

Liner orientation effects of combined-board warp

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Reducing the hygroexpansivity characteristics of linerboard should help minimize the occurrence of twist warp in combined board.

Combined-board warp must be avoided in the production of corrugated board. Excessive warp causes problems in feeding sheets to downstream equipment such as flexo folder-glueers. If the board is badly warped, jams occur, and the board may have to be scrapped.

In the late 1970s, members of the Corrugated Industry Development Corp. made a comprehensive study of the causes of combined-board warp and ways to control it (1-8). Among other things, they demonstrated that cross-direction (CD) warp is dependent on the moisture conditions of the single-face web and double-face liner when they are glued together.

Commonly, combined board may warp in the machine direction (MD) or cross direction or in various combinations of MD/CD warp. While warp is very dependent on the moisture conditions of the single-face (SF) and double-face (DF) liners at the time of bonding, it is a manifestation of the hygroexpansivity of the liners (2). Therefore, paper machine factors which introduce differences in the hygroexpansivity characteristics of the liners can be expected to affect their proclivity to warp.

Elastic stiffness vs. orientation

Institute of Paper Chemistry (now the Institute of Paper Science and Technology) research allows us to rapidly measure specific elastic stiffness as a function of angle from the machine direction (9). The results, plotted as polar diagrams, give information concerning headbox flows, jet-to-wire speed differentials, conditions in open draws, and drying constraints. Variations in these factors affect many board properties including hygroexpansivity and, hence, board performance.

A typical in-plane polar plot is shown in Fig. 1 (9). The area and major axis of the shape can be computed and the angle (called polar angle) the axis makes with the MD can be determined. The shape, area, and angle of lean of the polar plots vary across the width of the paper machine.

For example, Fig. 2 shows that the polar angles can

vary greatly across the width of a linerboard paper machine. On this machine, about 300 in. wide, the polar angles were highest at the front, near zero over the middle region, and sharply declined to about -10° near the back of the machine. The differences in polar angle have been attributed to stock flows from the headbox, which have a flow component at right angles to the MD. When the angular deviations become large, Baum noted that difficulties can be encountered in converting and end-use applications (9).

The shape, area, and MD/CD ratios also can vary greatly across machines, although the profile for a given machine is often quite constant (9). Factors influencing such profiles have been discussed by Baum and co-workers.

Corrugated board warp considerations

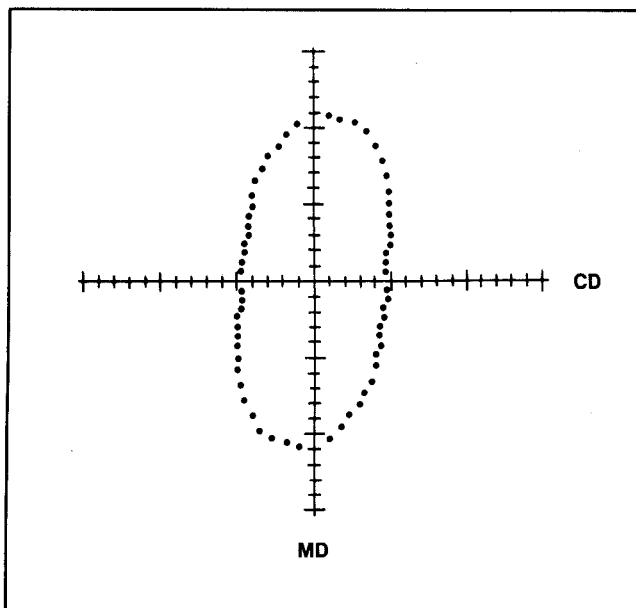
In the case of corrugating, two linerboard webs are glued to medium to make single-wall board. If their moisture contents and dimensional stability properties are too dissimilar, excessive warp is likely to occur. For example, combining edge-cut linerboard rolls from one side of the machine profile shown in Fig. 2 could be expected to cause twist warp because the liner polar angles deviate from the MD of the corrugated board. As the moisture content of the combined board changes with relative humidity (RH), the contraction or expansion characteristics of the two liners will twist the combined board because of the misalignment of the liner properties with regard to the machine direction of the corrugated sandwich.

Two extreme cases can occur. In one case, the polar angles of the two liners deviate in the same direction from the machine direction of the corrugated board (Fig. 3A). Less tendency for twist warp to occur would be expected with this configuration because the polar angle misorientations of the liners match each other. In the other case, the polar angles of the single- and double-face liners deviate in opposite directions from the machine direction of the corrugated board (Fig. 3B). Major twist warp should be obtained in this case because the dimensional changes of the liners will tend to twist the flutes as moisture content is varied.

