On-line measurement and control of strength properties

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Accurate strength information presents significant opportunities for quality improvement, reduced cost, and increased production.

Results from strength tests of paper produced on numerous paper machines indicate that there is significant variation in cross-machine direction (CD) strength values. The Mullen test (burst strength) profile on newsprint shown in **Fig. 1** indicates a 30% variation across the sheet. Accurate CD strength data are not routinely provided by testing laboratories because of the extensive sampling and testing required to produce an accurate strength profile.

Figure 2 provides burst-strength data from laboratory tests. With 20 Mullen samples taken at each slice position across a newsprint machine, there is a 1-σ variation of $\pm$10–15%. The standard error of the mean can be reduced to $\pm$3–4% by using the average of the 20 samples. Further reduction by a factor of two of the standard error of the mean would require 80 readings at each slice position. Few laboratories, if any, routinely test 20 samples at each slice from each reel manufactured. If, for example, only 10 tests are performed across the reel, the average machine-direction (MD) value obtained is certainly only an approximation, while a CD profile of strength constructed from these data would be quite unreliable.

Paper strength is known to be affected by such process variables as furnish, refining, formation, pressing, and drying stresses. However, the relationships between these variables and product strength for a given machine can only be determined after extended observation and analysis. The current level of understanding is poor because of the high costs involved in obtaining accurate, high-resolution strength information about the process. With the ability to measure strength on-line, an operator can track the effects of subtle changes in process variables, leading to a better understanding of how to control strength. On-line measurement of strength also provides other benefits, such as more uniform quality, reduced costs, and increased production.

The sensor has been tested on two linerboard machines, two newsprint machines, and one sack kraft machine. The sensor was designed to mount on a scanning sensor platform. This enables the sensor to report both MD and CD strength data.

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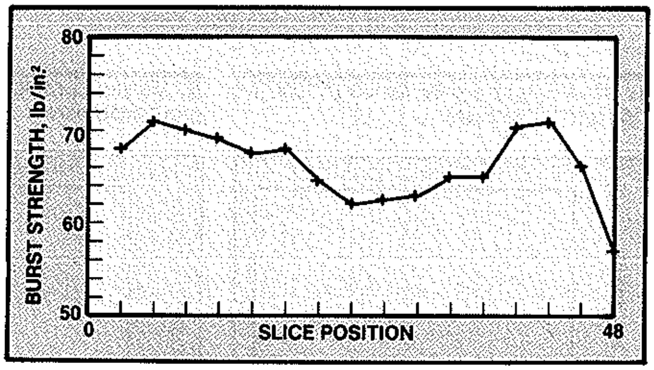
1. Laboratory burst-strength profile for newsprint shows a 30% variation across the sheet.



Correlation of sensor output and laboratory measurement

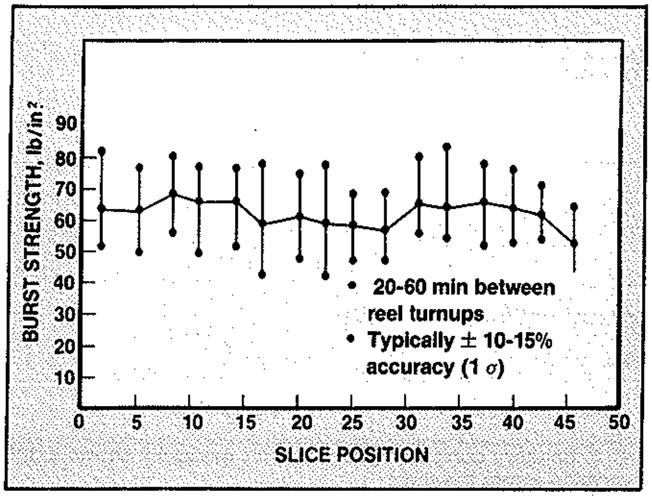
Sensor output has been correlated to laboratory tests of burst strength (Mullen) as well as MD and CD tensile strength, MD and CD STFI, and MD and CD tensile energy absorption. Some work was also conducted with correlation to internal tear resistance.

