Strand Movement During Oriented Strand Composite Mat Formation

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Abstract

The properties of strand-based wood composites are known to be strongly influenced by strand orientation and horizontal density variation. While the influence of these geometrical factors on performance has been extensively investigated for more than 20 years, little research has been reported on how the strands move during the forming process to become oriented and located. Better knowledge of strand movement will allow for understanding of and improvement in mat formation through rational modification of equipment settings and ultimately design concepts.

An industrial forming line was used to quantify the effect of strand length on strand movement from the bunker through the picker rolls, dissolving rolls, and orienting heads. Initial locations of dyed strands in the forming bin bunker were predetermined. After processing through the forming head, the location and orientation of individual strands were optically measured before and after the orienting deck.

Nine-inch strands were found to have a more variable flow rate through the picker rolls relative to 4-inch strands. Substantial strand mixing and horizontal travel across the width of the forming head occurs prior to the orientation deck. This indicates that modifications in the strand chute will influence the cross-direction movement uniformity and final product density variation more than orienting deck modifications. As expected, longer strands were shown to project significantly farther along the orienting deck as well as to provide better alignment. A particle screen analysis showed that the doffing and dissolving rolls generated 70 percent of the unders (smallest screen fraction) in the forming process.

The forming lines of oriented strand board (OSB) and laminated strand board (LSL) facilities are designed to create a product with a uniform density across the width and length of the strand mat. Most mills determine strand flow and subsequent weight variation in the mat by continuously measuring the average weight across the mat per unit length. The equipment must also accomplish this at high production rates (30,000 to 80,000 lb/h) on a continuous basis. Production constraints typically limit the ability to obtain detailed information about the movement of strands within the forming line. An opportunity arose to measure this movement on a state-of-the-art LSL forming line. Optical techniques were developed to quantify strand kinematics from the forming bunker through the orienting deck. Two variables, strand length (4- and 9-in.) and strand starting position (low, middle, or high and edge or center) in the forming bunker, were selected to test their effects on strand spread across the width of the forming head (cross-machine direction), projection along the length of the orienting deck (machine direction), and strand orientation.

There are three zones of strand interaction with rotating elements in a typical forming head: (1) the picker rolls, (2) the dissolving rolls, and (3) the orienting discs (Fig. 1). The picker rolls provide a uniform rate of material flow with time, while the dissolving rolls act to provide uniform coverage across the width of the forming line.

The function of the orienting discs is to move strands in the machine direction and orient them in a preferred direction. Strand orientation has been described by several measures, including percent alignment (Geimer 1976), mean and standard deviation of orientation angle (Shaler 1991), and mean angular deviation (Barnes 2002). The size and

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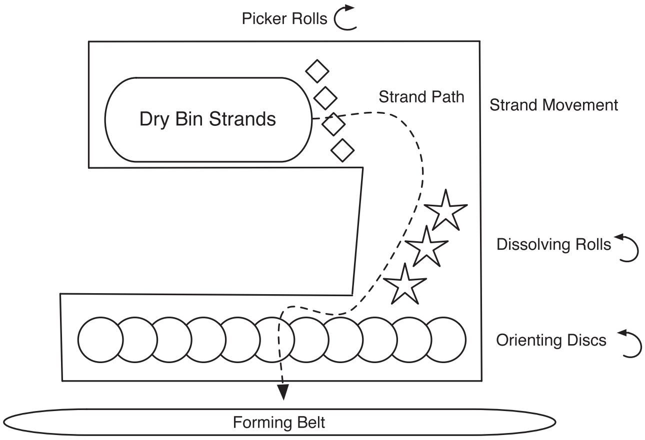

Figure 1.—Major elements of a strand forming head.

spacing of the orienting discs required to obtain best alignment depend on strand geometry (Barnes 2002, Geimer 1976). Industrial furnish contains a range of strand dimensions, which then requires progressively wider disc spacings along the deck length. Shorter strands preferentially drop through earlier along the former head length.

There are inherent variations in density within the plane (horizontal density gradient) of randomly formed strand composite mats, which are correlated with strand dimensions (Dai and Steiner 1994). Nonuniform loading of the forming bunkers causes additional density variations.

The movement of strands within a rotating blender has been described (Smith 2005, Dick 2006) and has been shown to be influenced by a number of factors, including rotational speed, number of flights, and loading level. Measures of strand kinematics from the picker rolls through the dissolving rolls were not found in the literature.

