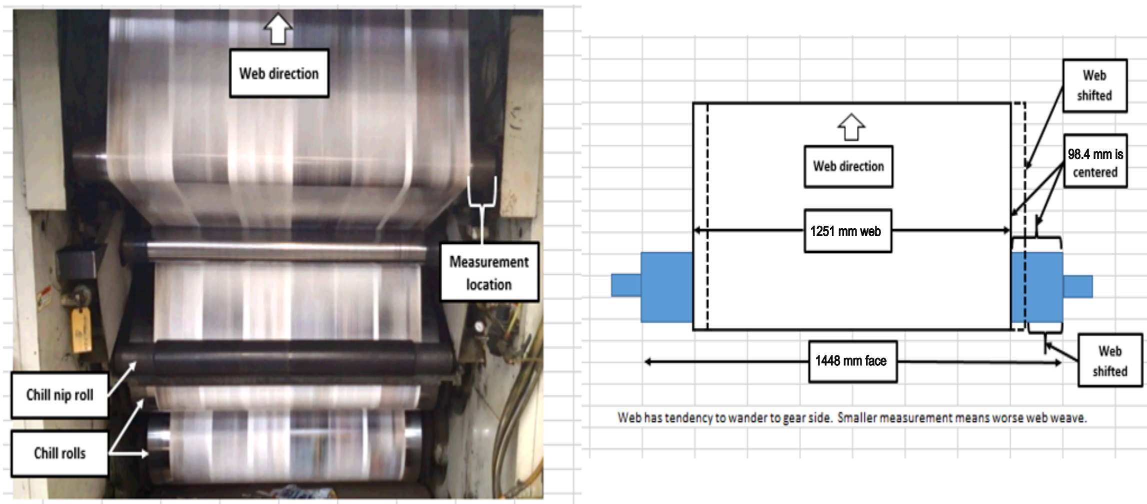


Figure 6: Paper density variation by roll position for the target and competitive paper machines (Shields, 2017)

The target paper machine experienced a higher level of lateral web shift than the competitive machine for both normal printing and blanket wash conditions. In normal printing conditions the target paper machine sheet was slightly off center at 92.07 mm (3 $^5/_8$”) while the competitive sheet was almost exactly centered at 98.42 mm (3 $^7/_8$”). See Figure 7 for an explanation of the measurements. In the four unit blanket wash condition (all eight printing blankets washed simultaneously), the ink and fountain solution feed were stopped and the water based blanket wash sprayed on the blankets with the printing nips closed and the press operating at normal speed. The maximum guide position column in Table 2 shows the extent to which the web guide had to move during blanket wash to keep the web centered on the slitters. The two digits in the maximum guide position result represent a percentage of the maximum travel of the web guide, for instance 60 %. The letter in the third position of the maximum guide position result represents the direction the web guide was acting to correct the lateral shift. The O represents “operating side”, G represents “gear side”. Therefore, 60 O indicates that the web guide was at 60 % of its’ maximum travel and correcting the sheet to the operator side of the press. This is typical of the lateral web shift. Air flow in the dryers is from the operator side to the gear side of the press, and the web moves towards the gear side. The web guide must correct the web back towards the operator side to center the sheet on the slitters.

The competitive paper machine had a similar response regardless of the pulp used to manufacture the paper, and was very nearly centered for all conditions, including blanket wash. Conclusions were that the lateral web position during normal printing is a predictor for blanket wash response. In a second portion of the trial, the web response to changes in the amount of applied fountain solution at constant ink supply rate was checked. Under normal printing conditions the web position was recorded. Fountain solution feed rate was increased until the printed surface was noticeably washed out indicating too much water was present in the image areas. The water amount setting, 5.3 mm (an increase of 15 % feed rate of fountain water), was



a) b)

Figure 7: Target printing press chill section exit; (a) actual measurement location; (b) schematic of measurement area (Shields, 2017)

recorded and web position noted before returning the fountain solution feed rate to standard. As each successive trial sheet was run, the dampening water feed rate was returned to the same setting as noted above. The results of this trial are shown in Table 2.

