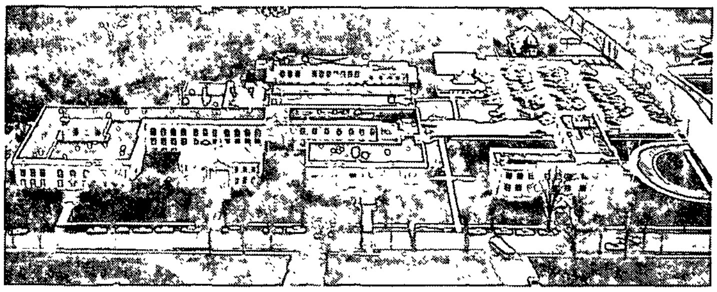

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ANALYSIS AND SIMULATION OF PROPERTY DEVELOPMENT IN FORMING NEWSPRINT

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ANALYSIS AND SIMULATION OF PROPERTY DEVELOPMENT IN FORMING NEWSPRINT

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ABSTRACT

Property data from a newsprint mill are analyzed using the performance attribute system of the MAPPS process simulation program to determine how well property development can be described and understood by means of novel modeling techniques. The analysis includes the stone groundwood mill, kraft mill and paper machine. Among the many factors considered are species characteristics, refining, screening, cleaning, pulping, bleaching, formation, anisotropy, drainage, dewatering and wet consolidation in the press section, drying, and calendering. Model predictions compare favorably with the handsheet properties of the pure groundwood and pure kraft furnishes and with those of the calendered newsprint.

The simulation model shows that only a few properties of the newsprint can be understood as a mixture of the kraft and groundwood properties. Many properties are altered by the papermaking operations which change the compressibility and bonding potential of the furnish. Converting operations such as calendering make the direct prediction of any mechanical or optical properties nearly impossible based solely on simple mixing rule concepts. However, using more fundamentally-based variables called performance attributes, it is possible to predict the characteristics of the mixtures based on the attributes of the entering furnishes and the papermaking and converting conditions. Ultimately, such techniques, could help to determine ways of reducing production costs by increasing the groundwood component in the furnish.

BACKGROUND

Substitution of costly kraft furnish with mechanical or recycled fibers for newsprint production is restricted by questions of mechanical properties and runnability. A major shift in furnish mix usually requires costly and time consuming experimental programs which can rarely be justified.

Using a systems simulation approach Van Scotter and Edwards (1980) found improved screening and refining configurations which reduced payout time while maintaining quality (tear) and runnability (drainage rate). Their calculations were based on straightforward mixing rules for these variables. Before a significant increase in mechanical pulp furnish can be envisioned, the effects of additional mechanical and optical properties should be considered. A systems approach to determine the effects on mechanical and optical properties of a change in furnish mix can provide a cost effective basis for further work.

MAPPS is a process simulation program which consists of modules which simulate both the mass and energy balances of process operations as well as more subtle effects of process conditions on fiber characteristics such as fiber length distribution, surface area or freeness, and tensile strength. The novel approach used by MAPPS is to represent the process flows in terms of the properties of the fiber and the fiber network as well as the flows of individual components. The additional characteristics are referred to as "performance attributes" because of their relation to the end-use performance characteristics of paper.

By combining the usual data such as component flows, temperature and pressure, with the attribute data, a more complete picture of the state of each process flow stream can be developed. The attributes are then used to compute the papermaking potential of the fibers at any point in the process. On the paper machine, both handsheet and machine paper properties can be determined.

With the addition of performance attributes, it is now possible to use a systems approach such as that used previously to a variety of problems and paper grades. The system has been shown to predict many handsheet properties through a TMP mill (Jones, 1988, 1989). More recently, MAPPS has been used to analyze the effects of multiple repulping steps on mechanical and optical properties of handsheets (Jones, 1989). With the addition of performance attributes, MAPPS can now more realistically simulate papermaking and converting operations such as sheet forming, wet pressing and calendering. Coating and multi-ply sheet-forming are under development.

Rather than relying on simple mixing rules, the performance attribute models provide a more fundamental means of calculating the effects of changing furnish characteristics. This novel and comprehensive approach to the application of modeling techniques in papermaking has not been undertaken before. As a test case, the data from a newsprint mill are analyzed with several purposes in mind.

1. To validate and identify weakness in the models.
2. To predict the effects on a variety of properties of a substitution of stone groundwood for kraft pulp.
3. To better understand the relationships between newsprint properties, operating conditions and furnish properties.

PERFORMANCE ATTRIBUTES

The performance attributes shown schematically in Figure 1 consist of commonly measured pulp characteristics. Attributes represent either fiber characteristics or features of the fiber network. Fiber attributes are broken down further into composition, shape and surface area groups. Network attributes consist of variables which contribute to contact area, bonding and anisotropy of the network.

Composition attributes are kappa number, yield, hemicellulose ratio, X_{hemi}, and absorption coefficient. Assuming the Kubelka-Munk theory to be valid, the absorption coefficient, C_K, for any fiber furnish is based on the average composition of the mixture and the specific absorption coefficients of the components, lignin, cellulose and extractives at that point in the process.

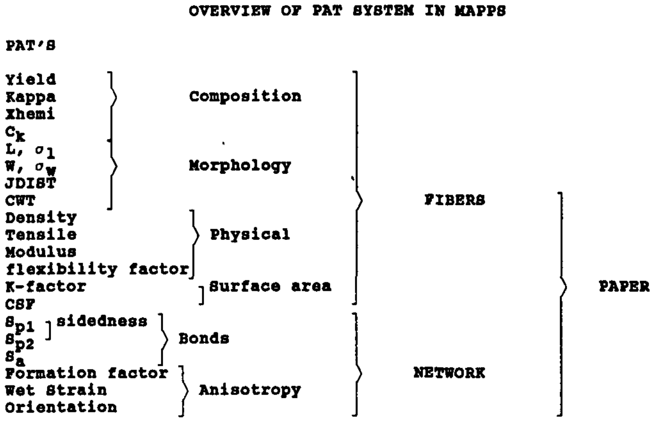

Figure 1. Performance attribute diagram.