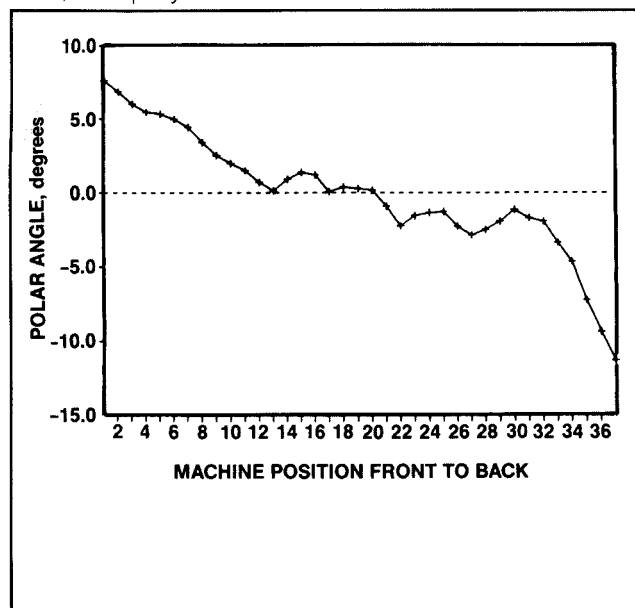
When stresses are applied to an orthotropic material along the principal axes, the shear and normal components of strain are uncoupled; that is, the normal stresses

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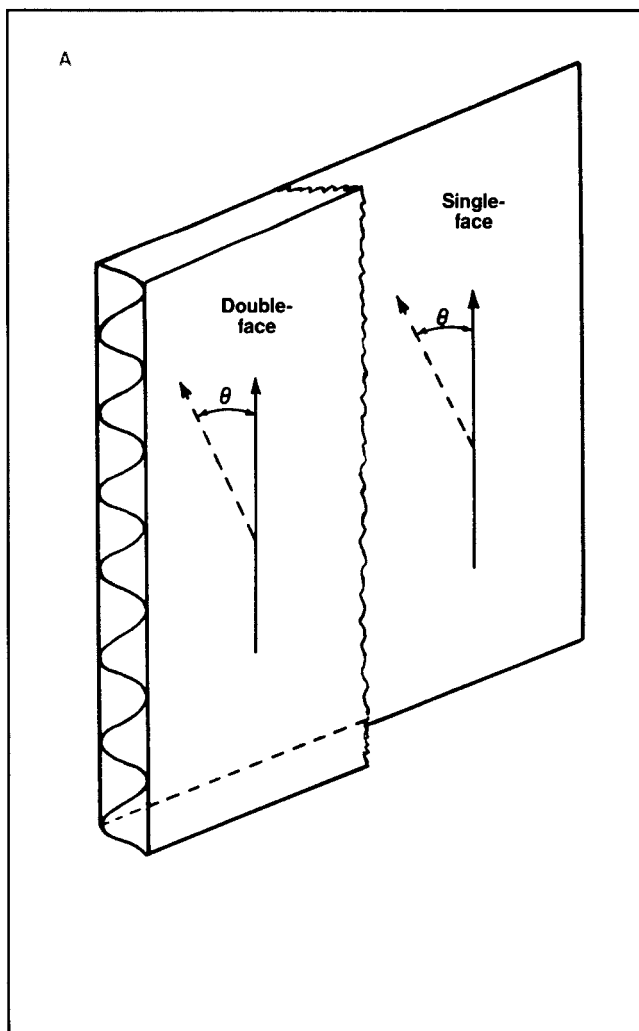
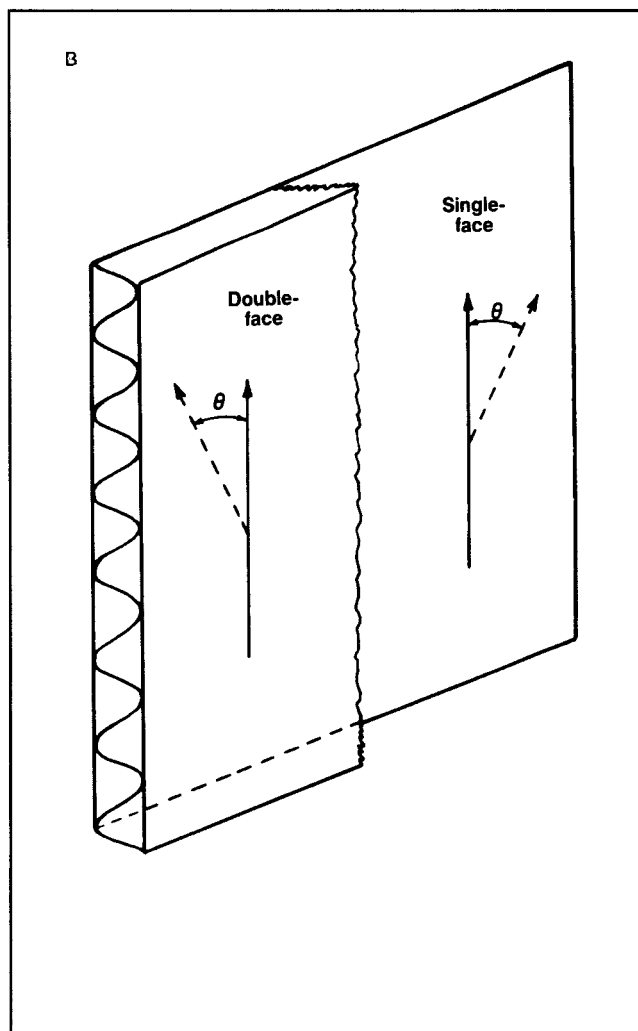
1. Typical in-plane polar plot