The objective of this research was to measure the movement and orientation of strands within an industrial forming head and to determine whether any systematic variation in density results from this process. Specific objectives were to quantify the effect of (1) strand length, (2) strand starting position in the bunker, and (3) boundary conditions (e.g., side walls) on strand movement through the forming head. All experiments were conducted with fixed values of rotational speeds, disc geometries, and shaft locations. The effect of changing such settings on movement may be significant, but a study of their influence was beyond the scope of this study.

Experimental Methods

The experiment consisted of three major steps: material production, imaging of strand movement in an industrial forming head, and quantification of strand movement using image analysis methods.

Material production

A Carmanah 12/48 ring strander was used to create 4- and 9-inch strands from aspen (*Populus* spp.) logs. Mean strand thickness was 0.050 inch (wet basis), with a coefficient of variation of approximately 10 percent. The 9-inch strand length was selected since it was the target length for the Louisiana-Pacific Corporation's LSL facility in Houlton, Maine, where this study was conducted. Previous studies showed that conveying, storing, screening, drying, and blending of strands reduces strand length and that a bimodal length distribution is created (Gaete-Martinez 2009). The 4-inch strands represent the second mode.

The strands were then screened using an Acrowood Trillium screen system to separate the strands into three size classes: overs, intermediates, and fines. Only the overs were used. The green overs were dried to approximately 10 percent moisture content (MC) using a Koch low-temperature strand conveyor dryer. A hot water solution of Rit fabric dye was used to color the dried strands to produce six visually distinctive groups. The colors were key to subsequent image analysis techniques. The dyed strands were then equilibrated to 7 ± 0.5 percent MC in a dehumidification dry kiln to minimize differences in flexibility and propensity for damage.

Industrial forming line experiment

The 103-inch-wide industrial forming bunker was modified by placement of a rolling side wall at midwidth. Four- or 9-inch colored strands (approximately 300 lb) were loaded into the forming bunker to create six distinctive zones (Fig. 2). This placement was used to determine whether strand kinematics was influenced by starting location in the forming bin. The strands were fed into the picker rolls for 30-second intervals at a constant belt feed rate. This was repeated six times for both the 4- and 9-inch strands.

After each 30-second interval, the line was stopped and strands were collected at one of two locations in the forming head. The collection points were located immediately above the orienting discs (preorientation) or on the forming belt below the orienting deck (postorientation; Fig. 1). As preorientation and postorientation strands could not be simultaneously collected, four preorientation and two postorientation data sets were obtained for each strand length. The distance from the orienting deck to the forming belt was the same for all runs.

At the preorientation location, two 48 by 103-inch strand collection panels were placed on top of the orienting deck, while six collection panels were necessary at the postorientation location. Each collection panel was composed of a low-density foam core wrapped in a batting material. The batting served to cushion the fall of strands, thereby minimizing movement after impact. The panels were removed and imaged (3,680 by 2,760 pixels), and the weight of strands collected on each panel was determined (±0.5 lb).

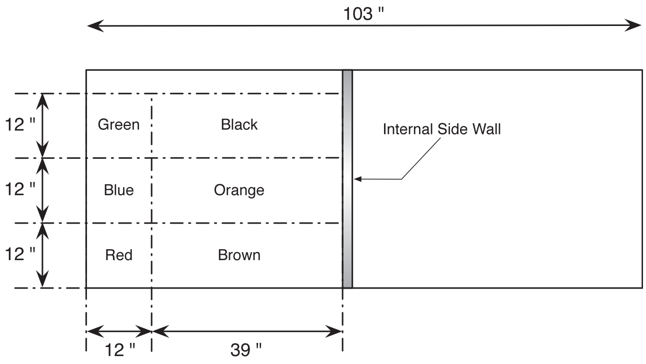

Figure 2.—End view of forming bunker with colored strands placed in six distinct zones.

Image analysis procedures

Images of each collection panel were corrected for lens distortion with an ortho-rectification technique using Photoshop CS4. Figure 3 shows a representative data set of ortho-rectified images obtained for 9-inch strands after orientation. Color polygons were then superimposed on all visible strands using visual judgment. The centroid location of the superimposed color polygons was determined and, in conjunction with knowledge of panel location in the forming line, used to measure the machine (*y* direction) and cross-machine (*x* direction) location and orientation (ø) of individual strands (Fig. 4). Out-of-plane strand orientation was not determined by this technique. In total 12,867 strands were measured. Additional procedural details are available in Perry (2010).