Laboratory strength tests were performed on the top 20 wraps at approximately 20 slice positions across the reel for each reel tested. Thus approximately 400 lab tests were needed to generate an accurate measurement of the "true" strength profile. **Figure 3** shows typical laboratory results for 49-g/m² sack kraft. The range of laboratory test values at each slice is indicated, with some slice positions exhibiting a range as great as 40%. Given this magnitude of variability, it was necessary to average the 20 sample values that were obtained at each slice in order to eliminate the short-term variations in the laboratory measurements, and determine the "true" profile. The average at each slice for all 20 layers is also plotted in Fig. 3.

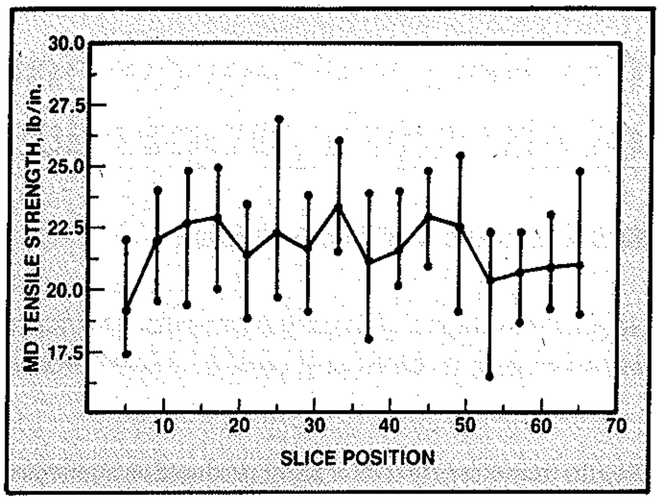
The average of the 20 readings at each slice position was compared with the sensor output for that slice at the time of reel turnup. Typically, the laboratory test averages at each slice exhibited greater slice-to-slice variability than the on-line sensor data. This can be explained by comparing the amount of paper measured by each method.

The on-line trended profile represents approximately 10 scans of measurement. Each slice average then represents 5 s of production, which in this case equals 125 ft of product. The top 20 wraps sampled from the reel at turnup represent

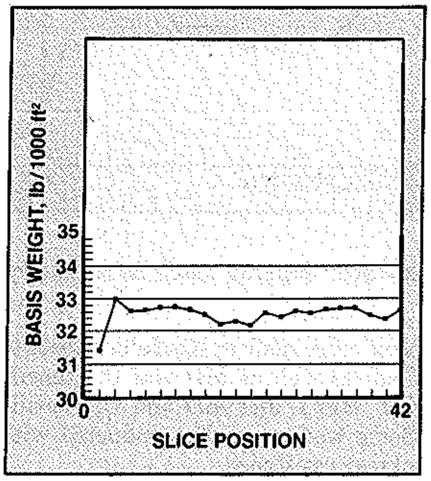
2. Burst-strength profile for newsprint based on laboratory tests. With 20 Mullen samples taken at each slice position across the machine, there is a 1-σ variation of $\pm$10-15%.



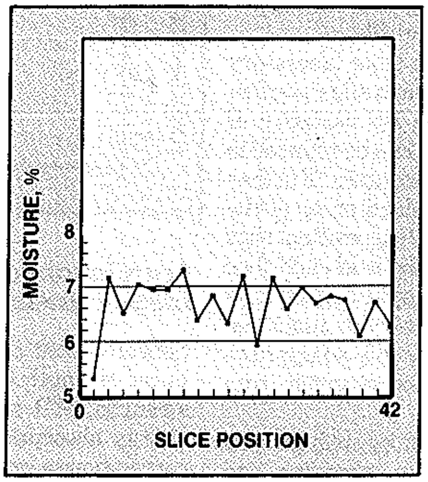
3. Typical laboratory results depict the MD tensile-strength profile for a 49-g/m² sack kraft. Laboratory strength tests were performed on the top 20 wraps at approximately 20 slice positions across the reel.