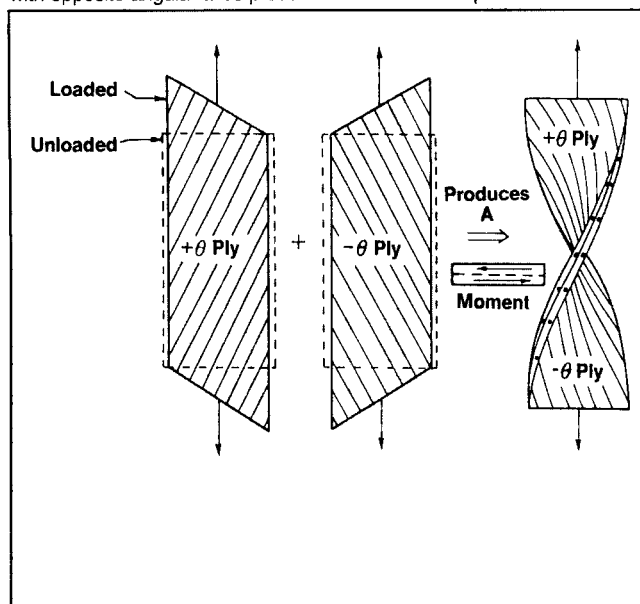
2. Large changes in polar angle can occur across a paper machine and, hence, affect quality.



3. Two opposite cases of liner polar angle misalignment. A: liner polar angles in the same direction. B: liner polar angles in opposite directions. Case B promotes twist warp.



4. Shear coupling deformation associated with combining two lamina with opposite angular axes produces twist in the composite structure.



produce only normal strains and shear stresses produce only shear strain. However, when the stresses are applied at angles to the orthotropic axes, the shear and normal stresses are coupled. For example, in Fig. 4, combining the two plies shown with opposite angles results in a moment which acts to twist the composite structure (10). This concept helps explain the generation of twist warp in combined board and provides the basis for a theoretical treatment of twist-warp generation.