Strand screening after forming

Since strand length has such a significant effect on the projection and orientation of strands in the orienting head, an additional study was performed to evaluate changes in strand geometry that may have occurred during the forming process. Prior to forming, the green strands were screened in the AEWC Trillium screen and separated into three size classes, and only the strands in the largest class (overs) were used in the industrial experiment. Strands from every panel of every forming line run were individually bagged and rescreened using the previous procedures and equipment. The three size classes were weighed, and their proportion of the total was determined. Geometric damage was defined as the percentage of fines and intermediates, termed unders, to the total weight. It was assumed that they were created by the mechanical actions of the forming line only and not by operational factors such as truck transportation, the conveyor drying process, and human handling.

Statistical methods

All statistics were performed using the R statistical package (version 2.8.1). Summary statistics, including median, mean, standard deviation (SD), variance, and mean absolute deviation for each data set were determined. All parametric and nonparametric tests were run at the 90 percent confidence level.

The Wilcoxon–Mann–Whitney (WMW) exact test was run to compare the location of the distributions' medians (Sprent and Smeeton 2001). The Ansari–Bradley (AB) test was used to test for equal variance between the distributions (Sprent and Smeeton 2001). Both tests were used to determine whether the differences between strand flow rate, spread, projection, orientation, etc., were significantly different between variables. Chi-squared tests were performed to determine whether experimental distributions came from a specific class of distribution (e.g., uniform distribution; Sprent and Smeeton 2001). This test determined whether data showed random strand orientation or some degree of alignment.

Results and Discussion

Effects of strand length on flow rate

The amount of strands fed by the picker rolls varied from 36.1 to 61.2 lb/min with mean feed rates of 51.9 and 49.4 lb/min for the 4- and 9-inch material, respectively (Fig. 5). The initial values were lowest for both strand lengths. This was