Fiber shape is represented by fiber length and width distribution parameters (mean and standard deviation, $\overline{L}$, σ_L, $\overline{W}$, σ_W), cell wall thickness, CWT, and by the type of distribution, i.e., normal, lognormal, etc., JDIST. Fiber physical properties are represented by fiber density, tensile strength, elastic modulus and fiber flexibility factor. Fiber surface area is represented by freeness, CSF, and K-factor. The latter parameter represents the effect of refining on the external surface area (hyrodynamic specific surface) development.

The complex effects of pulping and bleaching are treated perhaps somewhat simplistically as a reduction in kappa number or absorption coefficient and yield based on the Hatton equations in pulping and other relations for each unique type of bleaching. Hemicellulose is assumed to react before alpha-cellulose. Any reduction in alpha cellulose leads to a proportional reduction in fiber strength and elastic modulus. Compositional changes result in a corresponding change in absorption coefficient as well as bonding potential. The principal effects of bleaching are assumed to be similar to those of pulping. They differ only in selectivity and yield.

Refining, screening and cleaning operations affect and are affected by mainly the fiber length, fiber width, specific surface area, fiber strength, and bond strength. Depending on the type and severity of refining and pretreatment, the average fiber length and width decrease, longer fibers are converted into shorter fibers, fiber bundles are broken down into individual fibers, generating fines, fibrils may form (surface area increases) and fiber strength may increase or decrease depending on yield and refining severity. As pulp yield decreases, the bonding potential of the fibers during refining will increase due to the exposure of hydrophilic secondary walls.

Various fiber separations and pulp cleaning operations affect fiber length and width distributions differently. Differences between the accept and reject streams are all accounted for by the fiber length and width distributions (fiber component flows), consistencies, and fiber surface areas. Models for these operations are based on work by Yan (1975) and Strand and Edwards (1984).

Forming results in a network of fibers and the removal of substantial amounts of water and fine fibers. The network consists of layers of fibers with water-filled pores. The variation of fines and filler retention during the deposition process leads to a variation in fiber length distribution and contact area in the thickness direction. The network is represented by the degree of fiber contact of the top and bottom of the sheet, S_{p1} and S_{p2}, respectively. These attributes, which also represent the sidedness of the sheet, are generated during forming and tend to increase during wet pressing. The fiber contact areas are related to the hydrodynamic specific surface of the fibers (freeness) which is in turn related to the fiber length distribution and K-factor, and to the compressibility of the mat. Mat compressibility is related to fiber flexibility which is modeled in terms of yield, fiber stiffness factor, cell-wall-thickness and fiber modulus.

Sheet forming includes the effects of headbox and slice flow, gravity drainage, active drainage elements such as table rolls, foils and suction boxes, and the influence of a dandy roll. The paper machine includes the effects of particle and fiber retention, formation effects due to jet-to-wire ratio, consistency and fiber length, and the dandy roll. Profiles are generated for basis weight, white water consistency and drainage rate. The drainage resistance and active drainage element models are based primarily on work by Pires, Springer and Kumar (1988), Kerekes (1981), and Victory (1969).

Floc formation and breakup during forming lead to variations in density and basis weight in the plane of the sheet. This is modeled in terms of formation factor (Figure 1) which depends on jet-to-wire speed ratio, headbox consistency and average fiber length. Fibers tend to be oriented preferentially in the machine direction due to the difference in speed between the jet and the wire. Both fiber orientation and wet stretch of the sheet lead to stress anisotropy. These are represented by the formation, orientation, and wet stretch or shrinkage attributes. Formation effects are based on work of Halgren (1988).

In wet pressing, water removal and sheet consolidation are determined based on the maximum nip pressure and nip residence time. These are based on first order models of the dewatering and compression processes. Each are dependent on the compressive modulus of the mat, the basis weight of the mat and the felt, machine speed, press speed, lineal nip load, freeness, entering moisture, entering fiber contact area and other factors. The dewatering model is based on work of Wegner, Young and Caulfield (1982, 1983 and 1986), Wahlstrom (1981) and Beck (1986).

During drying most of the remaining inter- and intrafiber water is removed and the predominant water-cellulose hydrogen bonds are replaced by cellulose-cellulose bonds [Nissan and Batten

(1987)]. This process is represented by a conversion of a portion of the contact area to bonded area, S_a, which is the average over the thickness of the sheet. Conversion of contact area into bonded area is also influenced by the bonding potential of the fiber surfaces. The bonding potential is influenced by previous pulping, bleaching and refining operations. Polymers and wet end chemistry, which also controls bonding, is not yet accounted for in the system.

Shrinkage or stretch during drying will affect the cumulative sheet stretch attribute, wet strain. Directional tensile properties are influenced by fiber orientation, orientation, and stretch.

Calendering is modeled in terms of the nip intensity factor approach of Crotogino (1981). Heat transfer in the nip and on the roll surface is determined from the work of Kerekes (1979). In addition, the effects of moisture, temperature and composition on the thermal softening behavior, and the effects of excessive densification on both bulk and surface properties are included. Excessive densification in a relatively dry state leads to bond breakage which reduces S_a while increasing fiber contact areas, S_{p1} and S_{p2}. Calendering under moist and relatively high temperature conditions can reduce bulk and increase bonded area. The effects of roll modulus are not yet included. Integration of these various effects were influenced by the work of Charles and Waterhouse (1987).