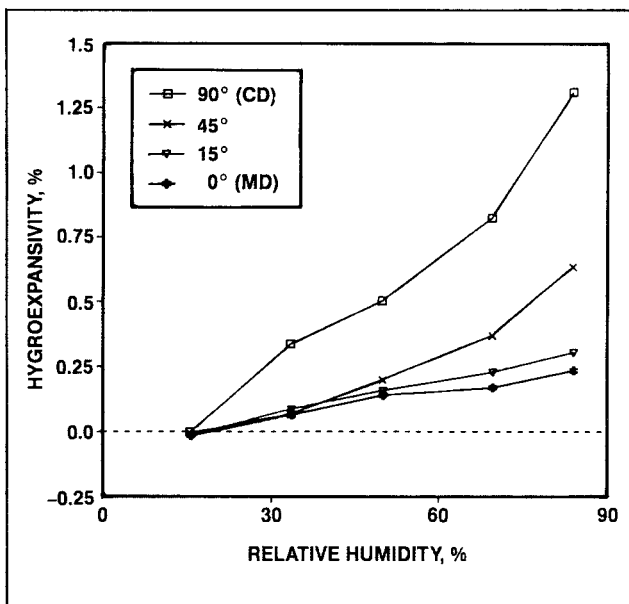
While warp is very dependent on the moisture conditions of the single-face web and double-face liner at the time of bonding, it is a manifestation of the hygroexpansivity of the liners. Therefore, papermaking factors that cause differences in hygroexpansivity of the liners can be expected to affect the proclivity to warp and the kind of warp. Figure 5 compared the absorption hygroexpansivity curves at various angles from the machine direction for the 42-lb liner sample used in this study. Much greater changes in sheet dimensions are obtained in the CD as expected. Thus, combining liners with opposite polar angle deviations results in strong CD hygroexpansion differences and, hence, promotes twist warp.

Experimental

To study the potential effects of liner polar angles on warp, combined boards were made using 42-lb single- and double-face liners cut at 0°, 10°, and 15° to the average polar angle for the sample. For this purpose, a 72-in.-wide roll of linerboard on hand at the Institute was selected. Ultrasonic stiffness polar diagrams were performed every 12 in. across the roll width to determine the ultrasonic stiffness characteristics across the width. The polar angles were essentially constant across the width of the selected roll and averaged 1.7° from the machine direction.

Linerboard sheets were then cut to have polar angles of -15°, -10°, -5°, 0°, +5°, +10 and +15° referenced to the polar angle of the base liner. The liners were fabricated

5. Absorption cycle hygroexpansivity curves show large differences with orientation.



into C-flute single-faced board on the Institute's pilot corrugator using a 26-lb medium and starch adhesive. Double-faced boards were then prepared to have the following orientations:

1. Polar angles of SF and DF liners in the same direction in the combined board: 0°, 5°, 10°, and 15°
2. Polar angles of SF and DF liners in opposite directions in the combined board: 0°, 5°, 10°, and 15°.

For one series of tests, the double-face liner and single-face board were conditioned at 50% RH prior to combining so that their moisture contents were about equal. For the second series of tests, the single-face web was conditioned at 90% RH and the double-face liner was conditioned at 50% RH to simulate combining a wet single-face with a dry double-face liner. A third series was prepared reversing the conditioning of the double-face liner and single-face web.

A polyvinyl alcohol adhesive was used for the double-backing operation; no heat was applied. After double-backing, the sheets were allowed to dry at 50% RH and then placed in other RH atmospheres to determine the effect of moisture changes on warp. This simulates temporary storage of sheets off the corrugator in various plant atmospheres. The test RH levels employed were 25%, 70%, and 90%.

The warp of the double-faced boards was measured relative to the centerpoint of the 12-in. × 40-in. sheets. The sheet was rested on a 4-in.-high center support for this purpose. Warp measurements were taken at each corner and at the center of each edge. The warp measurements at 50% RH were subtracted from the results at other RH levels to show how the warp changed due to humidity.

Discussion of results

Combined at equal moisture content

Combined boards made with liner polar angles deviating in opposite directions (Fig. 3B) from the MD of the combined board exhibited large twist warps when exposed to higher-RH atmospheres (Fig. 6). A three-dimensional view of the warped surfaces shows that the amount of twist warp increased steadily as the polar angle deviations increased from 0° to 15° (Fig. 7). These results indicate that such combined boards will be dimensionally unstable as they pick up or lose moisture. This can occur even if the moisture contents of the two liners are equal just before bonding. The combined board may appear relatively flat off the corrugator, but further changes in moisture will tend to cause warp to develop.

Similar results were obtained when these combined boards were exposed to RH levels of 70% to 20% after combining. However, the warp magnitudes were less than obtained at 90% RH because the dimensional changes were less. The direction of twist warp changed from high to low RH; for example, a high corner at 90% RH is a low corner at 20% RH (Fig. 8, compare to Fig. 7).

Figure 9 shows that the combined boards made with liner polar angles deviating in the same directions from the MD of the combined board tended to exhibit small changes in warp when exposed to 90% RH. This was true for the whole range of angular deviations studied.

Another series of sheets were prepared after conditioning the SF web and DF liner at 90% RH. The warp results were similar to those obtained when both sheets were conditioned at 50% RH, taking the RH differences into account.