Increasing the fountain solution feed rate caused lateral shift on both the target and competitive sheets. The target paper machine sheets were affected to a larger degree than the competitive sheets. The slitter guide column in Table 2 shows the extent to which the web guide had to move to correct the web position back to centered on the slitters. The target PM was off center at the chill exit under normal printing conditions and moved a further 25.4 mm (1”) laterally with increased fountain solution feed. The softwood PGW / increased SBK trial point started more centered under normal printing conditions and shifted less with increased fountain solution feed than the softwood PGW / normal SBK condition. Neither target PM condition was as stable as the competitive sheet, which was very close to centered at the chill exit under normal printing conditions (with very little web guide correction needed) and only 6.3 mm (¼”) of lateral movement with increased fountain solution feed rate.

Finally, the target paper machine web response to decreased fountain solution feed rate was noted for one of the pulp conditions. The fountain solution feed rate was reduced until scumming was visible in the non-image areas, indicating not enough water was present on the printing plate. The web position was noted as shown on the lower portion of Table 2. Reducing the fountain solution feed rate to the printing plate caused the web to move closer to center at the chill exit, and the web guide had to make less correction to center the web on the slit-

Table 2: Response of dampening solution on lateral web position for two paper machines

Mill trial point	**Trial point description**	**Normal printing** Web running poition (mm)	Slitter guide position	**Changed water feed** Web running poition (mm)	Slitter guide position	**Result** Difference in web position (mm)
	Fountain solution feed increased by 5.3 mm Flat/print/loss of density on signatures					
2	Target PM all softwood mech. pulp	82.5	60 O	57.1	80 O	25.4
3	Target PM all softwood plus increased kraft	92.1	25 O	76.2	35 O	15.9
6	Competitive PM standard	98.4	0	90.5	25 O	7.9
8	Competitive PM high HW mech. pulp	98.4	0	90.3	30 O	6.3
	Fountain solution feed decreased by 3.5 mm Scummings visible on signatures					
2	Target PM all softwood mech. pulp	82.5	60 O	88.9	30 O	−6.3

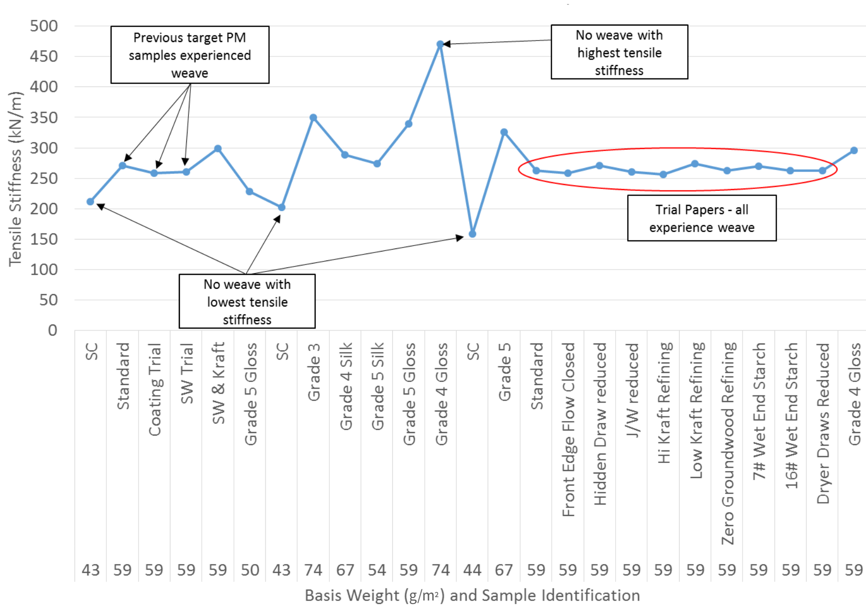


Figure 8: Tensile stiffness at printed moisture content for tested paper samples (Shields, 2017)

ters. For sheets from both paper machines the amount of water applied affects the chill section exit tension and lateral web position. The effect is greater on sheets from the target paper machine with one of the conditions showing a full 25.4 mm (1") of movement from normal to increased dampening water amount. The conclusions from this set of trials were that the paper machine rather than the pulp type was responsible for the effect of water on the lateral web position, and, the effect of additional fountain solution is similar (although not as severe) to the effect of blanket washing on lateral web position. This second fact indicates that the water amount taken on by the web during normal printing or blanket wash conditions is the most important printing press factor determining later web position.

