Comparing pulp mill Pulmac fiber quality testing with conventional laboratory pulp evaluation.

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The increasing use of fiber quality testing in pulp mills has created an interest in how this new technology relates to conventional laboratory pulp evaluation data.

The Pulmac PQ System *(1)* has made possible the reliable and economic measurement of pulp quality in a routine manner in the pulp mill, as defined by the FS (fiber strength) and L (fiber length) numbers *(2,3)*. The pulp industry currently relies on periodic standard laboratory evaluations of their pulp in order to provide on-going quality information. The high cost and elaborate nature of this procedure discourages its more extensive use in spite of the heightened focus on quality brought about by such well publicized activities as ISO 9000 accredation, Baldridge awards for quality, etc. A bridge is desirable between PQ System data which can be generated reliably, rapidly, and at low cost, and the pulp evaluation data which currently provides the accepted pulp quality standard for the Industry.

Test Program

Twenty-four different bleached kraft softwood pulps in dry lap form were obtained from six different North American market pulp mills. Multiple pulps from the same mill represented production at different times. All pulps in each set were tested (a) by a cooperating pulp mill laboratory using a standard PFI Mill based operating procedure, and (b) by Pulmac using the standard Pulmac PQ System procedures.

Results

The results from the conventional PFI Mill - handsheet testing data were expressed asTAPPI tensile (breaking length) at a constant (CSF) freeness (400) and TAPPI tear (milliNewtons*sq.meters per gram) at a constant tensile (7.0). PQ System results were expressed as FS numbers (wet zero span corrected to 60 gsm basis weight) in Newtons per cm, and L numbers (ratio of 0.4 mm wet short span value to wet zero span value). These data are presented in Table III in the appendix.

The overall variability in pulp quality exhibited by these samples is summarized in Table I (see next page). The precision of the test data is estimated in terms of the expected coefficient of variation (C.V.) for multiple tests on the same sample. For the Pulmac data this is an unambiguous number directly calculated from the 48 repetitive measurements used to generate each average value. The PFI mill procedure produces the reported parameters as averaged results from interpolation within two sets of data, but without replication. The expected C.V. is thus experiential, rather than specific to these data. Tappi Test methods (4) give repeatability data in terms which correspond to a C.V of 7.2% for Tear and 3.6% for tensile. Anectdotal information suggest that these may be somewhat high.

The typical *within* mill quality variation exhibited by these particular samples, while statistically distinguishable by fiber quality testing, may well not be so by PFI-handsheet testing. *Between* mill variation in pulp quality is sufficiently great, however, to be reliably distinguished by both systems of measurement.