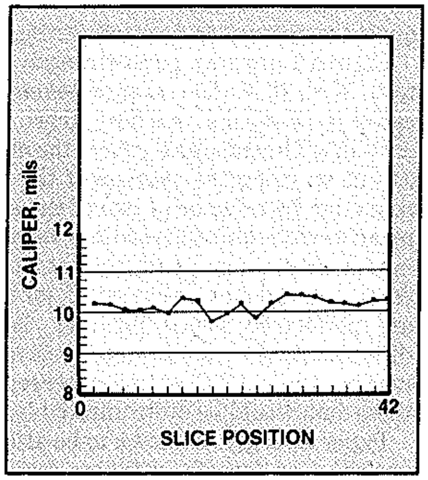
4. Basis-weight profile for 33-lb/1000 ft² (161 g/m²) linerboard



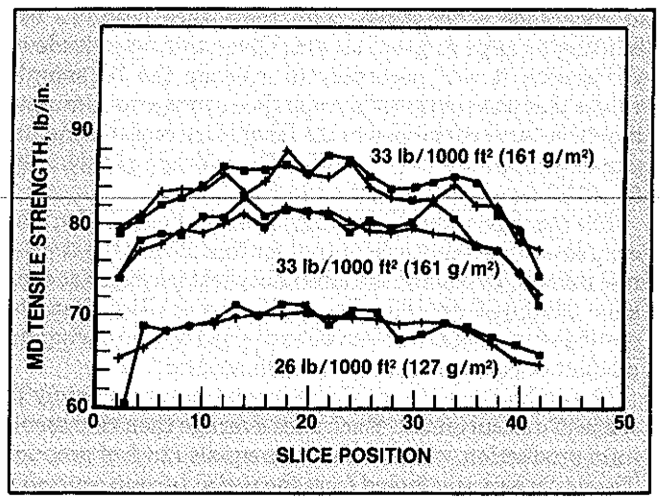
5. Moisture profile for 33-lb/1000 ft² (161 g/m²) linerboard



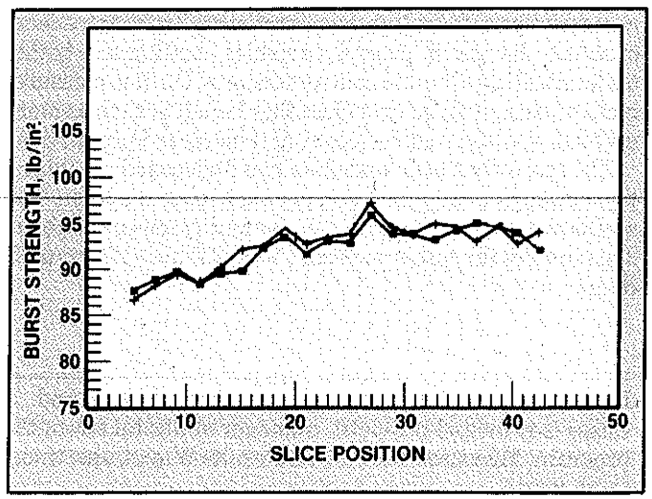
6. Caliper profile for 33-lb/1000 ft² (161 g/m²) linerboard



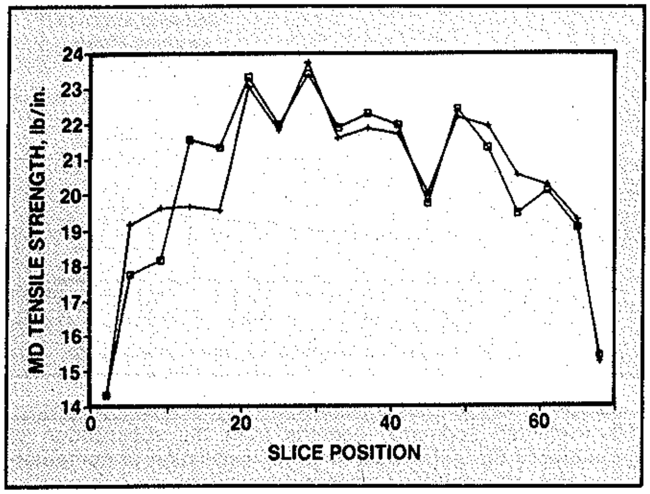
7. MD tensile-strength profiles of linerboard produced on the same machine as the linerboard profiled in Figs. 4-6. Each of the three profiles, which were taken on three separate days, exhibits decreased strength at the edges. + = sensor data; ■ = laboratory data.