The tensile stiffness at printed moisture content is shown for each of the samples tested in Figure 8. Papers with higher and lower tensile stiffness at printed moisture amounts are included in the sample set. None of the competitive papers experience lateral web movement during blanket wash, including the samples with lower tensile stiffness. Also obvious is the fact that all of the trial papers from the competitive paper machine have similar tensile stiffness at printed moisture content. None of the trial conditions had a measurable effect on tensile stiffness. It is apparent that the difference in lateral web position cannot be explained by the tensile stiffness at printed moisture.

3.2 Air permeability

Gurley air permeability of the samples was measured and the average results are plotted in Figure 9. Higher permeability (lower Gurley test results) should represent faster penetration time (Kettle, et al., 1997) and therefore more contact with fibers leading to lower web tension. The lowest Gurley permeability sheets are the SC sheets. These are the lightest basis weight papers and therefore have the lowest resistance to air flow. The SC sheets are typically made with a high proportion of mechanical pulp, which is stiffer than chemical pulp. The resulting sheets are therefore stiffer and bulkier. These two factors are likely reasons for the low Gurley permeability results. The papers with the highest results are those of the target paper machine. These papers contain a high proportion of coat weight and are heavily calendered forming a dense sheet. While the proportion of mechanical pulp is still significant for these papers, the coating and supercalendering are dominating factors. Most other samples range in the 1 000–3 000 s per 100 ml range. These papers range from heavier weight high kraft containing sheets with high levels of calcium carbonate in the coating to grade 5 papers with high proportions of mechanical pulp. It is unclear exactly how these papers are made, however they come mainly from mills with integrated SBK mills and it is possible that the base paper portion of the sheet is quite open due to low fines content or lower sheet consolidation during paper formation or calendering. While there are differences in air permeability, the papers showing highest air permeability (lowest Gurley permeability results) do not experience web movement. These are the SC sheets. In fact, the papers with the lowest permeability are those from the target PM. Two competitive sheets show the values in the same permeability range as the target PM and they do not experience lateral web movement on press. It appears that lateral web movement on the samples from target PM cannot be predicted by Gurley permeability. It is

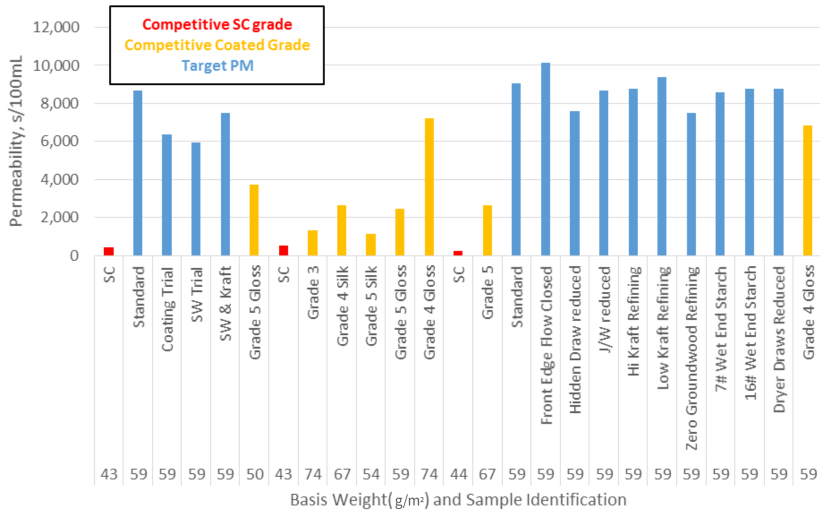


Figure 9: Gurley permeability results (Shields, 2017)

also apparent that the air permeability results do not correspond with the Emtec (Ultrasound Penetration Dynamics Analyzer) results (Shields, 2018). While the SC sheets have the lowest Gurley permeability results and the fastest absorption rate, the target PM has the second fastest absorption rate according to Emtec but the highest Gurley porosity results.