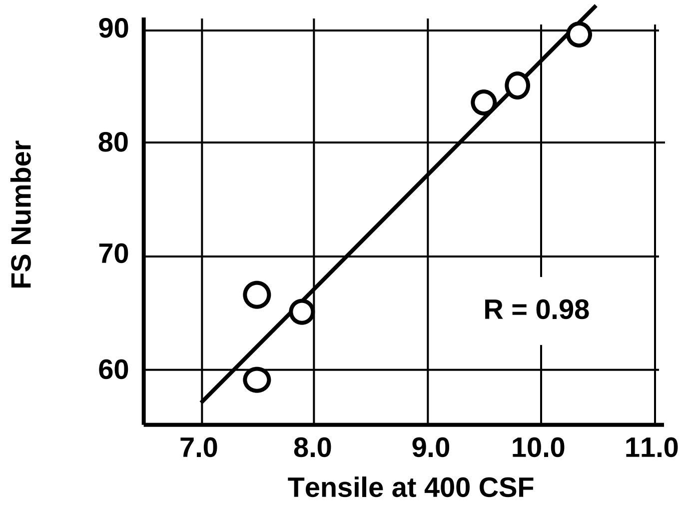
1. Variability in Pulp Quality

	PFI Mill Data				PQ System Data			
Sample Code	Tensile[1] at 400 CSF		Tear[2] at 7 Tensile		FS[3] Number		L Number	
	Avg	C.V.	Avg	C.V.	Avg	C.V.	Avg	C.V.
Test Precision	--	2-4%	--	5-7%	--	0.6%	--	1.2%
All Pulps (24)	9.1	13.1%	14.7	11.5%	78.9	13.8%	0.68	4.8%
Northern Pulps (17)	9.8	7.7%	14.9	12.2%	84.3	9.3%	0.69	4.5%
Southern Pulps (7)	7.6	5.3%	14.0	8.6%	65.8	3.3%	0.66	4.4%
Mill A (4)	9.8	1.7%	15.4	5.1%	85.0	2.5%	0.69	1.5%
Mill B (1)	7.5	--	9.0	--	59.0	--	0.58	--
Mill C (6)	9.5	3.5%	14.4	5.4%	83.1	3.9%	0.69	0.8%
Mill D (6)	10.3	4.2%	16.1	4.8%	89.4	5.4%	0.70	3.7%
Mill E (5)	7.5	5.7%	14.5	4.7%	66.3	3.6%	0.67	0.8%
Mill F (2)	7.9	2.7%	13.0	14.7%	64.5	0.3%	0.63	9.2%

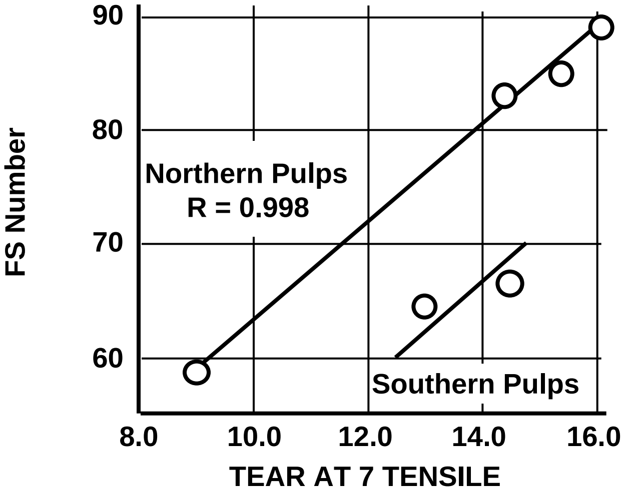
*1. Breaking Length, Km   2. milliNewtons*sq. meters per gram   3. Newtons per cm*

Since only the between-mill quality variation is sufficient to be unambiguously distinguished by the PFI-handsheet data, the within mill data has been averaged to provide the most acceptable basis for comparing PFI-handsheet data with Pulmac fiber quality numbers. This comparison is illustrated in Figures 1 and 2. It can be seen that both the tensile at constant freeness (400 CSF) and the tear at constant (7.0) tensile for the northern pulps correlate very closely with the FS number. The tensile correlation also embraces the data for the southern pulps. However, this is not the case for the tear correlation, where the data for the southern pulps fall on a line substantially displaced from that for the northern pulps.