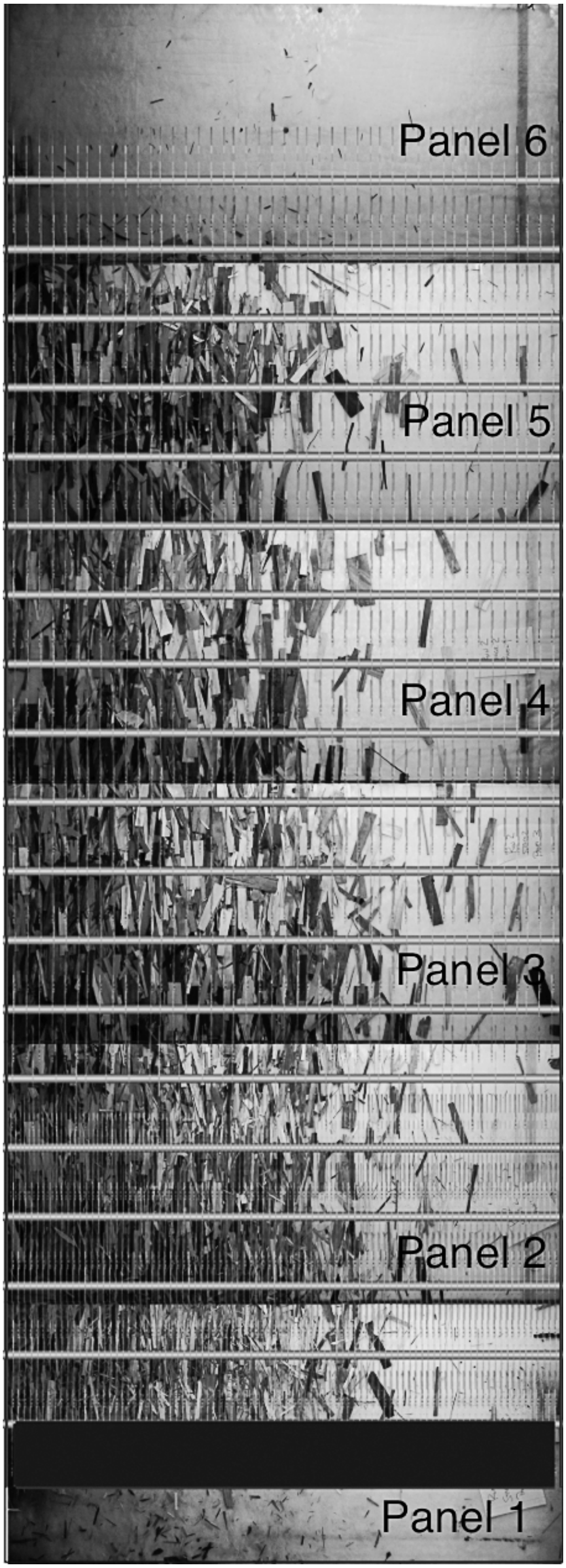

Figure 3.—Ortho-rectified image montage of 9-inch strands after orientation.

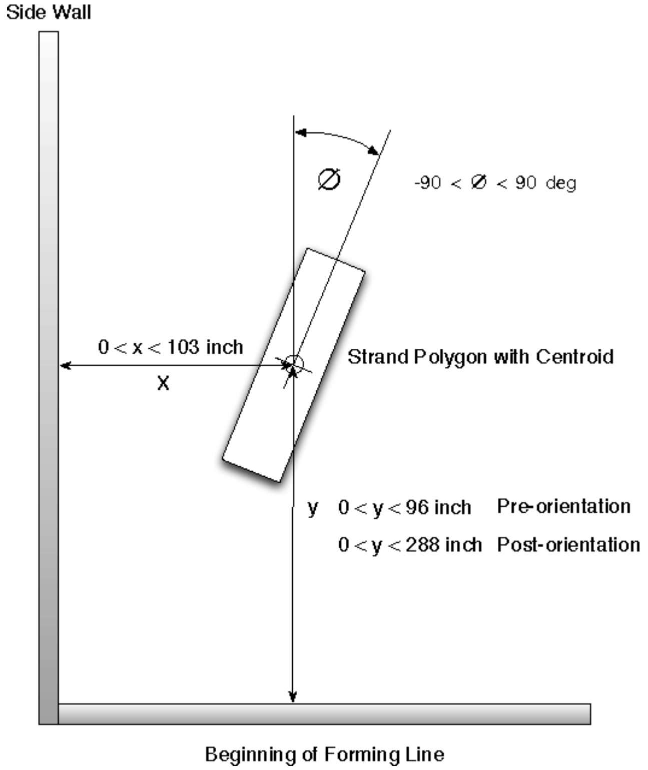

Figure 4.—Strand position descriptors (x, y, ø) along the forming line.

likely due to imperfect contact of the strand mass face in the dry bin with the picker rolls. The difference in flow rate was nonsignificant as judged by both a Student's *t* test ($P = 0.58$) and a WMW test ($P = 0.82$), which tested the mean and median flow rate (Sprent and Smeeton 2001), respectively.

The Student's *t* test and the AB test's *P* value of 0.03 confirmed that the variance in 4-inch material flow was significantly less than that of the 9-inch material. The difference in strand flow variation could have been related to strand length. The forming bin was loaded manually, which may have contributed to mass flow variation because the live bottom bin had a constant movement rate. A more significant cause of increased variation may have been difficulty in pulling the longer strands out of the forming bin because of increased friction forces, strand interlocking, and push-back of the strand pile from the picker rolls. Variations or pulses in flow rate may influence subsequent strand movement through the forming head. However, no quantification of this phenomenon was made.

Cross-machine movement of strands

Cross-machine movement of strands was quantified in two regions: (1) between the picker rolls and entering the orienting discs (preorientation), and (2) exiting the orienting discs and being deposited on the forming belt (postorientation).

The mean/median locations of strands in the bunker were 6 inches for the side strands, 31.5 inches for the center strands, and 25.5 inches when combining all strands. Strands exhibited a consistent movement in the cross-machine (x) direction from the initial condition to the preorientation location. This movement was observed for both edge and center strands (Fig. 6). One measure of this lateral movement, termed spread, was obtained by calculating the difference between mean or median initial location and the mean or median location of strands at the preorientation or postorientation position. The x location of the strands and associated spread for both collection positions and strand lengths are provided in Table 1.