Combined at unequal moisture content

To simulate the combined effects of liner polar angle deviations and unbalanced SF and DF liner moisture content, two additional sets of combined boards were prepared as follows:

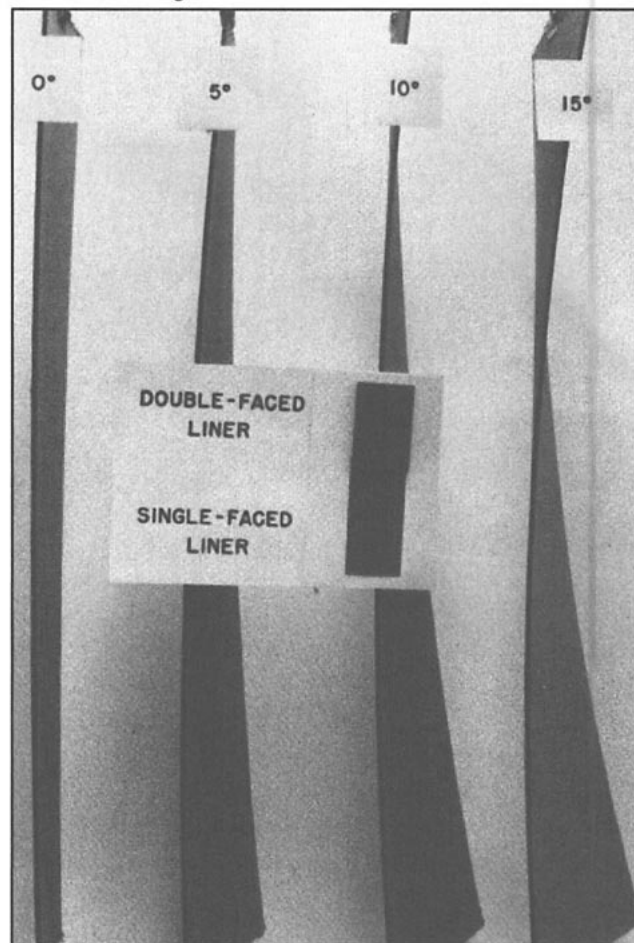
1. SF web at 90% RH, DF liner at 50% RH. Liner polar angles in opposite directions: 0°, 5°, 10°, and 15°
2. SF web at 50% RH, DF liner at 90% RH. Liner polar angles in opposite directions: 0°, 5°, and 10°.

These sheets were double-backed at 50% RH, and warp measurements were made after conditioning the sheets using the following sequence: 50%, 20%, 50%, and 90% RH.

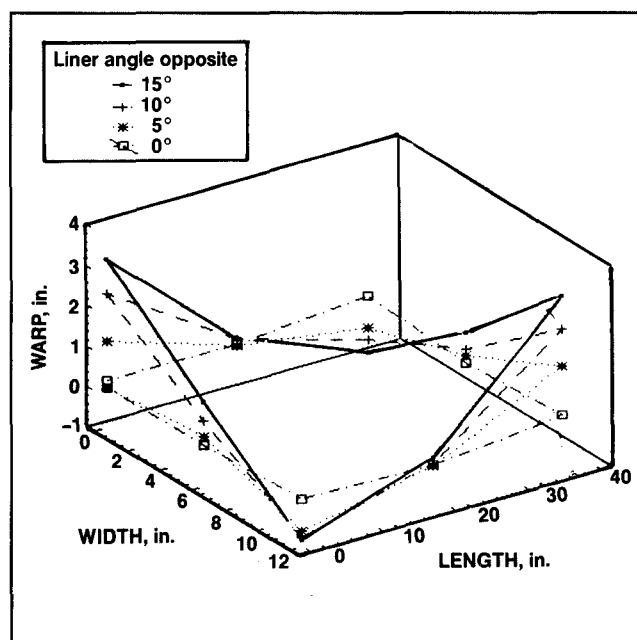
Figures 10-12 illustrate the degrees of warp obtained with the wet SF web combination at 20%, 50%, and 90% RH, respectively. At 20% RH, very large amounts of twist warp were obtained as the polar angles were increased from 0° to 15° (Fig. 10). This increase in twist warp would be expected based on the previous discussion. The twist warp is superimposed on CD warp (and some MD warp), which is caused by the imbalance in SF/DF moisture contents. In this case, the CD warp is toward the SF side, which was initially at a higher moisture content. Figure 11 shows that the twist warp is still very pronounced at 50% RH. At 90% RH, the amount of twist warp is less than that obtained at 20% and 50% RH, but the CD warp due to the initial imbalance in moisture content is still present.