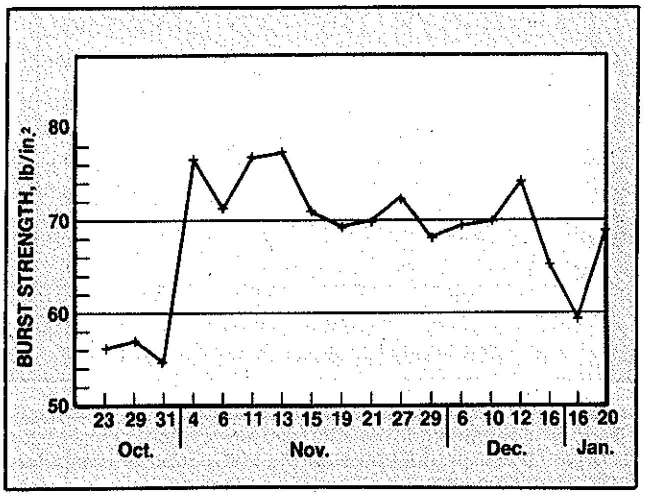
8. Burst strength for 26-lb/1000 ft² (127 g/m²) linerboard. + = laboratory data; ■ = sensor data



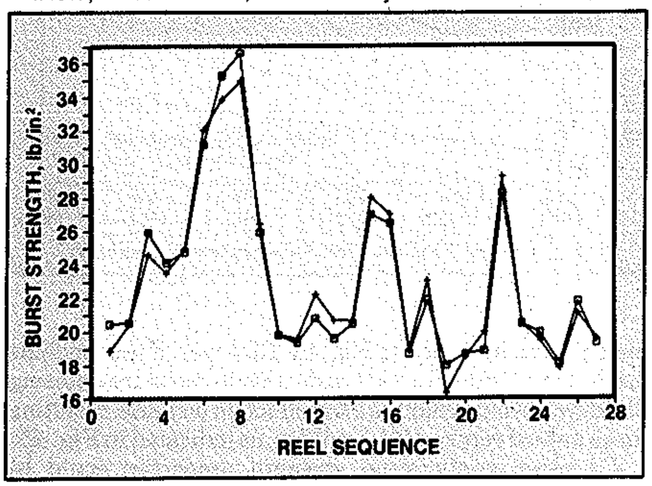
9. MD tensile-strength profile for 10-lb/1000 ft² (49 g/m²) bag kraft. The profile shows weak edges coupled with several peaks and dips. = × sensor data; ■ = laboratory data.



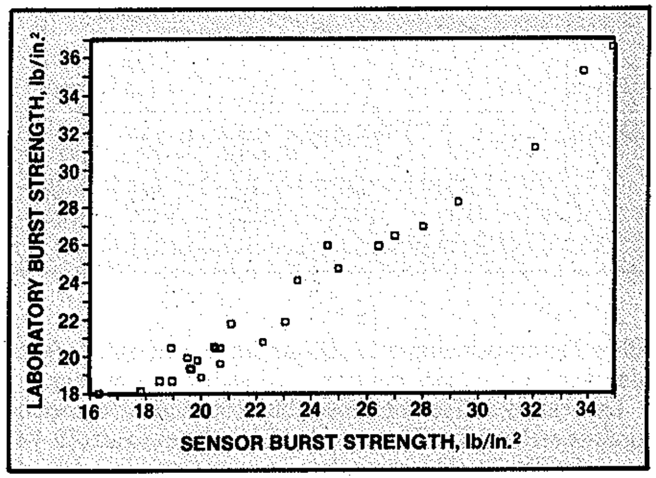
10. Variation in average burst strength for newsprint over a three-month period



11. Laboratory and sensor data on burst strength as a function of reel number for several grades of kraft bag (49–73 g/m²). $r^2 = 0.964$; $\sigma = 4.49\%$; + = sensor data; ■ = laboratory data