The positive strand spread values for the median and mean indicate material flow toward the free boundary of the system or central area of the forming head. Four-inch material had significantly higher median and spread values compared with the 9-inch material for all cases. The increased movement is likely the result of multiple factors, including aerodynamic effects of lighter 4-inch strands being blown around in the forming process and an increased number of collisions.

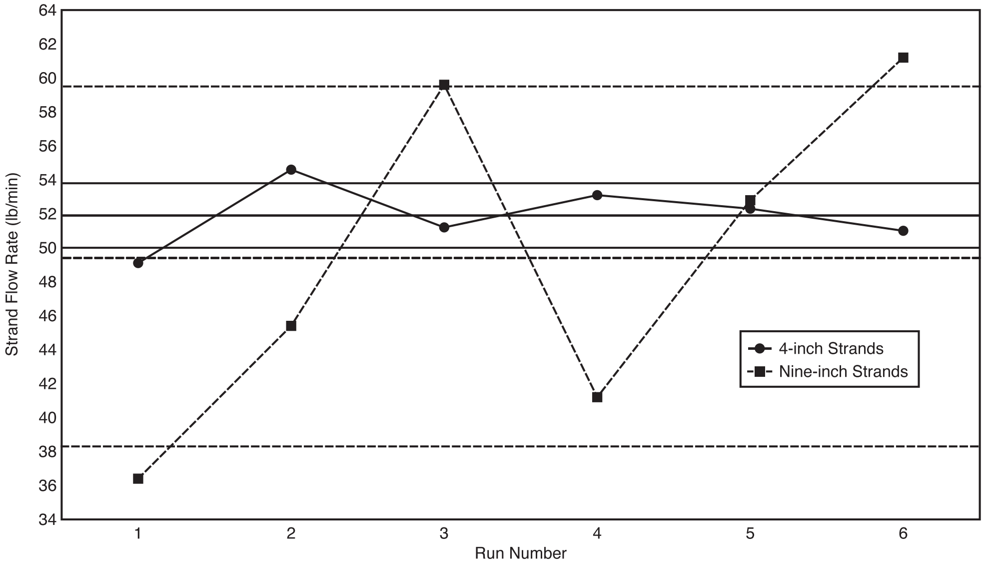

Figure 5.—Strand flow rate for 4- and 9-inch strands (mean ± 1 SD).

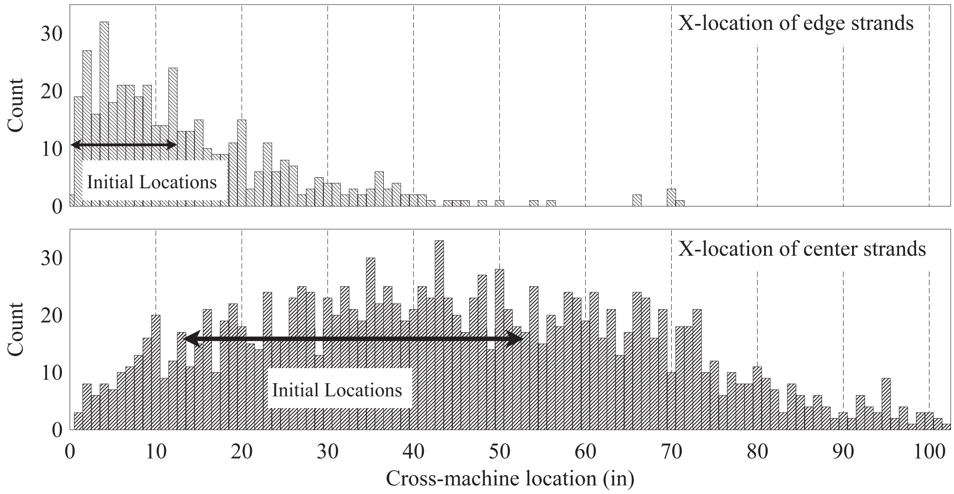

Figure 6.—Cross-direction location of 9-inch strands entering the orienting discs.

Although edge strands did mix with center strands, the magnitude of movement was less pronounced than that of the center strands. This was due to the free boundary within the forming head caused by placement of the temporary internal side wall in the bin. During production, the spread would be reduced as a result of strand-to-strand collisions. However, significant lateral movement and mixing of strands prior to entering the orienting deck is still expected.

Comparison of strand spread at the pre- and postorientation locations indicated no significant cross-machine movement occurred while dropping through the orienting deck. This implies that horizontal density variation is primarily created prior to orientation.