Figures 13-15 illustrate the warp obtained from the reverse case, that is, a high-moisture DF liner combined

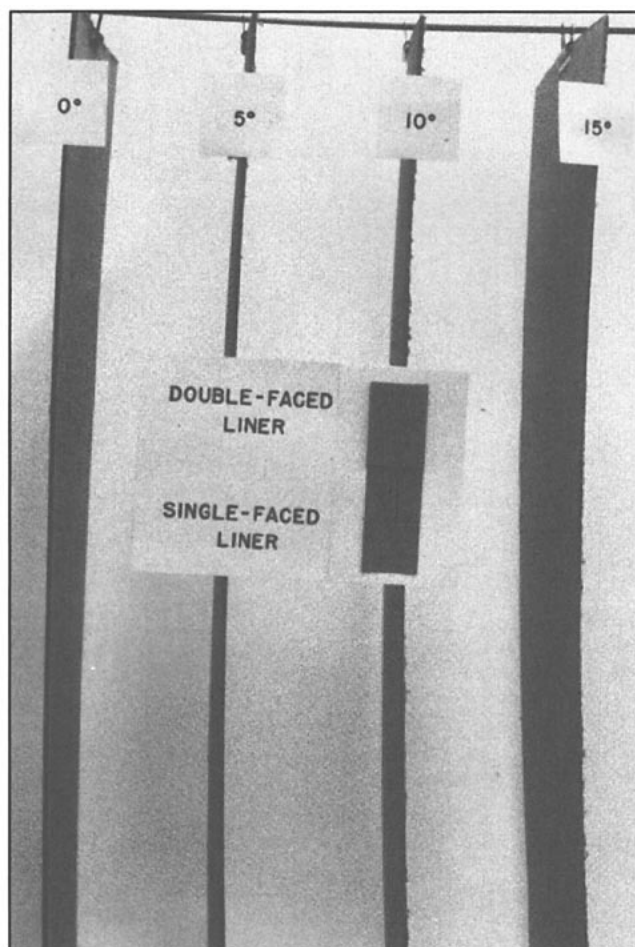
6. Combined boards made with the liner polar angles deviating in opposite directions from the MD exhibited large twist warps when exposed to 90% RH after combining.



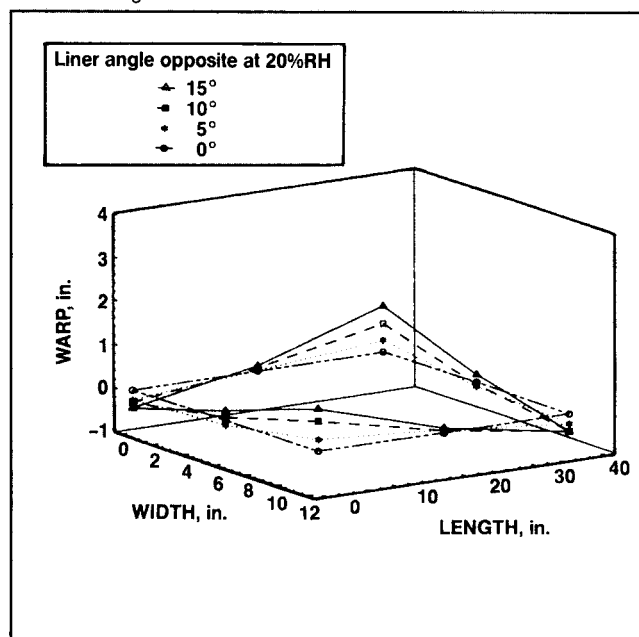
7. The amount of twist warp at 90% RH increased steadily with increasing liner polar angle deviation in opposite directions.



9. Combined boards made with liner polar angles deviating in the same directions from the MD of the combined board exhibit little twist warp after exposure to high RH.



8. At 20% RH, significant amounts of twist warp are obtained for opposite polar angle deviations, but the direction of warp is reversed from that obtained at high RH.



with a drier SF web. At 20% RH, large amounts of twist warp due to polar angle deviations were obtained as discussed above, but the twist is opposite from the wet SF case (Fig. 13). The twist warp is superimposed on a significant CD warp due to the imbalance in liner moisture. In this case, the CD warp is toward the DF liner side because it was the wetter liner at the time of gluing. Figure 14 shows that the twist warp is less evident at 50% RH along with a large CD warp. However, at 90% RH, the twist warp due to polar angle deviations became larger, and the CD warp due to moisture imbalance is also large (Fig. 15).