1. FS Number compared to Handsheet Tensile at constant Freeness, for between mill, averaged data.

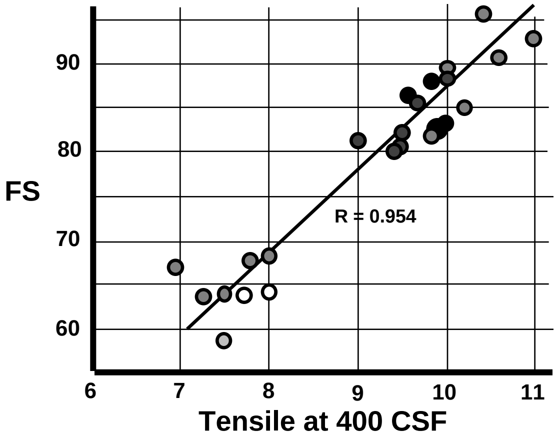


2. FS Number compared to Handsheet Tear at constant Tensile, for between mill, averaged data.

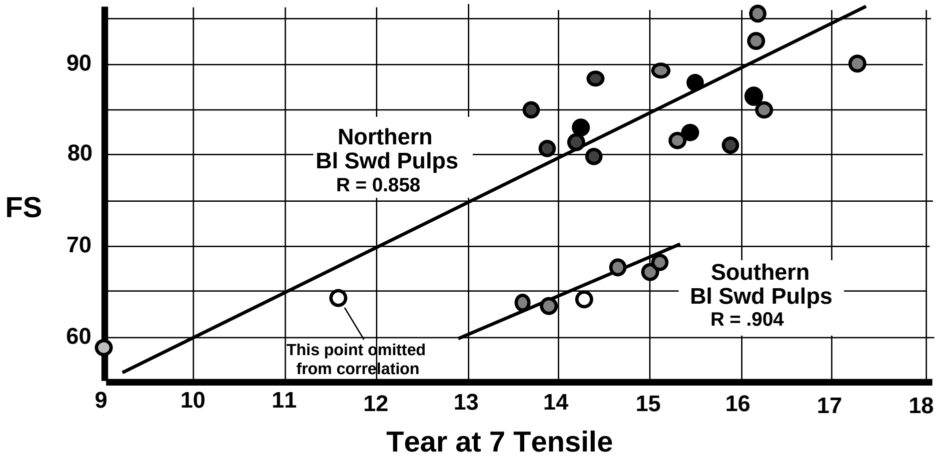


This general picture with an understandable loss in precision is also demonstrated when all the data are plotted, as illustrated in Figures 3 and 4.

3. FS Number compared to Handsheet Tensile at constant Freeness, for all data.



4. FS NUmber compared to Handsheet Tear at constant Tensile, for all data.



Discussion

The Tensile parameter: The upper limit of tensile strength attainable by any handsheet is established by the average number of fibers at any cross-section of the sheet, multiplied by their average strength. The FS number (wet zero span value) provides a sensitive indicator of this potential. Actual sheet tensile strength depends on how *uniformly* the tensile load can be transmitted through the fiber network. That is, tensile strength will increase as the fibers at any cross-section are more uniformly loaded, with the ideal and maximum attainable load being when all fibers share equally in load transfer across the cross-section. Uniformity of load transfer depends on the ease with which load can transfer back and forth between fibers. Shorter fibers and less bonding in the paper network reduce opportunities for this back and forth transfer of load, thus increasing the non-uniformity of load transfer and reducing available tensile strength. Actual tensile stength will, thus, be very dependent upon both fiber length and degree of interfiber bonding.

Comparing softwood pulps of nominally similar fiber lengths and at the same freeness (on the assumption that equal freeness means equal interfiber bonding) is obviously a means to reduce variability introduced by differences in fiber length and bonding, thus amplifying the connection of the observed tensile data with its maximum potential. For these reasons it is an expectation that differences in handsheet tensile strength at constant freeness will strongly relate to the pulps FS number. Figs 1 and 3 verify this connection. Being a softwood pulp and having a similar freeness by no means guarantees constant fiber length nor exact equivalence in degree of bonding. Thus discrepancies from the correlation due to fluctuations in these parameters would be expected. Nevertheless the data clearly indicate a strong dependence of the constant freeness tensile parameter of the handsheet on the FS parameter of the fibers.

The Tear Parameter: Tear strength of paper is a consequence of a far more complex interplay of relationships than is tensile strength. Tear strength measures the energy exerted in propagating a line of failure across a predefined tear distance. The tear failure line propagates as a series of events with each event defining the interaction of the failure line with each successive fiber which it encounters as it propagates. At each such encounter the fiber will either break or one end will pull out from the bonded structure. The total energy required to propagate a tear failure line is thus the energy used to break a fiber, summed over all the fibers on the failure line which have ruptured, plus the stripping energy needed to pull a fiber out of the network, summed over all the fibers on the failure line which did not rupture.

