Use of components of formation for predicting print quality and physical properties of newsprint

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ABSTRACT
The effect of newsprint formation on paper properties was studied. A new method for formation characterization was used in which formation is partitioned into its components as a function of scale of formation, over a range of scale of formation 0.6 - 37mm. Paper properties examined were burst, CD tear, MD tear, CD tensile strength, MD tensile strength, and print quality. A raw ranking of the quality of newspapers printed on various sources of newsprint was provided by the newspaper publisher. Also, the quality of solid printed sections of the newspapers was determined by an evaluation panel. We found significant correlations between formation and burst, formation and tear, and formation and print quality. For burst and tear, the correlation occurred for the components of formation in the intermediate range of 5-20mm scale of formation. There is a high sensitivity of these strength properties to the relevant components of formation. For print quality, the highest correlations occurred at small scale components of formation, below about 5mm. With the small sample size the results for tensile strength were inconclusive. Thus partitioning formation into its components promises to provide an effective way to control the strength and print quality of newsprint.

RÉSUMÉ
Nous avons étudié l’influence de la formation du papier journal sur ses propriétés. Nous avons utilisé une nouvelle méthode de caractérisation de la formation, qui décompose la formation en ses composantes pour les échelles de formation comprises entre 0.6 et 37mm. Nous avons examiné l’éclatement, la déchirure, la tension et la qualité d’impression du papier. Un classement grossier de la qualité de journaux imprimés de différentes sources de papier journal a été fourni par l’éditeur. Par ailleurs, la qualité d’impression de sections noires des journaux a été déterminée par un groupe d’évaluation. Nous avons trouvé des corrélations significatives liant la formation du papier à son éclatement, sa déchirure et sa qualité d’impression. Pour l’éclatement et la déchirure, la corrélation se produit aux échelles de formation 5-20mm, tandis que pour la qualité d’impression, ce sont les petites échelles de formation, en dessous de 5mm, qui sont les plus
importantes. Pour l’instant, nous n’avons pas obtenu de résultats significatifs pour la tension, à cause du faible nombre d’échantillons disponibles. Par conséquent, la décomposition de la formation en ses composantes est une méthode efficace de contrôle de l’éclatement, de la déchirure et de la qualité d’impression du papier journal.

INTRODUCTION

Papermakers have long been aware of the dependence of paper properties on the quality of paper formation. However, no satisfactory representation of the properties-formation relationship has been found. While paper properties are determined precisely by well-standardized tests, formation is obtained from a variety of commercial test instruments, each of which provides some proprietary single number as an overall index of formation quality. As no single number index of formation can describe the complexity of the two-dimensional nonuniform distribution of fibers across the sheet, these instruments are therefore blind to the key concept of scale of formation. Consequently, attempts to correlate paper properties to these imprecise formation indices have given disappointingly poor results, precluding the control of product quality by controlling formation. However, if this dependence of properties on formation was known sufficiently precisely, then paper properties could be optimized through control of the papermaking process using formation as the key intermediate variable.

Recently, a new method for the measurement of paper formation has been developed at McGill University. This procedure differs fundamentally from those used in the numerous commercial formation test instruments, each of which gives some single number as an overall index of formation. In the new method, a Fourier transform-based power spectrum analysis partitions the intensity of the nonuniformity of the formation into its components as a function of the scale of formation. We name that relation the Paper Formation Line. The range of scale of formation over which these components of formation are presently determined is from 0.6mm up to 37mm. For practical use we find it generally sufficient to define the Paper Formation Line by grouping the complete spectrum of results into 10 components of formation, each component of formation providing a quantitative measure of the nonuniformity of formation at a specific value of scale of formation. In contrast to the single number index of overall formation given by all established commercial formation test instruments, the McGill technology describes simply and quantitatively how the formation nonuniformity is distributed across the sheet. As papermakers have long understood qualitatively, the key characteristic of formation is more than the total amount of nonuniformity: it is how this nonuniformity is distributed across the sheet.