Effects of strand length on projection

Strand projection is the distance traveled along the length of the orienting deck. The weight of material on each collection panel provided a gross measure of projection (Fig. 7). Low Panel 1 weights were caused by a combination of reduced area of the panel due to experimental setup (Fig. 3) and a tighter orienter disc spacing. Most 4-inch material was deposited on Panel 2 followed by a rapid decrease such that almost no material projected to Panel 5.

The 9-inch material exhibited a bimodal weight distribution, with the largest amount deposited on Panel 3. The second mode at Panel 5 was caused by the reversal of orienting discs that forced all of the strands through the deck, which otherwise would have traveled to Panel 6. The reason for the reversal was to stop strands from passing over the end of the orienting deck. If this had not been the case, the weight distribution of the 9-inch runs would have exhibited a continuously decreasing weight along the deck, as was observed for the 4-inch material. The influence of strand length on projection distance is important to account for if mean strand length or length distribution changes.

Effects of strand length on orientation

Strand orientation was measured in the preorientation stage to determine whether there was prealignment occurring prior to the strands entering the orienting deck. Figure 8 shows that there was no prealignment in the 4-inch material, but the 9-inch material shows significant prealignment about 0°. Chi-squared test results confirm that the 4-inch orientation distribution is uniform ($P = 0.72$) and the 9-inch orientation distribution is nonuniform ($P = 0.00$). This prealignment would be caused by the walls and rotating doffing rolls and, to a greater extent, the dissolving rolls. Prealignment may aid increase strand flux to and alignment through the orienting deck, which could increase production rates and improve properties.

The combined 9-inch postorientation material had significantly better median orientation (0°) compared with the 4-inch material (1°; Fig. 9). More importantly, the variation about the 9- and 4-inch median was ±20° and

Table 1.—Influence of strand length and collection position on mean and median cross-direction strand movement.

		4-inch				9-inch			
		x location (in.)		Spread (in.)		*x* location (in.)		Spread (in.)	
Collection location	Starting location	Median	Mean	Median	Mean	Median	Mean	Median	Mean
Preorientation	Combined	38	40	13	15	35	38	10	13
	Edge	9	12	3	6	11	14	5	8
	Center	45	45	14	14	43	45	12	14
Postorientation	Combined	37	35	12	14	33	35	8	10
	Edge	10	13	4	7	9	10	7	10
	Center	44	45	13	14	40	41	9	10

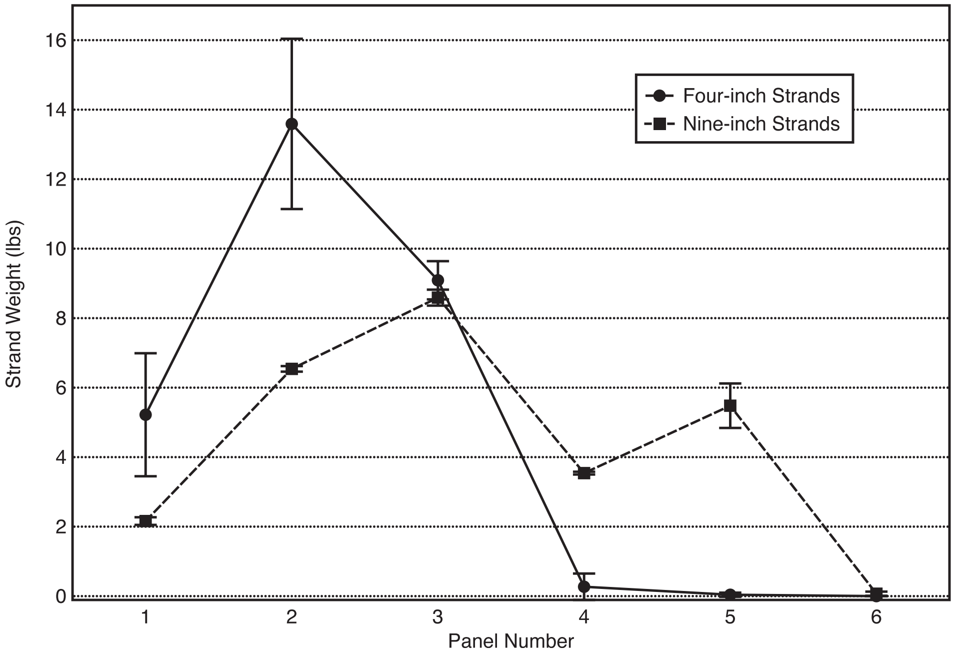

Figure 7.—Influence of strand length on strand weight (pounds) deposited along the forming line (error bars = ± 1 SD).