This can be expressed as:

$$\text{Tear} = (N_R \times E_R) + (N_P \times E_P)$$

where N_R is the total number of fibers along the failure line that ruptured, E_R is the average rupture energy, N_P is the total number of fibers along the failure line that pulled out of the network, and E_P is the average stripping energy associated with fiber pullout.

Although the force required to rupture a fiber is necessarily higher than that required to pull a fiber out of the network, the distance over which the rupture force acts is very much less than when fiber pull out occurs. This causes the energy absorbed by fiber rupture to be substantially less than the energy absorbed by fiber pullout (stripping energy). Stripping energy will increase with bonding and fiber length. Rupture energy will depend solely upon the fiber's strength and modulus. Whether a fiber will rupture or pull out will depend on how securely it is bonded into the network, relative to the strength of the fiber. That is, at a fixed level of bonding, more fibers will rupture as fiber strength declines.

The conventional view is that the tear value for any given pulp commencing at a zero bonding level, will increase with bonding (due to the enhancement of the stripping energy) until the rate of growth of E_P is offset by the rate of decline in N_P. That is, at some point a marginal increase in bonding will cause a sufficient increase in the number of fibers which rupture to produce a net decline in overall energy absorption. Thereafter the tear value will continue to fall. This qualitative description means that for any given pulp a *critical bonding* level must exist at which maximum tear strength will result. This will represent the point of optimum balance between bond enhancement of stripping energy, and bond induced reduction in the number of fibers which resist rupture.

The tear parameter of the standard laboratory handsheet is defined by the conditions of bonding which produce a particular tensile strength (i.e. in this case, 7 Km of breaking length). The corresponding tear value will depend on two factors; the maximum attainable tear value (dependent upon fiber strength and length), and the extent to which the bonding level needed to produce the target tensile strength differs from the critical bonding level needed to achieve maximum tear.

A major discrepancy in respect to the connection between the handsheet tear parameter and the pulp FS number is illustrated in Figs 2 and 4. In order to reasonably accomodate the tear data, it was clear that northern and southern pulps had to be considered separately, even though such a distiction was not required in order to deal with the handsheet tensile parameter (Figs 1 and 3).

It is well known that the thick walled Southern fibers have a bleached coarseness (weight per unit length) which typically exceeds that of thin walled Northern fibers by more than 50%. As indicated earlier, the FS number is a measure of the load bearing capability of the number of wet fibers clamped in a 60 gsm test sheet. That is, FS is proportional to (N x †), where N is the number of fibers clamped and † is the actual average strength of individual fibers. When comparing pulps of vastly different coarseness it must be realized that the number of fibers, N, at any cross section of a 60 gsm test sheet will be very different. This automatically means that the relation between FS and † will be different. For instance, for two pulps of identical actual fiber strength, †, whose coarseness differs by 50%, the higher coarseness pulp would exhibit 50% lower FS number due to the 50% reduction in N. The significance of coarseness is illustrated in Table 2 using average data from Figs 3 and 4.

2. Effect of Fiber Coarseness

	Avg FS Number	Relative Coarseness	Relative Fiber Strength, †
Northern Pulp	88	1.0	88
Southern Pulp	65	1.0	65
		1.3	85
		1.5	98
		1.7	111

The potential tensile strength of a 60 gsm test sheet depends on the strength of the total cellulose cross section; i.e. N x †. The FS number correctly reflects this value, independent of coarseness. That is, it doesn't matter whether N changes or † changes, the FS number will correctly reflect the impact upon the potential handsheet tensile strength. Tear strength is quite another matter.

From Table II it can be noted that the actual fiber strength, †, of the Southern fibers is likely to be 10 to 25% *higher* than for the Northern fibers, even though the FS number is 25% lower. The impact of this coarseness effect on tear is two-fold. The increased actual fiber strength means that the critical bonding level will be higher, increasing the stripping energy associated with fiber pullout. On the other hand the total number of fibers, N, across the tear failure line will be significantly reduced. It is likely that the increase in stripping energy outweighs the reduction in the number of available fibers, so that the maximum tear value will be enhanced, and the handsheet tear parameter would be expected to rise. It is thus likely that coarseness accounts for the difference in handsheet tear response between the northern and southern pulps identified in Figs 2 and 4.

