A NEW WAY TO DEAL IN THE STUD GAME[1]

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INTRODUCTION

About 1.8 million housing units are built annually in the U.S. With an estimated 1500 bd. ft. of studs used per unit (10), the annual total for new construction is nearly 3 billion bd. ft. Assuming a price of $200/M bd. ft., the total estimated value is $600,000,000. In addition there is the ever increasing remodeling and repair market. The stud market appears to be one that is worth defending.

The critical factor in stud production is straightness. Crook, i.e. "deviation of the narrow edge from a straight line", is usually the greatest problem. The maximum allowance of crook for stud grade under the National Grading Rule for Dimension Lumber is 1/4" while the requirements for strength and stiffness of the stud are low (12). The two most important reasons for the increasing popularity of steel studs are their straightness and the possession of punchouts for more rapid installation of wiring and piping (11).

There is considerable published information on the increasing difficulty with warp in dimension lumber. For example, the following papers from the Western Dry Kiln Clubs Annual Meetings over the past decade are just a sampling of the meetings' papers that have addressed the problem (1,2,5,6,7). Lulay and Galligan (7) have stated as follows: "Thus, if drying technology can maintain straightness and stability, great strides will have been made with small log lumber." (A major source of the warp problem is the increasing use of small logs.) They point out that in the case of wall and floor lumber markets, the most sensitive concerns are straightness and visual quality.

What type of drying technology could maintain both straightness and stability? Straightness is maintained by preventing warp and stability is maintained by appropriate moisture content (MC) control. One approach to reducing warp is the use of applied restraint, usually in the form of top load restraint and S-D-R, the intent is to hold the piece of warp-prone lumber straight as it is being dried, i.e. preventing the warp-inducing shrinkage forces from achieving their sordid desires. Saw-dry-rip has the added advantage of minimizing, or perhaps even eliminating, the effect of growth stresses on lumber warp.

If sufficient restraint is provided during drying, the piece of lumber theoretically will stay straight as the shrinkage forces are overcome by plastic flow (creep) of the wood. Creep is promoted by subjecting the lumber to high temperature, e.g. the use of high temperature drying.

Shrinkage forces are inversely related to wood MC, i.e. the lower the MC to which the lumber is dried, the greater the shrinkage forces. Consequently, the literature often recommends drying to an average MC such that the 19% maximum MC requirement is just met. The average MC will probably vary by species but

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perhaps it is in the order of 13 to 14%. There will, of course, be a distribution of individual piece MC's around that average. Perhaps 3 pieces out of 4 will have an average MC somewhere between 10 and 20%. One piece in 20 could even be greater than 19% and the MC specification will still be met. What MC will the lumber eventually attain in service? In the majority of building applications the eventual in-use MC, at least in cold climate areas, is probably going to be considerably less than the MC to which it was kiln dried. Also, at what MC does longitudinal shrinkage commence? If it commences at a lower MC than does perpendicular-to-grain shrinkage, then there is increased potential for longitudinal shrinkage and crook development subsequent to kiln drying.

In cold climates, during the first winter heating season in particular, significant post-drying will occur. The translation of this post-drying into warp is amply evident at building materials outlets, construction sites, completed structures and do-it-yourself projects. It mirrors back to the statement of Lulay and Galligan, "Thus, if drying technology can maintain straightness and stability, great strides will have been made with small log lumber", i.e. with the warp problem.

It would not seem to be in the long-term interest of the lumber industry to "ship the problem out the mill door." It seems that by doing the minimum drying required to meet the specs, that is in fact what happens. In the case of wall studs, steel and aluminum are more than just "waiting in the wings." For light commercial buildings in particular, metal studs are "coming on strong." (Well, no stronger than they need to be in order to meet the rather minimal strength requirements.) They are light, straight and come with holes to facilitate passage of electrical wires and plumbing. Could wood studs be basically permanently straight, contain some holes and have less than their current weights? We think the answer is affirmative. With respect to holes in wood studs, the grading rules already allow their presence. For the 2" face the rule book reads as follows: 3/4" hole or equivalent smaller per 1 lineal foot. On the 4" face a 1-1/2" diameter hole is allowed per lineal foot.

It is no secret that wood dries more readily from the end grain than from the side grain. Consequently, if hole generation were used to create end grain in studs, they should dry faster, and in particular dry faster to lower, more uniform MC's. Furthermore, if they were kept straight during this drying to a lower MC, a MC that is in keeping with their subsequent in-use MC's, possibly we then have approached satisfying this need for "maintaining straightness and stability."