3.3 Creep and hygroexpansion

Three samples were selected representing the target PM, a competitive PM at the same basis weight, and a light weight SC paper. The competitive PM and SC sheets are known to have no lateral movement on press. These samples represent a spread of basis weights as well as a comparison between coated and uncoated papers. The results of the creep and hygroexpansion testing is plotted in Figure 10. For the 50 % RH tests, no discernable creep occurred after the initial loading of the samples. Over 30 s, all three samples were stable at the reference length. Upon heating, all three samples contracted, with the target PM contracting most. Upon cooling and regaining moisture from the ambient conditions, all three samples recovered their original length while still under load. These results indicate that no plastic deformation is occurring over the test duration at 50 % RH, i.e. no creep occurs. The samples contract upon heating as the fibers give up moisture and shrink. The difference in the magnitude of shrinkage can be explained by the fiber

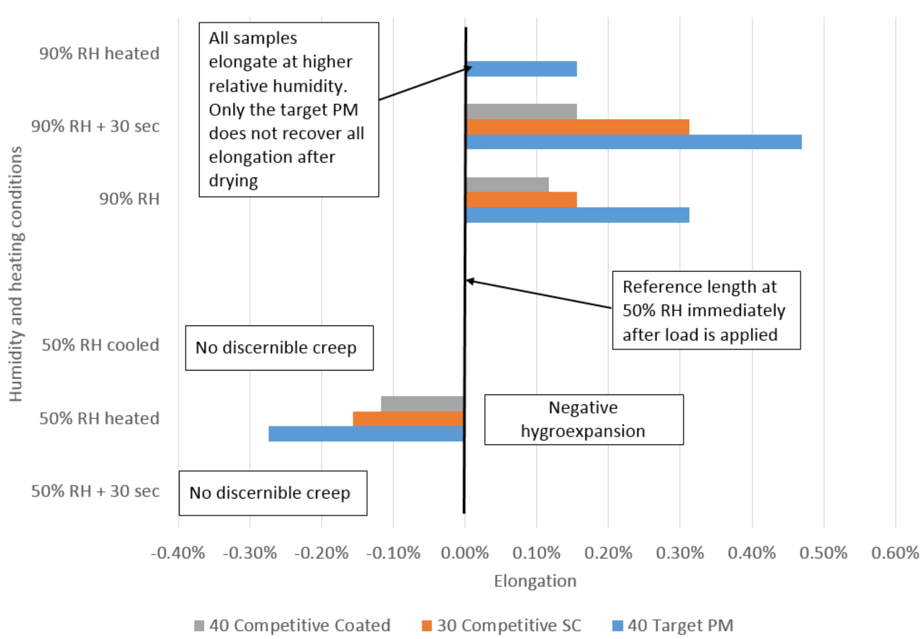


Figure 10: Creep and hygroexpansion test results for three paper samples (Shields, 2017)

orientation. Fibers shrink laterally. Papers that have higher fiber orientation in the measured direction will shrink less than papers with lower fiber orientation. The competitive coated sheet and the SC sheet have similar MD/CD tensile ratio results at 3.7 and 3.5 versus 2.4 for the target PM. For the 90 % RH testing, all samples measured longer after initial application of load than they were at 50 % RH. All samples also increased length after remaining under tension for 30 seconds. The competitive coated PM and light weight SC sheet regained their original 90 % RH length on heating while the target PM did not. The hygroscopic nature of wood fiber means that paper will absorb water. From 50 % RH to 90 % RH, the samples rise in moisture content approximately equal to that gained from printing 3 g/m^2 of water (Trollsås, 1995; Kela and von Hertzen, 2007). In fact, the SC sheet gains more than the printed water amount. The increased moisture of the samples at 90 % RH swells the fibers and increases the sample lengths. Analogous to the drying shrinkage, papers with higher fiber orientation in the measured direction will grow less than less oriented papers. The higher fiber orientation of the competitive coated and SC sheets results in less growth due to hygroexpansion.