Surface properties are based on the surface density which depends on the degree of fiber contact on each side of the sheet. Strength is based on bond area, S_a. All variables will change as the sheet passes through each nip. Properties which depend on surface characteristics such as roughness, scattering, gloss and sidedness will be correspondingly affected [Crotogino (1980)]. Tensile strength and other mechanical properties will be affected by the breakage or formation of bonds.

PROPERTY MODELS

The average contact area and other attributes are used to compute the sheet density based on a model developed from data of Alexander and Marton (1964). It is well known that tensile properties are strongly related to sheet density. Tensile properties are also influenced by network anisotropy factors such as formation efficiency, fiber orientation and stress distribution. The latter is affected by wet stretch in open draws, restraint during drying and possibly even microcreep during calendering. It is also well known that handsheet properties can differ from those of machine papers from the same furnish. The differences are assumed to be due solely to variations in sheet forming which lead to differences in sheet anisotropy.

Using an analogy for the apparent effect of sheet density on tensile strength and other mechanical properties, the variable called the effective bond density is calculated based on the sheet density and the formation efficiency. The mechanical properties are then based on the effective bond density and fiber properties using adaptations of models by Page, Seth and De Grace (1969, 1979) (MD breaking length and elastic modulus), Van den Akker (1978) (burst), and Karnis and Shalhorn (1979) (tear).

Optical properties such as scattering and brightness are based on the surface roughness and absorption characteristics of the sheet. Roughness is modeled in terms of contact areas, S_{p1} and S_{p2}. Absorption is based on the composition of the fibers, primarily lignin content.

Printing properties such as gloss and Gurley smoothness are based on the degree of surface densification which are related to S_{p1} and S_{p2} based on data by Crotogino (1980). Porosity is related to surface area development, Taber stiffness to sheet density and modulus and MD/CD tensile ratio to stretch and fiber orientation.

MODEL VALIDATION DATA

Data for the validation and analysis were provided by Champion International. The data consisted of operating conditions and handsheet properties for the kraft and groundwood mills and operating conditions and calendered paper properties from one of the fourdrinier paper machines.

KRAFT MILL OPERATION CONDITIONS

The kraft mill simulation included a continuous digester, blow tank, tall oil separation, white and black liquor control, liquor recovery, a three-stage brownstock washing system (simulated in one stage), a knotter, a 3-stage screen room (simulated in only one stage) and a decker. This was followed by a bleaching sequence consisting of a chlorination, caustic extraction and a hypochlorite bleach plant. The pulp was brought to a desired freeness in a final refining stage. Production was 272.4 MT/day per day.

Species characteristics were initialized from a species data base assuming a longleaf pine furnish. The final yield and kappa number were obtained by adjusting the cooking time. Bleached kappa number was obtained by adjusting the retention time and temperature in the bleaching stages. Final freeness is obtained by adjusting the power into the final refiner stage. Fiber length, freeness and fiber tensile are affected by the species, pulping, bleaching and the screening and refining operations.

Pulping conditions included a liquor to wood ratio of 3:1, liquor sulfidity of 0.262, heat up time of 1 hr, cooking time of 4 hr and a 1 hr blow time. Brownstock washers were run at 14.5% black liquor solids, outlet consistency of 10.9%, dilution factor of 3 and a displacement ratio of 0.85 in washer 1 and 0.6 in washer three. The reject system conditions included screening consistencies (0.8 to 1.5%) and efficiencies (65 to 95%), knotter efficiencies (95%) and refiner power (1.42 MJ/kg reject refiner, 0.79 MJ/kg final refiner). Freeness dropped from 735 to 670 across the kraft (Babit double disc) refiner with a power input of 1.78 MJ/kg.

Chlorination took place at 2.9% inlet consistency using 7.6% applied chlorine, a temperature of 37 C and kappa factor of 0.24. Residual chlorine was 0.01 g/L. In the extraction stages, pulp was preheated to 63 C with steam at 101 kPa, extracted at 48 C, with 2.8% NaOH to a pH of 10.2. Washing efficiency was 72% with outlet solids of 11%. Hypochlorite bleaching took place at 32 C using 5% hypochlorite charge. The residual chemical was 0.5 g/L. Pulp washing efficiency was 72% and outlet consistency was 11%.

GROUNDWOOD MILL DATA OPERATING CONDITIONS

The simulation flowsheet consisted of a refiner representing the grinder, operated at 2% consistency and a power input of 3000 kw hr/MT. Screen consistency was 1.2%. Rejects were refined in 4 Bauer single disc refiners (represented by one refiner) operated at 10% consistency refining to an outlet freeness of 400 to 600. The bleached pulp was refined in a single Sprout Waldron double disc refiner operating at 4% consistency and refining to about 60 mL. Bleaching took place at 10% consistency and 100 F with 5% applied chemical. The groundwood was thickened to a final consistency of 3%.

PULP PROPERTY COMPARISONS

Although space does not allow for a complete discussion of the data input to perform the mass and energy balances and process flowsheets, the simulated mass and energy balances were quite accurate. Those results of the mass and energy balance such as yield, kappa number and fiber length, which affect fiber and sheet properties, are summarized in Table I.

Table I. Comparison of pulp properties.

	Kraft		Groundwood	
	Sim.	Measured	Sim.	Measured
Yield	45.9	45.5	98	96.8
Mean fiber length (mm)	2.62	2.54	0.76	0.79
CSF (mL)	661	643	20	20
Zero span tensile (km)	28	39.6	13	19
Kappa number				
- digester	25.3	23	--	--
- extraction	5.1	7.3	--	--
Species	Longleaf pine	--	Longleaf pine	--
Fiber width (mm)	0.035	--	0.035	--
Cell wall thickness (μm)	2.5	--	2.5	--
Bleached fiber absorption coef. (km^2/kg)	1.5	--	10.6	--

The only obvious difference appears between the effective fiber strength used in the model and the measured zero-span tensile strength. The 50% difference between the two is accounted for in the form used in the breaking length model. A similar difference is shown for the groundwood fiber. The problem lies in the difficulty in specifying the tensile strength or modulus of the virgin pulp for any given species. The working measure of these properties is based on the zero-span test which requires a suitably formed sheet. This problem will only be resolved upon further investigation.