OBJECTIVES

The research described in this paper combines the use of predrilling and a new restraint system during drying in an attempt to attain stud straightness and stability. Predrilling has been investigated earlier with balsam fir studs and was found very beneficial for accelerating the drying (3). However, there was no apparent effect of predrilling upon warp when the studs were dried by the recommended conventional kiln schedule and with conventional stacking.

The ability of predrilling to cut the drying time in half was quite encouraging and it prompted considerations as to how better warp control might be achieved. Considerations led to the conclusion that it might be advantageous to stack the studs for drying with the wide faces orientated vertically and to combine this type of stacking with top load restraint. With this orientation, the weight (force) is acting perpendicular to the narrow edges of the studs. Also, as the studs dry there should be little opportunity for wood shrinkage to develop spaces between the studs into which crook can occur, which is the case for conventional stacking.

The use of "vertical stacking" is not new. The Kiln Operator's Manual shows a unit of lumber stacked vertically for drying in a kiln with vertical air circulation. Possibly vertical stacking has also been used in the past in attempts to reduce warp but the authors are not aware of published information on the subject.

The choice of aspen for the study was not based upon a perceived underutilization of the species. In fact, there is a growing body of opinion, at least in Minnesota, that aspen may be in short supply in the future due to its increased use for pulp and composite panels. Rather, aspen was chosen because of two important features: 1) it has a comparatively high green MC and dries non-uniformly, and 2) it is prone to warp, in particular the development of crook.

EXPERIMENTAL

Approximately 225 rough, green aspen 2 by 4's were obtained from Rajala Timber Company at Deer River, Minnesota and trucked to Kaufert Laboratory on the St. Paul Campus. The 2 by 4's ranged in length from about 100 inches to 10 feet so the initial step was to trim the pieces to 96 inches. The 8-foot studs were divided into two groups, one group for predrilling combined with the new restraint system and the other group for conventional processing.

The pretreatment group was predrilled with 3/8" diameter holes perpendicular to the narrow edge. The holes went clear through the 4" depth and were located 6" on center along two parallel lines. The two lines were located such that a 1/3" thick band of uninterrupted wood materialized on each wide face of the stud with the third band between the two parallel lines of holes. The holes were offset such that a hole in one line was opposite the midpoint of the 6" spacing between 2 holes of the parallel line. The amount of wood removed is equivalent to the 3/4" hole allowed in the grading rules.

The green studs were measured for crook and only those with crook of 1/4" or more had the value recorded. The studs were also weighed individually and measured in width. Thickness was not measured since all studs were blanked to 1 3/4" inches.

The studs were stacked for kiln drying with vertical orientation of the wide faces. This was accomplished by these of special "stacking racks", of which there were 3, one at each end of the 8' long kiln car and one at midpoint. The stacking racks consist of 3/4" diameter rods oriented vertically and welded at their bottom ends to a 1/4" thick steel plate about 2" wide. Each rack is clamped upright to an I-beam of the kiln car. The rods are 1-3/4" apart so that each slot can accept the thickness of the rough green studs.

The studs were separated vertically by 7/8" thick stickers placed at 2' intervals along the length of the unit. The dry paper birch stickers were planed to the 7/8" thickness just prior to the start of this research. There were 16 slots of full length studs, with 6 studs/slot. The center slot of the 17 available was utilized for sample boards. The sample boards were 45" long and the overhead stickers at this center slot location were notched out slightly to insure ease of sample board insertion and removal. The sample boards were quickly removable since they were accessed from the front end of the kiln charge. This meant essentially continuous drying with minimum disturbance during the weighings.

Once the unit was stacked, concrete weights were placed on top of plywood cover boards supported by kiln sticks. Due to the presence of the stacking rack we could only place 2 of the 4 available concrete weights. This constituted 250 lbs/concrete weight, for a total of 500 lbs. Unfortunately, this total weight restraint did not remain in effect during the entire kiln run. The concrete weights, especially the one between the front and middle stacking racks, hung up on the 1/4" thick steel plate that was used to maintain a constant distance between the vertical rows of steel rods. This steel plate is 2" wide, like the one at the bottom to which the vertical rods are welded, and has 25/32" diameter holes drilled on 2-1/4" centers so that it can be slipped on to the vertical rods. Unfortunately, the concrete weights rested on the spacer plates, and as the lumber dried the spacers did not drop evenly but became canted and thus were able to partially suspend the weights.