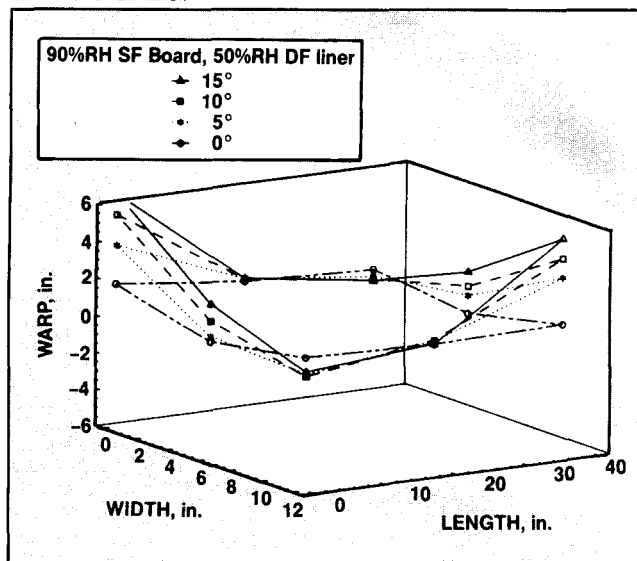
These results indicate that improvements in liner uniformity should help box plants minimize warp problems. A current Fourdrinier Kraft Board Group study is directed to evaluating liner and medium paper machine stiffness profiles. It also will develop information on paper machine causes of variations and possible control measures. Presently, when problems occur in the box plant, it may be possible to reduce twist warp by turning one of the liner rolls around to bring the polar angles into the same orientation.

Conclusions

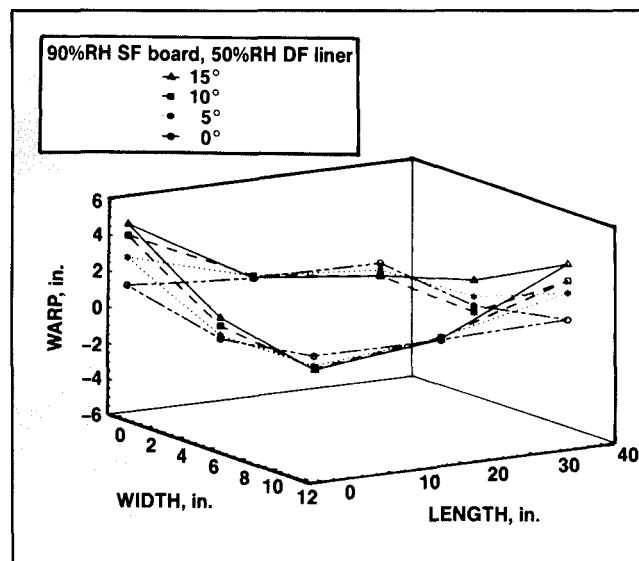
Briefly summarizing, the results indicate:

1. When liners having oppositely oriented polar angles and equal moisture contents are made into combined board at 50% RH, large twist warps occur as the combined-board moisture is changed. For this case:
 - The degree of twist warp increases as the polar angle difference between liners increases.
 - Relative to the 50% RH condition at the time of gluing, the degree of twist warp increases as RH (moisture) increases.
 - At RH levels lower than the 50% condition at the time of gluing, the direction of twist warp reverses but is still large.
 - Thus, such combined boards are dimensionally unstable as they pick up or lose moisture.
2. Elastic theory for composite structures indicates that a moment is generated when liners having opposite polar angle deviations are combined and, subsequently, are stressed. The moment causes twist warp when the liners expand or contract as moisture content is changed. This concept explains why twist warp occurs.
3. When liners having polar angles deviating in the same direction from the MD and equal moisture contents are made into combined board, little twist warp develops as moisture content is changed.
4. With liners having oppositely oriented polar angles and unequal moisture content at the time of gluing, large amounts of twist warp can occur depending on the ambient RH. The twist warp is superimposed on CD warp (and some MD warp), which is caused by the imbalance in SF/DF moisture contents. For this case:
 - The amount of twist warp increases as the polar angle difference increases.
 - The direction of the twist warp changes depending on which liner component is driest at the time of gluing.