±37°, respectively. This shows that longer strands align approximately 50 percent better. It should be noted that the deck height above the formed mat was kept constant for all runs, but this height, and the resultant free-fall distance, was larger than the mill's normal operations. Increasing free-fall distance reduces strand alignment quality (Geimer 1976, Suzuki and Takeda 2000).

Studies have shown that using strands shorter than the forming head's design length value leads to lower alignment quality of the composite (Dai and Steiner 1994, Meyers 2001, Barnes 2002, Van Houts et al. 2003). The industrial forming head used for this study was designed for a 9-inch strand length, so decreased alignment with the 4-inch strands was expected. The relative quality of orientation was quantified by the median and, more importantly, the variance around that median.

Strand damage

Preorientation material had a mean unders generation of 5.3 ± 0.3 percent of total strand weight. Postorientation material had a mean unders production of 7.4 ± 0.6 percent of total strand weight. This indicates that most geometric damage (5.3%) was done by the doffing rolls and dissolving rolls, where only 2.1 percent of the damage was done by the orienting discs. Four-inch pre- and postorientation material percent unders were significantly higher than the 9-inch

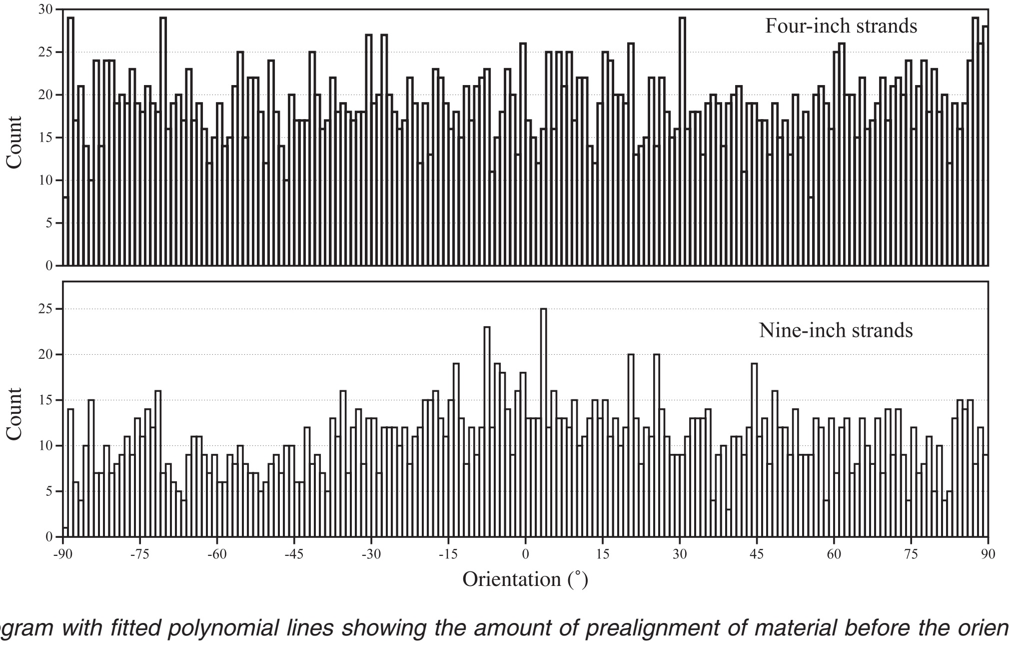

Figure 8.—Histogram with fitted polynomial lines showing the amount of prealignment of material before the orienting deck.