When the samples are heated at 90 % RH the competitive samples regain their original fiber length at 50 % RH, however they do not shrink to the level they did when heating from 50 % RH. This seems consistent with the concept of creep. The samples have gained moisture in the amorphous regions of the fiber wall and grown in dimension, due to both hygroexpansion and softening of the amorphous matrix, which allows some movement of the microfibrils. In the case of the two competitive sheets with high fiber orientation, the creep seems to be quite small; just the difference between 0.1 % and 0.15 % respectively for the competitive coated and SC sheets.

For the target PM sheets, the elongation remaining after heating from 90 % RH is significantly higher than that for the competitive sheets. The target PM sample has less fibrillar reinforcement in the applied load direction than the competitive sheets, due to the lower fiber orientation. The amorphous matrix will soften a similar amount as the competitive sheets, however more movement of fiber walls should be possible due to the lower microfibrillar reinforcement. It seems most likely that the mechanism allowing the extra creep on the target PM is the lower fiber orientation yielding lower reinforcement in the loading direction, while the amorphous components are soft. The additional creep is estimated at 0.4 %, the difference between the strain at 90 % RH heated and 50 % RH heated results.

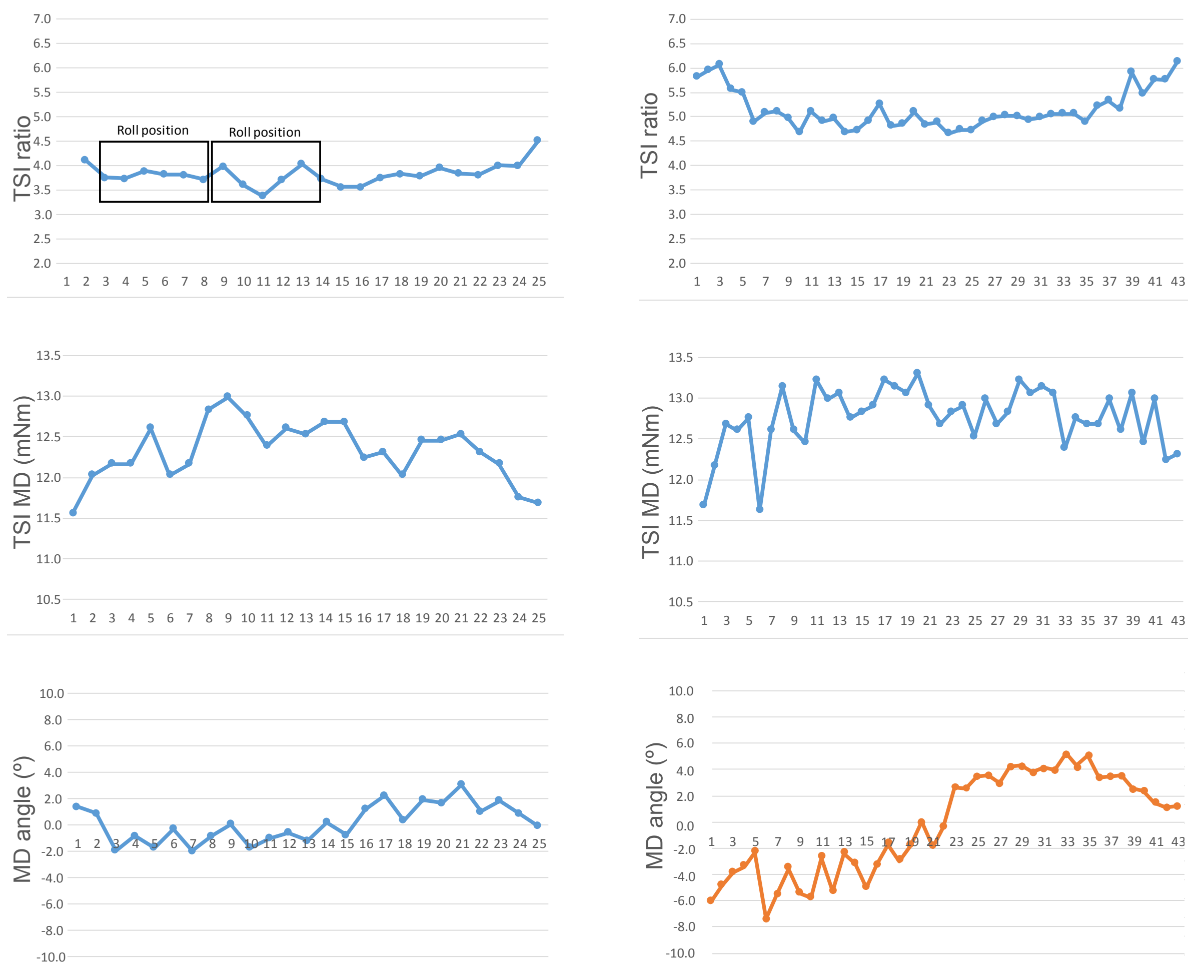
3.4 Ultrasonic measurement

Samples for which cross machine direction strips were available were measured for fiber orientation properties using ultrasonic measurement techniques. This included the 11 target paper machine trial samples plus one competitive sheet. Figure 12 shows the comparison of the target PM standard front edge roll and competitive coated sheet for TSI ratio, TSI MD and MD angle. The black boxes on the TSI ratio charts indicate the locations of the rolls used for the trials. As with the MD/CD tensile strength ratio, the TSI ratio of the competitive sheet is substantially higher than the target PM. The TSI MD values are slightly higher for the target PM than the competitive PM indicating that at equivalent basis weight the target PM would have a slightly higher tensile stiffness than the competitive sheet. It was found earlier in this section that tensile stiffness is not an indicator of lateral web movement performance.

