INVESTIGATION OF FIBER TILT IN PAPERBOARD

John M. Considine and David W. Vahey
Materials Research Engineers

Forest Products Laboratory
One Gifford Pinchot Drive
Madison, WI 53726, USA
jconsidine@fs.fed.us

The introduction of short, tilted rods to reinforce polymer composite laminates has resulted in near doubling the strength of lap shear specimens [1]. Paperboard is predominantly a multi-layered structure, similar to composite laminates in many ways. Improved bonding between layers should have a positive influence on mechanical performance. Tilted fibers, or z-direction oriented fibers, can improve performance by bonding non-adjacent plies. Presence of fiber tilt should enhance shear and compression behavior without additional fiber. Our goal in this work was to test for the existence of fiber tilt in paperboard using directionally sensitive mechanical and optical tests, and to measure its effect on important mechanical properties.

No direct fiber tilt measurement techniques exist for paper. SEM images may indicate fiber tilt but fiber bonding is unknown and angular orientation is difficult to quantify. Microtomography [2] is capable of demonstrating the appearance of tilted fibers, but is influenced by the presence of fillers [3]. Appropriate network modeling may clarify the influence of tilted fibers on mechanical properties. To our knowledge this has not been undertaken in paper.

Because fiber orientation has a strong influence on in-plane mechanical properties, fiber tilt may have a similar influence on out-of-plane mechanical properties. Habeger and Whitsitt [4] have developed a model for compressive paperboard strength which depends on in-plane and out-of-plane stiffness. These stiffness values are primarily determined by stock preparation. However, small changes in papermaking, such as in the jet-to-wire velocity ratio, may provide some beneficial fiber tilt and improve mechanical behavior.

Previous work [5] identified papers and paperboards which showed indirect evidence of fiber tilt. This work closely examines the materials from that earlier study to determine how the presence of fiber tilt affects other properties.

TESTING AND ANALYSIS

Tape pull tests [6] were used to indicate the presence of fiber tilt in representative paperboards. To determine the tilt of fibers aligned along the machine direction (MD), internal bond strengths were measured according to TAPPI Internal Bond Strength (Scott

type) T-569 [7] with two additional requirements. Internal bond tests were performed in both MD+ (pendulum motion toward the reel) and MD- (pendulum motion toward the headbox), on both the wire-side and felt-side, and 50 replications were performed instead of the normal 5 replications. Directional brightness [8] was measured to determine if fiber tilt could be verified optically. Out-of-plane shear tests [9], short-span compression and tensile tests were performed to determine possible effects of fiber tilt on other mechanical properties important in applications which use paperboard as a structural component.

Scott-Bond results agreed with tape-pull screening tests; i.e., if tape pull tests indicated the presence of fiber tilt, the results were also found in Scott-Bond tests. When test differences occurred between the two machine directions, they were not large, but were statistically significant. For the linerboard in Figure 1, Scott-Bond strength measured on the wire side in the MD+ direction was statistically lower than the other results. Similar results were found for directional brightness.

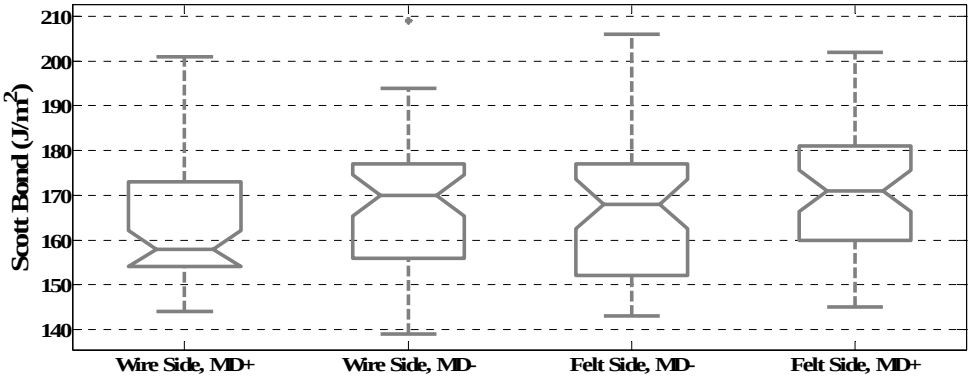

Figure 1. *Box plot of Scott-Bond data for our Linerboard F. Each box has lines at the lower quartile, median, and upper quartile Scott-Bond values. Whiskers are lines extending from each end of the box and show the range of the data values. Outliers are noted with '+' symbol. Notches which do not overlap indicate differences at the 90% confidence level.*

Table 1 shows pertinent tensile, compressive and shear strengths for three linerboards. Scott bond tests showed by far the largest directional differential for Linerboard F. Tensile and compressive properties are similar for all three linerboards, but Linerboard F had much higher shear strength, perhaps enhanced by fiber tilt.

Table 1. *Some strength results for three linerboards.*

	Linerboard A	**Linerboard E**	**Linerboard F**
Tensile: $\sigma_{max - MD}$ (kN/m)	14.37	14.31	14.18
Compression: $\sigma_{max - MD}$ (kN/m)	7.99	7.04	7.23
Shear: τ_{max} (z-MD) (MPa)	6.01	5.72	7.63
Wire Side: Scott-Bond MD+MD- Test Differential (%)	3.0	1.6	7.6

CONCLUSION

Indirect measurements of fiber tilt via Scott bond and out-of-plane shear strengths appear to differentiate between materials with and without fiber tilt. The observed correlation between paperboards that display evidence of fiber tilt and improved shear suggests that significant benefits will result from redirecting the fiber distribution in paper without additional fiber. Efforts to produce controllable fiber tilt in the laboratory continue.

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