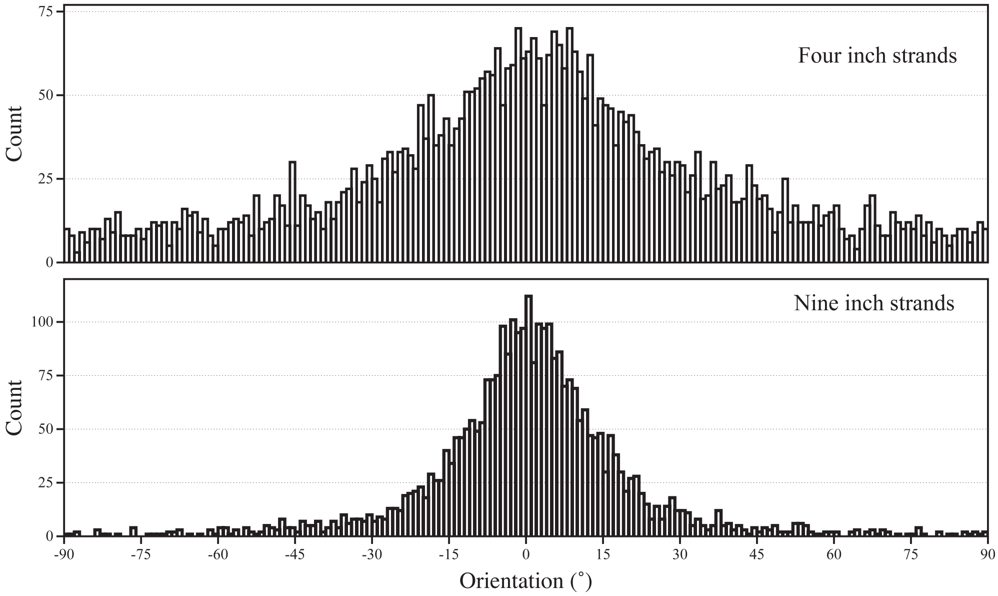

Figure 9.—Cumulative distribution function showing 9-inch postorientation strands having a significantly tighter variance compared with 4-inch strands.

strands, 17.9 ± 1.7 percent and 25.7 ± 8.7 percent, respectively. The ratio of the percent unders generated in the preorientation stage to the percent unders generated in the postorientation stage was 0.7 for each length class. This ratio indicates that 70 percent of the geometric damage done in the forming process was attributed to the doffing and dissolving rolls. Future work should study the effects of the specific process variables such as rotational velocity and tine design on geometric damage and ways to reduce it.

When postorientation geometric damage analysis was broken down by panels, it was found that the highest percentage of unders fell through onto Panel 2 (Fig. 7). Small strands should drop through the deck first as a result of the tight orienting disc spacing, and therefore, the percent unders should lessen on each successive panel. However, both 4- and 9-inch material had lower unders percentages on Panel 1 because only half of the panel area received strands and because of increased strand interactions owing to high volume under the bunker outlet. The 4-inch material exhibited a similar pattern, with most of the unders passing through the deck at Panels 1 and 2 and very few strands reaching Panels 5 and 6. After Panel 1, the 9-inch material followed a similar pattern with the exception of an increase at Panel 5. The increase was caused by the reversal of several orienting deck shafts, which forced all the strands through the deck at that point, which acted as a grinder and created more unders. This was an important discovery because final product performance is derived from the quality of geometry and alignment of the strands, both of which were decreased on Panel 5. This experiment allowed this unforeseen problem to be remedied immediately by reversing these discs.

This experiment reveals opportunities about future forming line designs because manufacturing facilities strive to continually improve their production efficiency. In a strand-based facility, one focus could be on improving strand geometry. The strand length distributions currently used at OSB or LSL facilities encompass a much greater range of strand geometries than were used in this experiment.

Conclusions

A technique was developed that allowed the determination of strand kinematics within an industrial oriented strand composite forming head. Nine-inch strands were found to have a more variable flow rate through the picker rolls relative to 4-inch strands. Cross-direction strand movement analysis showed that all strand mixing and horizontal travel across the width of the forming head occurs prior to the orientation deck. For the mill, this means that the doffing and dissolving rolls are working as designed. For the industry, it indicates that modifications in the strand chute will influence the cross-direction movement uniformity and final product density variation more than orienting deck modifications. As expected, longer strands were shown to project significantly farther along the orienting deck and to provide better alignment. The effective behavior of an industrial furnish will be strongly influenced by the range in strand geometries entering the forming head. Strand geometry was also found to change as a result of moving through the forming head itself. A fines analysis indicated that the doffing and dissolving rolls generated 70 percent of the unders in the forming process. This indicates that changing disc design, disc spacing, shaft spacing, or rotational velocities may reduce the generation of unders and improve product stiffness and strength.

Acknowledgments

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