COMPARISON OF FIBER ORIENTATION AND TENSILE-STIFFNESS ORIENTATION MEASUREMENTS IN PAPER

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INTRODUCTION

Since the pioneering work of Baum, Habeger and others in the 1980's [1-4], measurement of the mechanical properties of paper using ultrasound has become common in the test labs of mills around the world [5]. Implementation of the technology on-line is a continuing effort owing to the difficulty inherent in coupling ultrasound energy to and from a moving sheet [6,7]. For on-line measurement of sheet structural properties a non-contacting optical reflection measurement is attractive [8].

We have had the opportunity to subject cross-machine paper strips from two mills to both ultrasound and optical "fiber-orientation" tests to examine the relationships between the results. Both determine an orientation angle, in degrees. Both measure sheet anisotropy as an MD/CD orientation ratio. The optical test has no counterpart to the ultrasonic test's ability to measure MD and CD tensile stiffness index (TSI). On the other hand, the optical test can measure orientation separately on each side of the sheet [8,9], and possibly at several depths [10], while the ultrasonic test produces measurements characteristic of the bulk value of the sheet.

The ultrasonic test is sensitive to fiber-to-fiber bonding and internal drying stresses in the sheet, while the optical test is sensitive to the distribution and physical layout of fibers, without regard to bonding or internal stress. Sheets with the same fiber distribution but different bonding will measure the same optically but not ultrasonically. While measurements made with the two devices will often correlate with each other, there is no guarantee that this will be the case. In fact it is more interesting when they fail to correlate. In that situation, the information gained from using the instruments in combination is greater than that gained from using either instrument separately.

SAMPLES

Two mills contributed cross-machine strips from Fourdrinier papermachines for test. One mill contributed five strips of blue copy paper spanning twelve hours of production. Another mill contributed six strips of white office papers of grammage 79 and 89 gsm.

This mill's samples were estimated from reel numbers to span approximately one week of production.

TESTING

The cross-machine strips from both mills were tested ultrasonically using the L&W Tensile Stiffness Orientation (TSO) tester (Lorentzen & Wettre North America, Alpharetta, Georgia) [5]. We performed optical-based fiber orientation measurements using a Surface Fiber Orientation Tester, or S-FOT [9]. For testing we cut multiple squares, 10.2 cm on a side, from each strip at positions from which known TSO results were previously obtained. We averaged S-FOT and TSO results from different strips corresponding to the same or nearly the same cross-machine position. These averages provided the profiles shown in Figures 1 and 2. Averaging over reels was justified on the basis that the TSO profiles varied only slightly over the time period of the sampling.

ANALYSIS

Figures 1 and 2 show very different responses from the S-FOT and TSO related to the structure and stiffness differences encountered in the two samples. In blue copy paper (Figure 1), the average S-FOT angle is approximately twice the TSO angle except at the second front-middle position (FM2), where the difference between the two results is within experimental error. The relationship between optical- and ultrasonic-measured angles has been discussed in the literature [11,12]. The factor-of-two correlation slope describing most of the profile indicates the likelihood that wet-straining during drying is reducing the stiffness orientation angle relative to the structural orientation angle. At FM2, the closeness of the two angles suggests that FM2 is a region of increased drying restraint. This region would be hard to discover without the existence of both optical and ultrasonic measurements.

Figure 2 shows the average optical and the ultrasonic angle profiles for the white office papers. The angle difference between the felt and wire profiles average 10º, much larger than the differences observed in Figure 1. While this is obviously important to sheet performance, only the average angle is plotted in Figure 2 to highlight the interesting clockwise rotation of the optical profile relative to the ultrasonic profile. The large angle differences between the S-FOT and TSO profiles, ramping from -4.8º in the front to +5.4º in the back, suggest the importance of wet straining during drying [12]. However, wet straining aligned in the machine direction does not help to explain the large angle ramp.

The domed profile of the geometric-mean tensile stiffness index (TSI) in Figure 3 may help to explain the ramp. A simple model is that the direction of wet straining is proportional to the normal to this curve at each position. The angle of the normal to a curve relative to the vertical axis is, for small angles, equal in magnitude to the derivative of the curve. Figure 4 demonstrates that the local derivative of the TSI profile in Figure 3 correlates very well with the ramp in angle difference inferred from Figure 2.

To further justify the model, we need more information about moisture history and drying dynamics. However, the results of Figures 1-4 clearly demonstrate the role of drying in the complex relation between stiffness orientation and fiber orientation. Taken together the two measurements allow an improved understanding of sheet performance issues to a degree not possible when either measurement is used alone.

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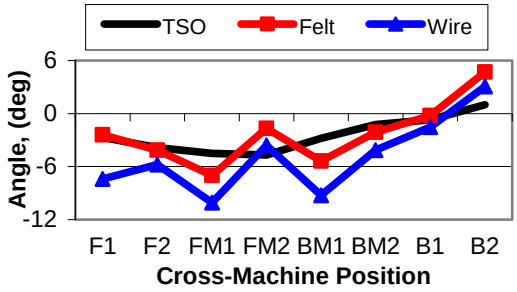

Figure 1. *S-FOT (Felt and Wire) and TSO profiles for blue copy paper.*

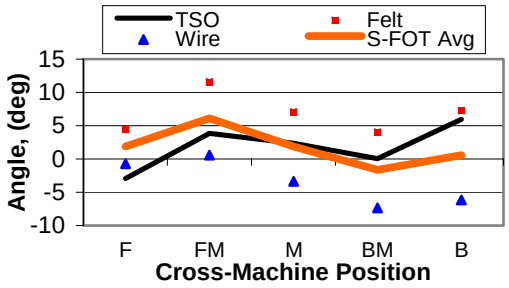

Figure 2. *S-FOT (Felt and Wire) and TSO profiles for white office papers.*

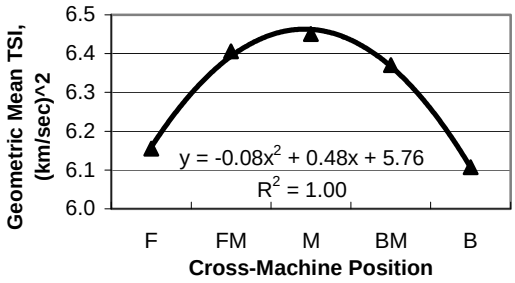

Figure 3. *The profile of the geometric mean of the MD and CD TSI measurements for white office papers.*

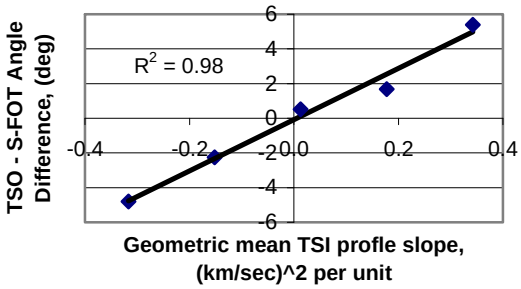

Figure 4. *Correlation between the TSO-S-FOT angle difference and the local slope of the geometric-mean TSI profile.*

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