In Figure 2 a portion of the fiber data are plotted on a grid with yield vs. the log of the freeness. The groundwood operating point is shown at 98% yield and at two freenesses of 50 and 20, respectively. In either case the newsprint freeness-yield operating point was located approximately on a straight line connecting the kraft and SGW operating points. Newsprint freeness was 130 and 96, respectively. Weight-average fiber length is based on a log-normal distribution for fiber length and in this case is dominated by the groundwood fraction. Other attributes were based on the weight-average of the two furnishes. It will be shown that the newsprint furnish behaves like a furnish at a mixture yield of 79%.

NEWSPRINT PAPER MACHINE CONDITIONS

Papermaking conditions were specified for the simulation based on typical operating data from the paper machine area. A small number of simulation parameters were adjusted to achieve agreement with this data for the typical newsprint furnish. These parameters were not changed for the study of the effect of groundwood content discussed later.

The newsprint was formed from 38.5% kraft and the remainder groundwood on a conventional fourdrinier followed by two straight-through presses and a dryer section. The sheet was then passed through a single nip conventional calender.

Headbox consistency was controlled at 0.6% with 100% virgin fibers (38% kraft, 61% groundwood) at a wire speed of 1420 m/min (23.67 ft/min) and a jet-to-wire speed ratio of 0.96. The headbox was assumed to operate at atmospheric pressure with a pond height of 1 m, lip extent of 50 μm and a slice angle of 90 degrees.

The dry line occurred at 8.8 m at a consistency of 18 to 19%. The 9.4 m forming section consisted of a 3 m gravity drainage section followed by 22 foils with an average foil angle of 3 degrees, 1 flat box operating at a suction pressure of 20.27 kPa. Trim was 1% and all was recycled. The slice height was adjusted in the neighborhood of 0.018 m to achieve the above jet-to-wire ratio of approximately 1 and to optimize formation efficiency. Final mat moisture and basis weight at the couch of 40 g/sq m were obtained by adjusting parameters which control mat filtration resistance and retention. White water consistency was found to decrease from 0.317 to 0.293% along the wire.

The two-nip wet press achieved maximum nip pressures of 240 and 261 kPa when operating at 1483 and 1498 m/s, respectively, with a felt basis weight of 1313 g/sq m. Consistency increased from 19 to 21% to 37 to 38 across the press section. For simplicity all roll diameters were assigned a value of 0.86 m. Compressive modulus of the mat was adjusted to achieve the desired dewatering and mat consolidation.

White water streams from the wire section, press section and trim were combined with broke and 80% was passed through the disk saveall. The filter cake was returned to the stock prep area for consistency control.

The dryer can section consisted of 39 cans consuming 206 kPa steam. Moisture dropped from 63 to 7%. Although calendering conditions were not available, hard nip calendering was simulated at a roll speed of 432.9 m/min, lineal nip load of 500 kN/m, roll surface temperatures of 30 C and roll radii of 0.1 m.

PAPER PROPERTY COMPARISONS

Kraft handsheet properties were available, in the form of beating curves, at the blow tank, decker and after each bleaching stage. Except for brightness, these data did not indicate a significant (i.e., greater than 10%) change in the key properties when compared at the same freeness. Therefore, only the final bleached pulp handsheet properties are compared. Property development within the groundwood mill is considerable. However, only the final handsheets were available for comparison. Data for the calendered newsprint (yellow pages grade) were obtained from tests at The Institute of Paper Chemistry.

The predicted results and % difference between measured and simulation are summarized in Table II. Also included are typical values of data variability (plus or minus %).

Table II. Summary of paper properties.

	Kraft Handsheets		Groundwood Handsheets		Calendered Newsprint (Yellow Pages)		
	Sim.	Diff.* %	Sim.	Diff.* %	Sim.	Diff.* %	Data %
Density (g/cc)	0.66	5	0.41	12	0.71	3	± 4
MD breaking length (km)	8.5	0	2.5	16	4.3	-16	
Burst factor	67.7	6	16.6	43	15.4	6	± 2
GM tear factor	160	20	21	14	61.6	-13	± 10
MD stretch (%)	2.6	-22	1.5	7	0.7	-14	
Scattering coeff. (m^2/kg)	12.0	-49	89.4	5	33.6	-38	
Opacity (%)	85.6	2	103	9	89	-1	
Brightness (%)	61	-13	60	0	53	-7.5	
Elastic moduli:							
MD (GPa)					5.84	-1	
CD (GPa)					2.42	27	
Shear (GPa)					1.70	27	
Porosity (sec/100 cc)					86	15	± 3
Sheffield roughness					71.1	--	
Taber stiffness factor					0.023	--	

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*Difference = 100 (Sim-Data)/Sim.

**Typical newsprint brightness.

Mechanical properties of the kraft handsheets are, of course, higher than those of the groundwood handsheets due to the relatively higher sheet density, bond strength, and fiber tensile strength. Higher sheet density results from the higher degree of fiber-fiber contact attributed to reduced fiber stiffness. Higher tensile strength is attributed to reduced damage in refining and minimal cellulose degradation of the kraft pulp. Scattering coefficient is lower due to the higher level of bonding and reduced numbers of scattering sites (fewer fines). Brightness is higher due primarily to the significantly lower absorption coefficient. The predicted scattering of the well-bonded sheets (both kraft and calendered) tend to be low. This results in an underprediction of the sheet brightness for the kraft handsheet and the calendered newsprint.