The chart of MD angle shows that across the paper machine, there is less variation in the target paper machine than on the competitive PM. An increase in MD angle has the effect of changing the fiber orientation and therefore the tensile ratio. The higher deviation near the edges on the competitive PM TSI ratio illustrates this point. The summary of all rolls is displayed in Table 4. The TSI ratio is lower than for the competitive paper machine for all target PM trial points except one. For the reduced groundwood refining test the chart of TSI MD shows quite a bit of variability in the CD. This trial point was made in succession with the other conditions that did not have this variation or magnitude. This measurement result is considered invalid.

Table 4: Summary of ultrasonic measurements for target PM conditions and one competitive paper (Shields, 2017)

TSI parameter	Compet. paper	Standard paper	Edge flow closed	Increased strain at 20 % solids	Reduced drying restraint	Reduced J/W ratio	Higher kraft refining	Lower kraft refining	Reduced grounwood refining	Increased wet end starch	Reduced wet end starch
TSI MD (mNm)	12.8	12.3	11.8	12.0	11.8	11.8	12.4	12.1	11.7	12.2	11.8
Std. dev.	0.4	0.4	0.5	0.4	0.4	0.6	0.5	0.5	0.6	0.4	0.5
TSI ratio	5.2	3.8	3.9	4.2	3.8	3.6	4.1	4.1	5.0	3.8	4.0
Std. dev.	0.4	0.2	0.3	0.5	0.4	0.3	0.4	0.4	1.7	0.5	0.4



a) b)

Figure 11: Ultrasonic tensile properties test results for 25 and 43 roll positions, respectively, for sheets taken from (a) target PM standard front edge roll, and (b) competitive coated paper roll; tensile ratios for the two sheets were 3.8 vs. 4.8 (Shields, 2017)

From the print testing results, the reduced J/W ratio performed poorly. In Table 4 the measurement for TSI ratio is the lowest at 3.6 of any sample tested. The two samples that tested highest for the target PM were the Increased strain at 20 % solids and the Edge flow closed sample.

The average results for the CD strip do not show the reason for the improved printing result. The tensile ratio of the area that the roll was cut from does show a possible tendency towards higher TSI ratio. In both cases the area of the roll tended towards a ratio of 4.5. The only item of interest from these results with respect to the lateral movement performance appears to be TSI ratio, which although the magnitude of the result is higher, is similar to that found using the ratio of MD to CD tensile strength (Shields, 2018). Tensile ratio appears to be of significance in determining reasons for weave on the target PM.