12. Correlation of laboratory-derived and sensor-derived burst-strength data from Fig. 11. $r^2 = 0.964$; $\sigma = 4.49\%$



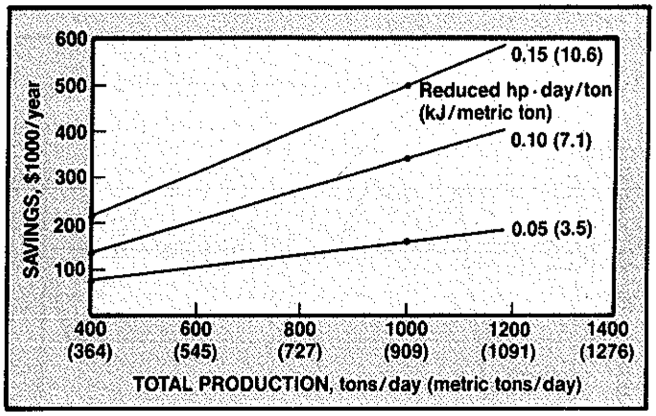
about 0.5 s, or 12.5 ft of product. Consequently, the on-line sensor data would be expected to be less variable, since the sensor measurement averages the strength values at about ten times more paper than the laboratory method.

The strength of some products on some machines has been shown to vary by more than 20% across the width of the sheet, even when basis weight, moisture, and caliper profiles are well controlled. **Figures 4, 5, and 6** provide respective profiles of basis weight, moisture, and caliper on 161-g/m² linerboard. With the exception of slightly low moisture at the first slice, these profiles are consistently quite flat. The strength profiles that appear in **Fig. 7** compare strength sensor output to laboratory tests on three separate days. The advantage of the on-line measurement is apparent when sufficient lab data are averaged at each slice to produce a meaningful strength profile for comparison. Each of the profiles exhibits decreased strength at the edges. From these data, it could be concluded that edge weakness is a product of some characteristic of the paper machine, such as unrestrained drying at the edges or press-roll crown. CD tensile strength, burst strength, and MD and CD STFI all showed similar characteristics. Obviously, CD controls of basis weight, moisture, and caliper were insufficient to control CD strength uniformity.

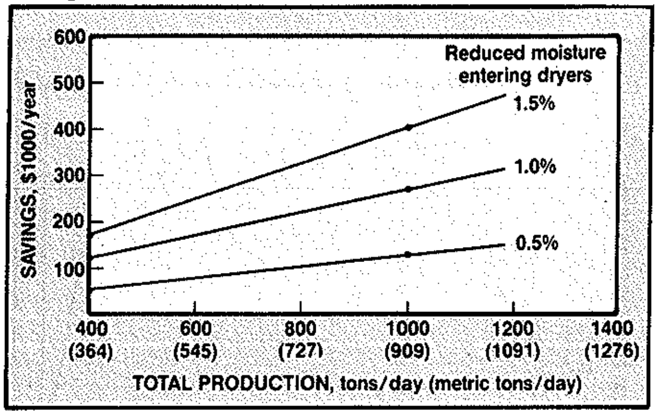
Other paper machines exhibit different strength-profile characteristics. **Figure 8** shows the burst profile from a different linerboard machine. In this case, the sheet is weaker toward the front edge and significantly stronger at the back edge. **Figure 9** is a tensile-strength profile on 49-g/m² sack kraft showing weak edges coupled with several peaks and dips.

The sensor also measures MD variation, which has been found to be quite considerable, even within a grade over a period of time. In **Fig. 10**, the average burst strength for newsprint varied by as much as 30% over a three-month period. Burst strength varied this widely even though the controlled variables on the paper machine remained unchanged. The utility of a strength sensor in this application would be twofold: it could help in locating the factors that influence burst strength in the final sheet, and it could then be used to provide real-time strength data to control these factors. Reduced strength variability in the product would