In addition to the higher density and fiber strength of the kraft sheets, tear factor is higher due to higher average fiber length.

The groundwood fibers are stiffer and form a bulkier sheet. A significant fraction of the inherent tensile strength of the fibers is lost during grinding. These two factors contribute to the significantly lower sheet tensile. The stretch is also lower due to the lower density. Burst is far lower due to the multiplicative effect of lower stretch and lower geometric mean tensile.

As whitewater is mixed in prior to forming, the freeness drops from 70 to 40 and then rises to 100 after loss of fines on the wire. This results in a freeness which is related to the weighted average of the logs of the freenesses of the kraft and groundwood as shown in Figure 2. The newsprint mixture is more compressible than would be predicted and the result is a denser sheet than expected. In fact, the machine paper is denser than the kraft sheet even though it is made at somewhat less severe densification conditions than a handsheet as will be shown later.

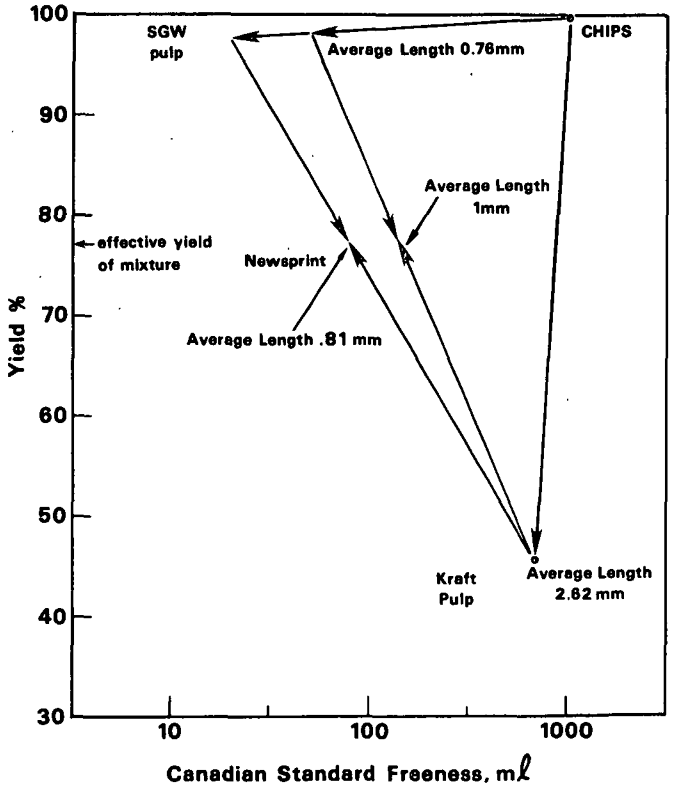

Figure 2. Effective freeness of newsprint.

The calendered newsprint properties are in reasonable agreement with the exception of the scattering coefficient and the brightness which are both somewhat low for the same reasons as mentioned above. Density of the calendered paper is higher than that of the pure kraft handsheet. The predicted density of the precalendered newsprint is approximately 0.69 so the increase in density due to calendering is only about 0.02 g/cc. However, there are no measurements to confirm this density rise.

Although many properties such as breaking length, tear, scattering and opacity are intermediate between those of the groundwood and kraft handsheets as might be expected, stretch is significantly lower than either pure component. As a result, burst is lower for the newsprint than for the pure groundwood handsheet due to the cumulative effect of straining the sheet after the couch, in the dryer section and on the calender nips. It is assumed without the support of data that restraint normally stretches the sheet 1% in making a typical handsheet while the wet stretch is approximately 3% on the calendered sheet. Wet stretch can also reduce dry sheet density, although this is not taken into account here.

Some of these properties such as breaking length are dominated by the averaging effects of the fiber tensile strength. Properties which are predicted to be strongly density dependent such as stretch do not fall between the pure furnish properties.

Elastic moduli in the MD, CD and shear planes compared reasonably well with the measured values. The models are derived from data of Fleischman (1982) which were made at a variety of densification conditions and fiber orientations. However, factors such as species effects were not considered. Sheffield roughness predicted for the calendered paper falls within the general range seen for other calendered newsprint grades.

EFFECT OF VARIABLE GROUNDWOOD CONTENT

Having established reasonable agreement for the base case mixture, a series of cases were run from 100% kraft to 100% groundwood, the results of which are shown in Figures 3 through 6.

Machine Drainage and Dewatering

It was first thought that a change in the furnish would have a strong effect on drainage and water removal. However, the machine and white water system appeared to adjust to the increase in groundwood content. Only at the highest groundwood levels was dewatering in the press section impaired. A 10% increase in steam flow to the dryer section resulted in the same final dryness. Other runnability characteristics will be related to both average tear or breaking length and to defects in the sheet. While it is shown that tear will decrease, thus negatively affecting runnability, other contributors to runnability such as the shives level, were not analyzed. However, shives will increase in proportion to the groundwood content and should also have a negative impact on machine breaks.

Mixture Attributes

Figure 3 shows the variation in mixture attributes which most affect mechanical and optical properties such as freeness, fiber tensile, log-mean fiber length, mixture yield and absorption coefficient. With the exception of freeness, these properties change linearly with groundwood content.