Conclusion

The quality of bleached kraft softwood market pulps as defined by standard laboratory beating and handsheet data can be comparably assessed by measuring the Pulmac PQ System FS (wet zero span) number. This being so, the rapidity, precision, and low cost of Pulmac data acquisition recommends it as a means to reliably and economically monitor pulp quality at the frequency appropriate to accomodate modern trends in quality management.

Literature cited

1. Wavell F. Cowan, Pulp & Paper 60(13): 108 (Dec.1986)
2. Wavell F. Cowan, Pulp & Paper 60(5): 84 (May, 1986)
3. Wavell F. Cowan, Pulp & Paper 60(11): 103 (Nov.1986)
4. Tappi Test Methods 1992-1993,Tappi press 1992, T220(4), Sect.14. Precision.
5. Os-32-94/T New, CA 910809.04

3. Basic Data, Mill One

	PFI Mill Data		PQ System Data	
Sample Code	Tensile at 400 CSF	Tear at 7 Tensile	FS Number	L Number
Northern Species				
A-1	9.8	15.5	87.0	0.70
A-2	10.0	14.3	83.8	0.68
A-3	9.6	16.2	86.4	0.69
A-4	9.9	15.5	82.6	0.68
B-1	7.5	9.0	59.0	0.58
C-1	9.7	13.7	85.8	0.69
C-2	10.0	14.4	88.2	0.69
C-3	9.5	13.9	80.7	0.68
C-4	9.4	14.4	80.0	0.69
C-5	9.0	15.9	81.4	0.69
C-6	9.5	14.2	82.4	0.96
D-1	11.0	16.2	92.5	0.70
D-2	10.0	15.2	89.1	0.69
D-3	10.2	16.3	85.0	0.68
D-4	9.8	15.3	82.9	0.66
D-5	10.6	17.3	90.8	0.71
D-6	10.4	16.2	95.9	0.74
Southern Species				
E-1	8.0	15.1	68.5	0.66
E-2	7.5	13.9	63.7	0.66
E-3	7.3	13.6	63.9	0.67
E-4	7.8	14.7	68.3	0.67
E-5	6.9	15.0	67.3	0.67
F-1	7.7	14.3	64.3	0.67
F-2	8.0	11.6	64.6	0.59

4. Basic Data, Mill Two

Sample Code	PFI Mill Data: Tensile at 500 CSF	PFI Mill Data: Tear at 7.5 Tensile	PQ System Data: FS Number	PQ System Data: L Number
Northern Species				
G-1	8.8	18.6	72.8	0.66
G-2	8.5	13.4	70.0	0.62
G-3	9.5	14.4	67.1	0.63
G-4	10.6	14.6	71.4	0.61
G-5	10.1	15.1	73.5	0.60
G-6	9.7	14.2	72.6	0.61
G-7	10.7	16.9	76.5	0.62
G-8	10.7	15.6	71.5	0.65
H-1	11.9	19.2	87.7	0.73
J-1	11.6	16.5	82.5	0.66

5. Basic Data, Mill Three

Sample Code	PFI Mill Data: Tensile at 400 CSF	PFI Mill Data: Tear at 9 Tensile	PQ System Data: FS Number	PQ System Data: L Number
Northern Species				
K	9.5	12.2	67.6	0.67
L	10.5	12.8	72.1	0.64
M	11.9	15.0	80.1	0.68
N	11.4	14.4	78.0	0.66
O	11.1	14.3	80.1	0.66
P	11.7	14.5	77.0	0.72
Q	12.3	15.1	89.9	0.69
R	11.2	14.0	81.6	0.65
S	11.8	16.0	87.3	0.72
T	11.9	15.0	82.2	0.70
U	11.5	15.5	87.2	0.63
V	12.1	14.8	87.0	0.68