This method has been used to identify which range of scale of formation determines offset print quality of uncoated fine paper [1] and tear strength of newsprint [2], as well as to establish the high sensitivity of these properties to formation in the specific range of scale of formation found to be important. The method of partitioning formation into its components has been used as well for determination of the CD profile of these components and for documenting of the stability of
formation over time for linerboard [3] and newsprint [4]. The components of formation concept has been also applied to full sheet mapping of newsprint formation [5] and to investigation of the strength properties - paper formation interaction [6]. The first results of an approach to characterize all paper grades by this method have been presented recently [7].

**APPLICATION TO NEWSPRINT**

For newsprint, properties of interest to end-users are printability and strength properties. Thus the new formation determination method is used here to explore the relationship between newsprint formation, its physical properties and its printability, with the objective of using these results as a predictive tool to control the quality of paper without the delay for measuring all its many strength and printability properties. As paper properties also depend on factors other than formation, the precision of the use of the results will depend on the strength of the formation / property correlation, which must be determined. The present exploration was carried out by determining the effect of each of the 10 components of formation on a number of these properties. For each property, the controlling range of scale of formation was investigated. Then the sensitivity of the correlation between the property and the component of formation at this specific scale was examined. Thus it was established in which range of scale of formation does formation dominantly control each property, and by how much.

**APPLICATION TO NEWSPRINT: COMPONENTS OF FORMATION**

We worked with five samples of 48 g/m² newsprint from two companies, four from the same mill of company A, the fifth from company B. The four samples from company A were as two pairs of two samples. The two pairs were produced on different days, while within each pair the two sheets were duplicate samples from same production. A customer who had purchased the paper from the two companies then printed its newspaper on the same day on three of the five batches of paper. There were five newspapers in total, one printed on the paper from company B, two printed on company A paper from one sample, and two printed on another sample company A paper. A raw ranking of the print quality on all five papers was made by the customer, characterizing the print quality as “best, poor and awful”. The “best” print quality was on paper from company B.

Fig. 1 shows the Paper Formation Lines for the unprinted samples of these five papers, normalized to the paper for which the print quality was ranked as “best” by the customer. The Paper Formation Line for each of the five papers represents the average of 20 determinations of 66x66mm areas of that paper, the size used by our formation tester, with these 20 determinations distributed uniformly over a sheet of about 50cm x 3m. The Paper Formation Line normalization means that when at some scale of formation that specific normalized component of formation of a test sheet is 1.25, for example, the formation nonuniformity of the test sheet at that scale of formation is 25% larger (worse) than that of the “best” paper. Fig. 1 indicates that the Paper Formation Lines of the four batches of paper from company A are greater than one over the entire range of scale of formation, from 0.6mm to 37mm. Therefore paper from company B is...
unambiguously the “best” paper, having the best formation at all scales of formation. However, if
the four company A papers are worse over the entire range of scale, the extent by which they are
worse varies substantially with scale. At the two extremes of scale of formation, i.e. below 2 mm
and above 30 mm, the components of formation of the four papers with poorer formation are about
20% to 30% worse than the best paper. But over the intermediate range of scale of formation, 5 to
8 mm, the components of formation of the four papers of poorer formation on Fig.1 are up to 55%
worse than those of the best paper. It is therefore impossible to make any simple, overall
quantitative comparison of the formation of these five papers. At some values of scale of formation
the difference is only about 20%, but at other scales of formation the difference is up to 55%. Such
differences are highly significant. Thus it is necessary to identify which scales of formation affect
key paper quality attributes and therefore are relevant to the user, then make the quantitative
comparison for those specific scales of formation. Another conclusion from Fig. 1 is that the two
pairs of samples from company A, although produced at different times, follow a generally similar
pattern. However the two sheets of pair 2 are consistently of somehow better formation than the
pair 1 sheets.