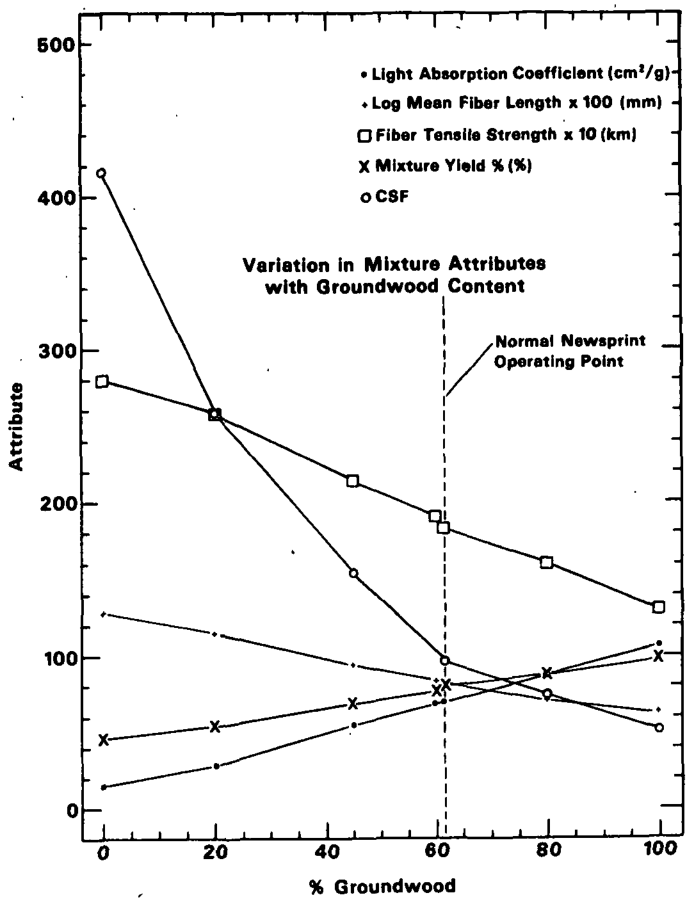

Figure 3. Effect of groundwood on attributes.

Mixture Properties

Figure 4 shows the variation in various tensile properties and formation efficiency which affects bond density and hence tensile strength. The density values shown at the bottom of Figure 6 should also be referred to at this point.

The reason cited for the higher density of the calendered paper is the response of the sheet to the densification conditions in the wet presses due to the lower freeness of the mixed pulp after dilution of the mixed furnish with the white water prior to forming and after loss of fines on the wire. The effect is more apparent when comparing in Figure 6 (bottom) the density of the 100% kraft handsheet (0.66 g/cc) with that of a handsheet made from 100% kraft furnish fed to the newsprint paper machine after dilution with white water and forming (0.82 g/cc). The standard TAPPI handsheet is made with a wet pressing pressure of 413 kPa. The densification conditions in the wet presses do not lead to the same level of densification on the actual machine paper even after calendering (0.71 simulation or 0.69 measured).

Thus the simulation predicts correctly that the sheet made on the paper machine from a furnish which is 68.5% stone groundwood will be denser than that of the handsheet made from 100% kraft. It also shows that the densification conditions are not as severe in the presses on the machine as would be experienced by the handsheet under standard TAPPI handsheet forming conditions.

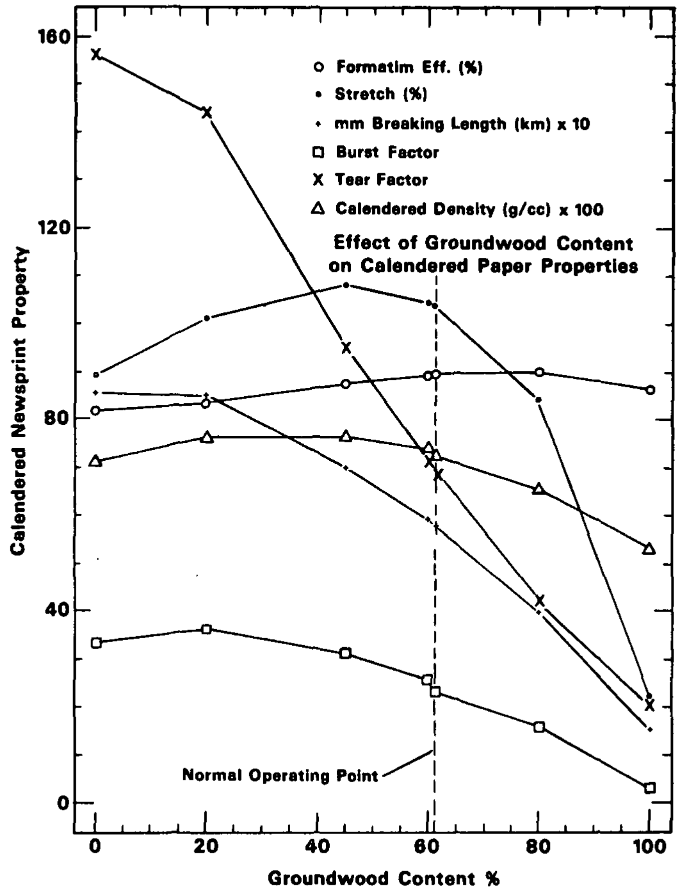

Figure 4. Effect of groundwood on tensile properties.

As shown in Figure 6, the density of both the hypothetical handsheet made from fibers passed through the paper machine and the machine paper itself pass through a very shallow maximum over a very large yield range. The density of both begin to drop above the 60% groundwood. The drop is more severe as the groundwood component of the mixture rises from 80 to 100%.

For the 100% groundwood, the handsheet and machine paper densities are essentially the same regardless of the forming conditions. The reason for this is that the fines content and corresponding freeness levels are very similar in all cases. Thus, the sheet consolidation behavior is very similar for all three types of sheet.