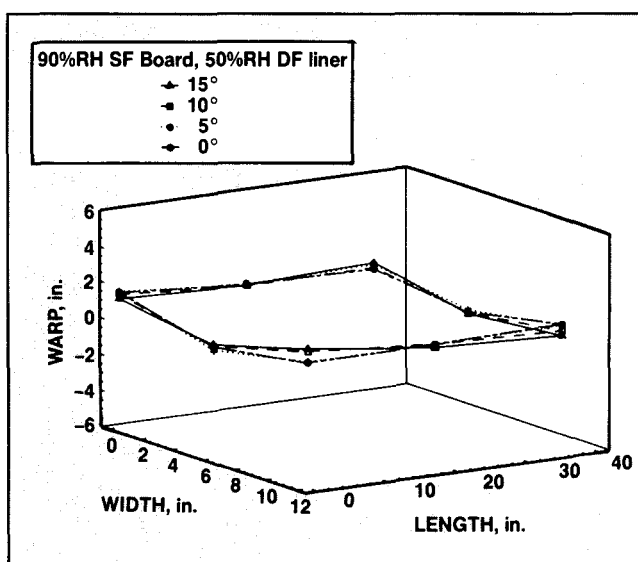
10. At 20% RH, large twist warps are obtained due to liner polar angle differences. CD warp is also present due to combining a wet SF web with a drier DF liner.



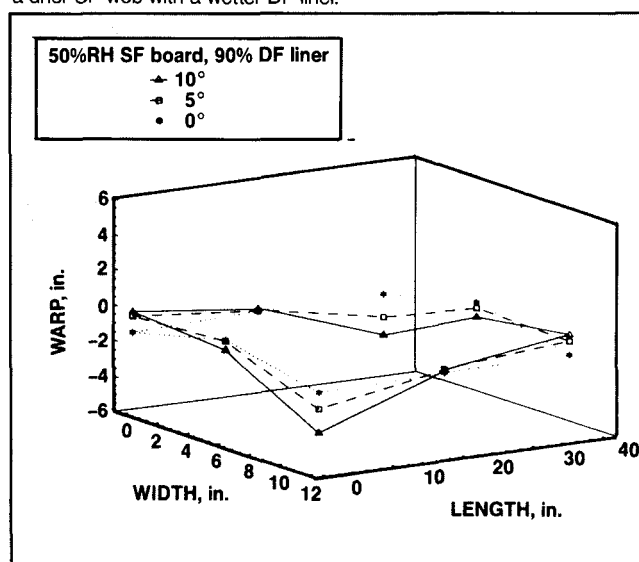
11. Twist warp and CD warp are present at 50% RH due to polar angle differences and unbalanced moisture content at the time of gluing.



12. Less twist warp was present at 90% RH, but CD warp was still evident due to the wetter SF web at the time of gluing.



13. At 20% RH, large twist warps are obtained due to polar angle differences. CD warp toward the DF side also is present due to combining a drier SF web with a wetter DF liner.



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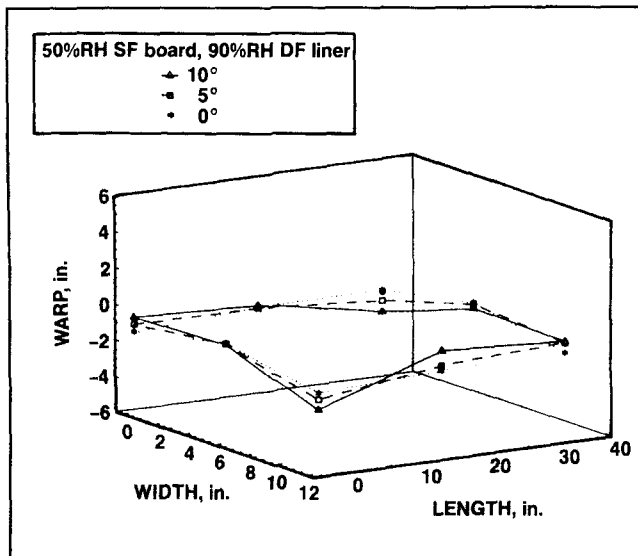
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14. Twist warp also was present at 50% RH due to polar angle differences, and CD warp was present due to initial moisture imbalance.



15. At 90% RH, the twist warp direction reversed from the 20% RH results. CD warp toward the DF side was large due to combining a drier SF web with a wetter DF liner.