APPLICATION TO NEWSPRINT: PHYSICAL PROPERTIES
Five physical properties (MD and CD tear, MD and CD tensile, burst) were measured in our
laboratory according to CPPA test methods on the same samples for which the components of
formation were determined. A constraint on obtaining data for paper property - paper formation
correlations is that the areas of measurement of physical properties and formation are different. We
cut sheets of 8.5x11 inch, about 215x280mm, from the received sheets. Each such sheet was
mapped with 9 determinations of formation, then replicate determinations of one property was
made for that sheet. This procedure was carried out for all physical properties measured, for all
five papers. By this process we obtained the mean value of about 20 determinations for burst, 15
for tensile (in each direction) and 8 for tear (in each direction), along the mean value of 9
determinations of formation for each sheet prior to strength measurement. For each of these
properties, and for all 5 papers, the correlation: paper property vs. components of formation as
determined on the same sheet, was processed for each of the 10 components of formation. An
example of these results is Fig. 2, with the burst / components of formation correlation, for the
range of scale of formation from 0.6mm - 37mm range. Fig. 2 contains two types of information:
the strength of the correlation as represented by the R² value, and the sensitivity, indicated by the
slope. Both aspects are discussed below.

Fig. 3 presents a synthesis of the results of the correlation between burst strength and components
of formation of newsprint, giving the R² of that correlation plotted as a function of scale of
formation. With an R² value of 0.96 at 22mm scale of formation, the correlation between burst and
this component of formation is much higher than at other scales of formation. Figure 3 shows that
the 18-30mm scale structures of the paper have more effect on burst strength than those at either
smaller or larger scale. Thus, to improve the burst strength of the newsprint tested here, the
papermaker must improve dominantly the 18-30mm scale components of formation.

The second type of information provided by Fig. 2 is the sensitivity of burst to the components of formation: at the scale of formation giving the highest $R^2$ correlation (22 mm), each reduction of 1% in the component of formation causes an increase of 1.3% in burst. As the components of formation are determined with high precision (repeatability of about 1%), monitoring components of formation provides a reliable indication of changes in burst strength. In summary, not only is burst highly correlated with the component of formation at 22mm scale of formation, but the sensitivity of this effect of formation on burst is very strong as well. Consequently, changes in the papermaking process which improves formation at that scale by a measurable amount will provide an appreciable improvement in burst as well.

The same procedure was carried out for the other physical properties: MD and CD tear, MD and CD tensile. The $R^2$ - scale of formation graphs are shown on Figs. 4a for CD tear, on Fig. 4b for MD tear. Although there are some differences between MD and CD tear, Figs. 4a and 4b indicate that the region of scale of formation 5-14mm provides the highest $R^2$ values for tear strength in both directions. The maximum values of $R^2$ are 0.75 for CD tear and 0.83 for MD tear. Selecting scale of formation of 14mm as that for which the $R^2$ is the highest for CD tear and only slightly less than the highest for MD tear, Figs. 5a and 5b show the sensitivity of CD and MD tear strength to this specific component of formation. A striking aspect of these results is that as formation gets better, tear strength decreases. These results confirm the same trend in the tear strength - formation quality relation found in two of our earlier studies, one in 1998 [2] for newsprint, and one for linerboard in 1999 [6]. As was discussed here with Fig. 2 in the case of burst, Figs. 5a and 5b show there is a high sensitivity of tear to formation in the highest $R^2$ region. These figures indicate that an increase of 1% of the 14mm component of formation causes an increase of 0.4% in CD tear and 1.4% in MD tear. Again it is seen that monitoring components of formation can serve to predict changes in tear strength.

Thus formation of newsprint tested in this study was found to have a strong effect on burst, CD tear and MD tear. For the effect of components of formation on MD and CD tensile the results are inconclusive. This is not surprising as the present work was done with a small sample size. Thus further work with a larger sample size is required before any conclusion concerning the tensile strength - formation components relation can be made. With a sample size of five, the probability of obtaining an $R^2$ value of 0.96 by pure chance is below 0.5%. Thus the components of formation / burst correlation results are highly significant. However, the probability of obtaining by chance $R^2$ values of 0.75 and 0.83 is about 7% and 4%. Thus the results for MD and CD tear are significant, being at about the 95% confidence level.