4. Conclusions

The purpose of this work was to determine the papermaking reasons for lateral shift of the moving paper web, made on a particular paper machine, on a specific printing press during heat set web offset printing. While there are differences in air permeability of all tested 25 papers, the papers showing highest air permeability (lowest Gurley permeability results) did not experience web movement, and they were the SC sheets. In fact, the papers with the lowest permeability were made at the target PM. Two competitive sheets tested in the same permeability range as the target paper machine did not experience lateral web movement on press. Thus, it appears that lateral web movement cannot be predicted by Gurley permeability. Creep is a good indicator of lateral movement on the press. Most likely, the mechanism allowing the extra lateral movement on the target PM is the lower fiber orientation of the sheet yielding lower reinforcement in the loading direction. The reason for lower web tension in the target paper machine web is most likely due to lower fiber orientation. Fibers oriented in the direction of stress have reinforcement from the cellulose microfibrils. During printing, the matrix softens to some degree due to the addition of water. The stiff microfibrils serve to reinforce the matrix and prevent movement. Fibers oriented in the cross direction do not have this reinforcement. Therefore, a less oriented sheet has less reinforcement from the microfibrils and is more susceptible to movement of the matrix. Thus, of all tests executed, tensile ratio appears to be the only factor of significance in determining reasons for weave on the target PM.

List of abbreviations and glossary

Hydroexpansion	Expansion caused by penetration of liquid water into the pores of fiber wall.
Hygroexpansion	Expansion caused by penetration of water vapor into the pores of fiber wall.
J/W	Ratio of headbox jet velocity to forming fabric velocity
LWC	Light weight coated paper
MD	Machine direction
CD	Cross machine direction
PGW	Pressurized groundwood
PM	Paper machine
RH	Relative humidity
SBK	Softwood bleached kraft
SC	Supercalendered
TAPPI	Technical Association of the Pulp and Paper Industry
TSI	Tensile Stiffness Index

References

Brezinski, J.P., 1956. The creep properties of paper. *Tappi Journal*, 39(2), pp. 116–128.

Kajonto, I. and Niskanen, K., 1998. Dimensional stability. In: K. Niskanen, ed. *Paper Physics*. Helsinki, Finland: Fapet Oy, p.p. 222–259.

Kipphan, H., 2001. Offset Printing. In: H. Kipphan, ed. *Handbook of print media.* Berlin, Heidelberg, Germany: Springer-Verlag, p.p. 206–359.

Kela, L., and von Hertzen, L. (2007) *Printing Press Runnability.* KCL 0526370.

Kettle, J., Matthews, P., Ridgway, C. and Wågberg, L., 1997. Investigation of the pore structure of paper by novel porosimetric techniques: application to super and soft-nip finishing. In: C.F. Baker, ed. *The Fundamentals of Papermaking Materials*: *Transactions of the XIth Fundamental Research Symposium.* Cambridge, UK, September 1997. Letterhead, Surrey, UK: PIRA International, p.p. 1355–1393.

Lindblad, G. and Furst, T., 2001. *The ultrasonic measuring technology on paper and board: a handbook.* Kista, Sweden: Lorentzen & Wettre.

Niskanen, K., and Kärenlampi, P., 1998. In-plane tensile properties. In: K. Niskanen, ed. *Paper Physics*, Helsinki: Fapet Oy, p.p. 138–191.

Shields, G.W., 2017. *Papermaking factors affecting lateral web position during commercial heat set web offset printing*. Master Thesis. Western Michigan University.

Shields, G., Pekarovicova, A., Fleming, P.D., Pekarovic, J., 2018. Papermaking factors affecting lateral web position during commercial heat set web offset printing. *International Circular of Graphic Education and Research*, 11, p.p. 14–23.

TAPPI, 2011. *TAPPI T 460 om-11 Air resistance of paper (Gurley method)*. Atlanta, USA: TAPPI.

TAPPI, 2013. *TAPPI T 402 sp-13 Standard conditioning and testing atmosphere for paper, board, pulp handsheets and related products*. Atlanta, USA: TAPPI.

Trollsås, P.-O., 1995. Water uptake in newsprint during offset printing. *TAPPI Journal,* 78(1), p.p. 155–160.