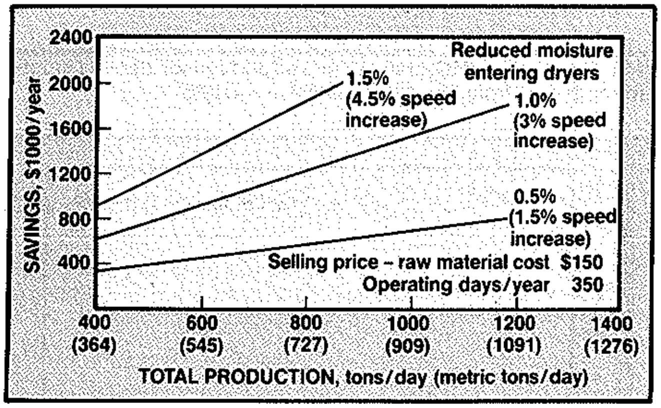
13. Projected economic benefits from a reduction in use of refiner energy with the installation of computer-based strength control on a linerboard machine



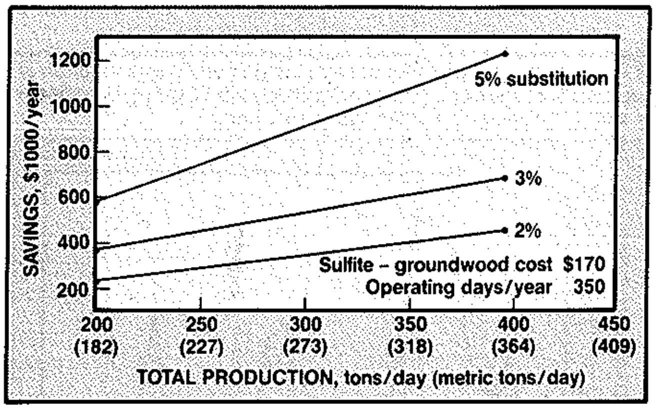
14. Projected economic benefits from a reduction in moisture entering the dryers with the installation of computer-based strength control on a linerboard machine



15. Projected economic benefits from an increase in throughput for dryer-limited production with the installation of computer-based strength control on a linerboard machine



16. Projected economic benefits from the substitution of groundwood for sulfite pulp with the installation of computer-based strength control on a newsprint machine



allow the manufacturer to operate more efficiently while also providing a more uniform product to the customer.

Laboratory and sensor data on burst strength are plotted against reel number for several grades of sack kraft (49–73 g/m^2) in **Fig. 11**. The same data are presented in a plot of laboratory burst strength vs. sensor burst strength in **Fig. 12**.

Economic potential of strength control

With the installation of an on-line strength sensor, the availability of real-time, accurate MD and CD strength information can be expected to produce an immediate improvement in product quality. Operators can use the on-line strength measurement to locate and manually control the major factors contributing to strength properties more quickly than they are currently able to do with incomplete test data from the laboratory.

On-line measurement makes computer control of strength a possibility. Strength control on a linerboard machine could be achieved by supervisory control of the refiners. **Figure 13** shows that, at \$0.04/kW·h energy cost, a 1% reduction in refiner energy would result in a savings of \$300,000/year on a 1000-ton/day machine. Reduced refining would produce a sheet that dewaters more readily, yielding steam savings. If the moisture of the paper entering the dryer is reduced by 1.0%, a reduction in dryer steam would save an additional \$250,000/year for the same machine, as indicated in **Fig. 14**. However, if the machine were dryer limited, a 1.0% reduction in moisture entering the dryers would enable a 3% production increase, resulting in an annual return of \$1.5 million, as indicated in **Fig. 15**.

On other applications, strength properties could be optimized by controlling the stock-blending operation. In the manufacture of newsprint, a 2% substitution of groundwood for chemical pulp on a 400-ton/day machine could be expected to yield approximately \$400,000 in annual savings, as indicated in **Fig. 16**.

Conclusion

The wide variability observed in data derived from laboratory strength tests indicates that several hours of testing are required to yield meaningful data for a single reel of paper. Such extensive testing is rarely done, and the operator is never provided with a true picture of product strength. The strength sensor has been shown to be useful to indicate MD and CD strength of linerboard, newsprint, and lightweight sack kraft. Further developments expected in this area include measurement of other paper grades and computer control of strength.

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