APPLICATION TO NEWSPRINT: PRINT QUALITY
The paper formation / paper strength properties study described above was done on five sources of paper, from two production days for company A, with two samples from each day’s production, and with one paper from company B. For the paper formation / print quality study examined now, we had newspapers printed on the same day on paper from two productions from company A and on paper from company B. Thus for the print quality investigation the newspapers were printed on three sources of paper, two from company A, one from company B. We had two copies of the same newspaper which were printed on each of the two batches of company A paper, but just one copy of that same newspaper printed on company B paper. Thus we had a total of five newspapers. As the customer noted that print quality was different between the two sides of the sheet, one sample of solid printing was taken from each side of each of the five newspapers. Thus we had a total of 10 solid print samples.

For these ten newspaper sections we carried out a print quality evaluation. This evaluation of print quality was accomplished using the Proscale method developed by Donderi and Aspler [8]. A number of evaluators rank the print quality visually. Proscale requires a minimum of ten evaluators, but recommends the use of fifteen. The present study used fifteen evaluators, who rated both sides of solid printed sections of the five newspapers according to the uniformity of the solid black print. The size of the rated areas of solid print was about 4x4 cm. In the Proscale method, each evaluator can choose their own scale, subject only to the constraints that a higher number means a better print quality and that all numbers be greater than zero. The Proscale algorithm normalizes all of the ratings and gives the average rating for each sample. Since both sides of the newsprint were used in the subjective evaluation some differences were noted, in accordance to the comments of the customer. The front side was rated higher than the reverse side, for all samples except one.

Correlations were made between the print quality ratings and the components of formation at each of the ten scales of formation noted above. Figure 6 shows the sensitivity of print quality to components of formation for 0.6mm and 37mm. At scale of formation 0.6mm, the R² values are high at about 0.6, but for larger scales of formation the R² values dropped steadily to 0.37 at 37mm scale of formation. As we only have three independant samples, the R² values shown on this graph are of limited validity. While these preliminary results indicate that the quality of solid printing on commercial newsprint is controlled dominantly by the components of formation in the small range of scale of formation, further study is required to establish definitively that relation.

**CONCLUSIONS**

It was found that the burst strength and MD and CD tear strength of two newsprints were most strongly affected by the intermediate scale of formation, in the range 5-20 mm. Preliminary results indicate that the print quality of solid black sections of commercially printed newspapers is dominantly affected by the smaller scale of formation, below about 5mm. Thus strength and solid print quality of newsprint are affected by quite different components of formation. The present
investigation reinforces the utility of the new method of partitioning formation into its components as a function of scale of formation because of the additional evidence that specific paper properties of specific grades of paper are controlled by different components of formation.

Because of the small sample size of the present study the quantitative results can only be taken as approximate. For this reason the MD and CD tensile strength results were inconclusive and the print quality results can only be considered as preliminary.

Further work with a larger sample size will allow precise determination, for print quality and strength properties, of both the controlling range of scale of formation and the sensitivity of the property to that specific component of formation.

These correlations to be determined between the components of formation and the various paper properties will then allow the papermaker to use this new method of measurement of formation to control those properties specified by its customers. When obtaining the necessary data is complete, this procedure can be used in a control loop for the papermaking operation.

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REFERENCES


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Fig. 1: Relative Paper Formation Lines of company A papers, reference sheet company B paper
Fig. 2: Effect of scale of formation on the components of formation - burst relation
Fig. 3: Effect of scale of formation on the component of formation - burst correlation
Fig. 4a: Effect of scale of formation on the component of formation - CD tear correlation

Fig. 4b: Effect of scale of formation on the component of formation - MD tear correlation
Fig. 5a: Sensitivity of CD tear to the 14mm component of formation

Fig. 5b: Sensitivity of MD tear to the 14mm component of formation
Fig. 6a: Sensitivity of print ranking to the 37mm component of formation

\[ y = -939.28x + 54574.50 \quad R^2 = 0.37 \]

Fig. 6b: Sensitivity of print ranking to the 0.6mm component of formation

\[ y = -37.31x + 1892.50 \quad R^2 = 0.60 \]