The differences between the sheet densities under these three conditions are reflected in corresponding differences in the mechanical and optical properties of the sheets. Formation efficiency is predicted to increase as groundwood is added as a result of the short average fiber. This tends to counter the effect of the drop in sheet density on sheet tensile properties. Note that stretch goes through a maximum at about 50% groundwood. The sharp drop-off in stretch at higher groundwood content has a severe impact on burst factor. Tear factor tends to decrease in a roughly linear fashion with groundwood content. The reasons are that all the variables which control tear such as fiber length, fiber strength and sheet density (numbers of fibers sheared) and shear strength all decrease.

Figure 5 shows selected surface and optical properties versus groundwood content. Scattering increases almost exponentially with groundwood content due to the increase in fines content and reduction in bonding potential. Scattering is predicted to be lower due to the relatively higher density of the machine paper. However, the measured scattering is significantly higher. Perhaps this is due to the addition of fillers which add scattering sites.

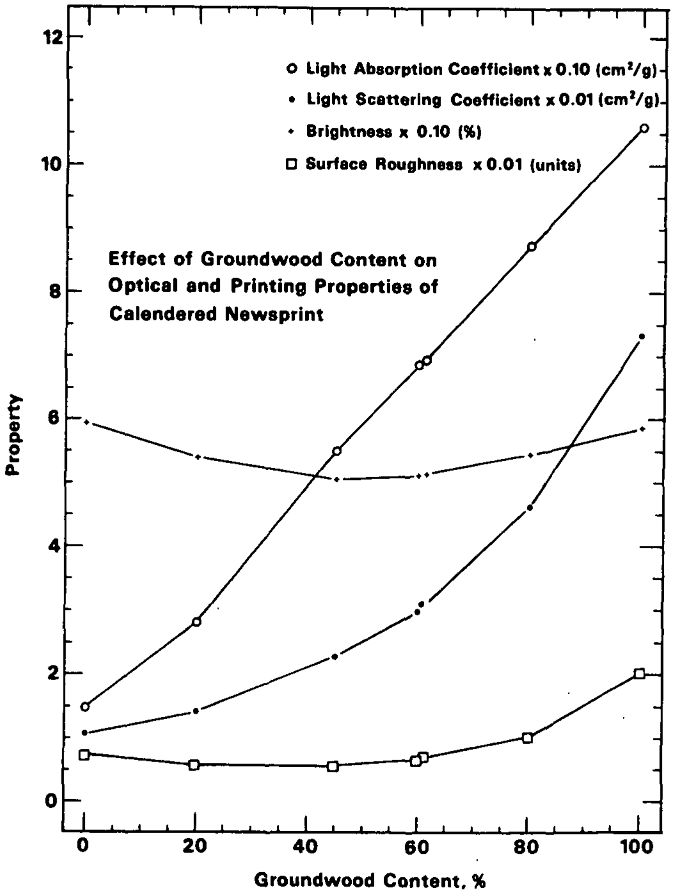

Figure 5. Surface and optical properties.

Absorption coefficient increases linearly based on the application of Kubelka-Munk theory. Brightness passes through a minimum at about 50% groundwood. The trend in brightness is reasonable although brightness is supposed to increase to over 60% at the low groundwood levels. It should also be pointed out that no direct measurements of absorption were available and that brightness of the actual grade tested was even lower than predicted due to the presence of yellow dye which cannot be accounted for in the model at present.

Referring again to Figure 6, density as discussed above is a result of many processes which affect the individual fibers and the network. Fiber stiffness is reduced by lignin removal. However, surface area and bonded area is improved by producing more fines during grinding and refining. Flexibility is also improved during refining, particularly at lower yields. The compressibility of the mat, however, tends to be greater for the higher yield furnish. Thus the effect of furnish composition tends to cancel over a large range in yield. Fiber stiffness effects appear to predominate as the groundwood content exceeds 75 to 80%.

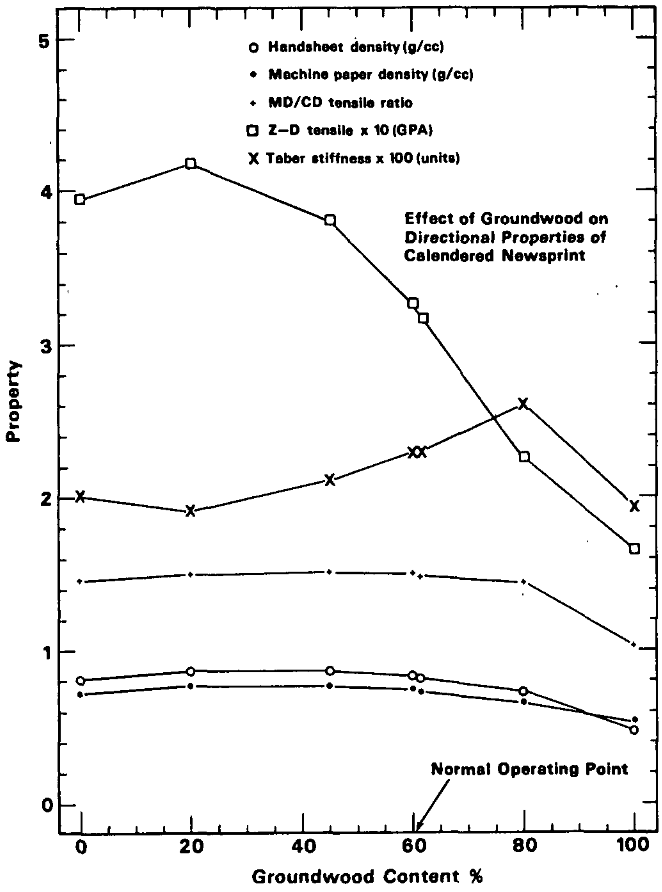

Figure 6. Directional properties.

Z-D tensile which some associate with bonding is predicted to pass through a maximum at about 20% groundwood and then steadily decrease. However, Taber Stiffness Factor, which is also associated with bonding levels, remains relatively constant over most of the range despite the strong density dependence of this factor. MD/CD tensile ratio tends to increase with increasing groundwood content but then decreases again as the furnish approaches pure groundwood. The directional properties are functions of mixture tensile strength and bond density (i.e., formation and density) as well as fiber orientation and stretch. For this reason, it is difficult to determine the cause of the variations.

CONCLUSIONS

This preliminary analysis has shown that it is now possible to realistically simulate sheet forming and property development in complex operations such as newsprint production. The results show that a more fundamental approach is needed to handle the wide variety of factors which influence paper properties. Simple mixing rules cannot be applied to complex operations of this sort. The results show that tear should be expected to decrease linearly while burst factor will decrease more rapidly with increased SGW content.

While most properties are negatively affected by groundwood content in the upper range, it may be possible to reduce the impact by increasing the average fiber length of both furnishes, increasing the freeness of the groundwood at the same or lower shives level, and by decreasing the stretch experienced by the sheet on the machine and in the calender.

Pretreatment of the chips to reduce the severity of the strength reduction in the groundwood mill would also add to the strength of the mixture. While drainage rate and dewatering may not be adversely affected, runnability, i.e., machine breaks, is expected to decrease linearly with increasing groundwood based on tear, tensile and shives levels.

Systems of relatively simple models which account for a variety of factors should prove to be most useful when integrated into a millwide data base. Once the model is developed and tuned to the typical operating conditions, it should enhance the millwide system in a variety of ways: as a data reconciliation tool, for set point optimization, for model reference control, and most frequently, for troubleshooting.

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REFERENCES

Alexander, S. D., Marton, R., McGovern S. D., "Effect of Beating and Pressing on Fiber and Sheet Properties II. Sheet Properties", Tappi 51(6):283-288(1968).

Beck, D. A., "Re-examining Wet Pressing Fundamentals: A Look Inside the Nip Using Dynamic Measurement", Proceedings 1986 Engineering Conference, 1986.

Caulfield, D. F., Young, T. L., Wegner, T. H., "How Web and Press Parameters Interact to Control Water Removal in the Wet Press", Tappi J. 69 (6):90-93(June 1986).

Caulfield, D. F., Young, T. L., Wegner, T. H., "The

Role of Web Properties in Water Removal by Wet Pressing", Tappi 65(2):65-69 (1982).

Charles, L. A., Waterhouse, J. F., "The Effect of Supercalendering on the Strength Properties of Paper", Proceedings International Paper Physics Conf., Mont-Rolland, Que., Can., 1987.

Crotogino, R. H., "Supercalendered and Conventionally Calendered Newsprint", Tappi 63(11):101-105(Nov. 1980).

Crotogino, R. H., "Machine Calendering - Recent Advances in Theory and Practice," Trans. Tech. Sec. 7(4):TR75-87(Dec. 1981).

Fleischman, E. H., Baum, G. A., Habeger, C. C., "A Study of the Elastic and Dielastic Anisotropy of Paper," Tappi J. 65(10):115-118(1962).

Halgren, H., "The Influence of Stock Preparation on Paper Forming Efficiency on a Paper Machine", Proceedings XXIII EUCEPA Conference, Harrogate UK, Vol. 1, 1988.

Jones, G. L., "Simulating the Development of Pulp and Paper Properties in Mechanical Pulping Systems", Pulp Paper Can. 89(6):T214-222(1988).

Jones, G. L., "Simulation of the Performance Characteristics of a TMP Mill", to appear in Pulp Paper Can., 1989.

Jones, G. L., "Strategies for End-Use Performance", Proceedings of the TAPPI Contaminant Problems and Strategies in Wastepaper Recycling Seminar, Madison, WI, 1989.

Kerekes, R. J., "Heat Transfer in Calendering", Trans. Tec. Sec. 5(3):TR66-76(Sept. 1979).

Nissan, A. H., Batten, G. L., Jr., "Unification of Phenomenological, Structural and Hydrogen-bonded Theories of Paper, Using Percolation Concepts," Nordic Pulp and Paper Research J. 1987:8-14.

Page, D. H., Seth, R. S., and De Grace, J. H., "The Elastic Modulus of Paper I., The Controlling Mechanisms", Tappi 62(9):99(1979).

Page, D. H., "A Theory for the Tensile Strength of Paper," Tappi 52(4):674(1969).

Peel, J. D., Hudson, F. L., "Application of Elasticity Theory to a Supercalender Nip", Paper Tech. T164, 7(5):460-470(1966).

Pires, E. C., Springer, A. M., Kumar, V., "Computational Model for Water Drainage in Fourdrinier Paper Machines", Tappi J. 71(4): 133-139(April 1988).

Seth, R. S., Page, D. H., "Fiber Properties and Tearing Resistance", Tappi J. 71(2):103-107 (Feb. 1988).

Shalhorn, P., Karnis, A., "Tear and Tensile Strength of Mechanical Pulps", Trans. Tech. Sec., 5(4):TR92-99(Dec. 1979).

Strand, B. D., Edwards L. L., "Optimum Design, Operation and Control of Mechanical Pulping Systems," Tappi J. 67(12):72-75(1984).

Van Den Akker, "Importance of Fiber Strength to Sheet Strength", Tappi 41(8):416-425(1958).

Van Scotter, K., Edwards, L., "Minimization of Chemical Fiber Furnish in Newsprint", Tappi 63(5):115-119(1980).

Wahlstrom, B., "Opportunities in Pressing", Tappi 64(1):75-78(1981).

Wegner, T. H., Young, T. L., Caulfield, D. F., "Role of Fiber Geometry in Water Removal by Wet Pressing", Tappi J. 66(4):85-88(1983).

Yan, J., "Kinetic Theory of Mechanical Pulping", Tappi 58(7):156-158(1975).