For conventional drying the studs were stacked in the conventional manner, using the surfaced 7/8" stickers on 2' intervals. Three plywood runways were built into the center of the charge so that the 6 sample boards could be accessed from the front of the charge, i.e. the same as for the predrilled studs. Since there were no stacking racks involved, we were able to use all 4 of our 250 lb. concrete weights to obtain 1000 lbs. of top load restraint. This amounted to about 35 lbs./ft^2 of lumber stack, considerably less than what is used in industry practice.

We elected to dry according to the recommended FPL schedule for 8/4 aspen with the following modification; at an estimated average MC of 25% depart from the schedule and utilize a dry bulb temperature of 240°F with a 50°F wet bulb depression. Using high temperature drying after removal of the free water was intended to minimize collapse while still giving the beneficial effect of high creep (plastic flow) on warp. Table 1 summarizes the actual kiln conditions.

Table 1. Summary of the kiln conditions for the two runs. Air velocity for both runs was about 1000 fpm.

	Hours	dbt (°F)	Wbt(°F)	MC Range (%)
Predrilled	0-42	141	125	90-50
	43-54	141	120	50-40
	55-95	141	110*	40-22
	96-110	240	190	22-6.5
Undrilled	0-29	141	125	81-50
	30-50	141	120	50-40
	51-116	141	117*	40-26
	117-134	240	190	26-6.6

*Additional insulation was recently added to the kiln in conjunction with doing energy quantification research for red oak drying. This addition has apparently greatly reduced condensation on internal surfaces. Without the condensation, the kiln was not able to reach the depressions called for by the schedule at the dbt of 140° F. The depression realized became a function of the temperature and relative humidity of the make-up air.

Following drying, the studs were weighed individually and measured for width and thickness to the nearest 1/32 inch. Studs were checked for crook in excess of the allowable 1/4".

RESULTS AND DISCUSSION

Drying Rate

Figure 1 compares the drying rates for the predrilled and undrilled studs. The predrilled dried to the final MC in about 20% less time compared to the undrilled. It is apparent that the generation of end grain did enhance drying but not the degree obtained on the research with balsam fir studs (3). With balsam fir, 9/16" diameter holes drilled along the centerline of the 2" face edge on 4" centers cut the drying time in half when using the recommended FPL schedule.

Figure 1 shows that the added end grain had more effect as the MC got lower. This would be expected. Early in drying the rate is not as diffusion-dependent since the moisture is being lost from the surface layers. However, as the average MC was reduced, the length of the perpendicular-to-grain diffusion path for the undrilled wood steadily increased. In the predrilled pieces this scenario was modified as the presence of the holes reduced the distance that core moisture had to travel before leaving the wood. This suggests why the pattern used for the balsam fir was more effective than that used herein for aspen. Having the holes down the centerline of the 2" face probably gave the greatest assist to the removal of core moisture. Holes 17/32" in diameter, drilled 6" on center down the centerline of the narrow face, would have removed the same amount of wood as did the pattern of 3/8" diameter holes but the benefit to drying would probably have been greater.

Moisture Content and Crook Data

Table 2 summarizes data with respect to crook and moisture content.

The average estimated final MC's for drilled and undrilled, based upon five sample boards, were essentially identical. However, when a resistance-type moisture meter was used to check final MC's, a considerable difference was noted for the drilled and undrilled. (Figure 2 illustrates how these readings were obtained.) Out of 384 attempts for the predrilled studs only 10 attempts registered, i.e. had a reading greater than 6%. These 10 values gave an average of 6.8%. For the undrilled studs, 136 of the 392 attempts registered on the meter. The average for these 136 readings was 11.9%.

This raised an interesting question, "why was there such a difference in MC values for the drilled and undrilled studs by meter evaluation when the sample boards indicated that the two types were dried to essentially the same average MC?" What is suggested was that the drilled and undrilled studs contained the same weight of water at the end of drying but that the water was distributed differently. In pursuit of this idea, shell and core MC sections were cut from the five undrilled sample boards and the five predrilled sample boards in the manner depicted in Figure 2. Table 3 summarizes the data obtained. First it is noted that the ovendry values for the predrilled and undrilled were 7.3% and 8.4%, i.e. about one and two percent higher than the values estimated from weighing the respective sample boards. Presumably the differentials were due to the inability to accurately estimate the MC from the use of sample boards, even though intermediate MC's were determined for the sample boards when the estimated average MC's were only about 25%.

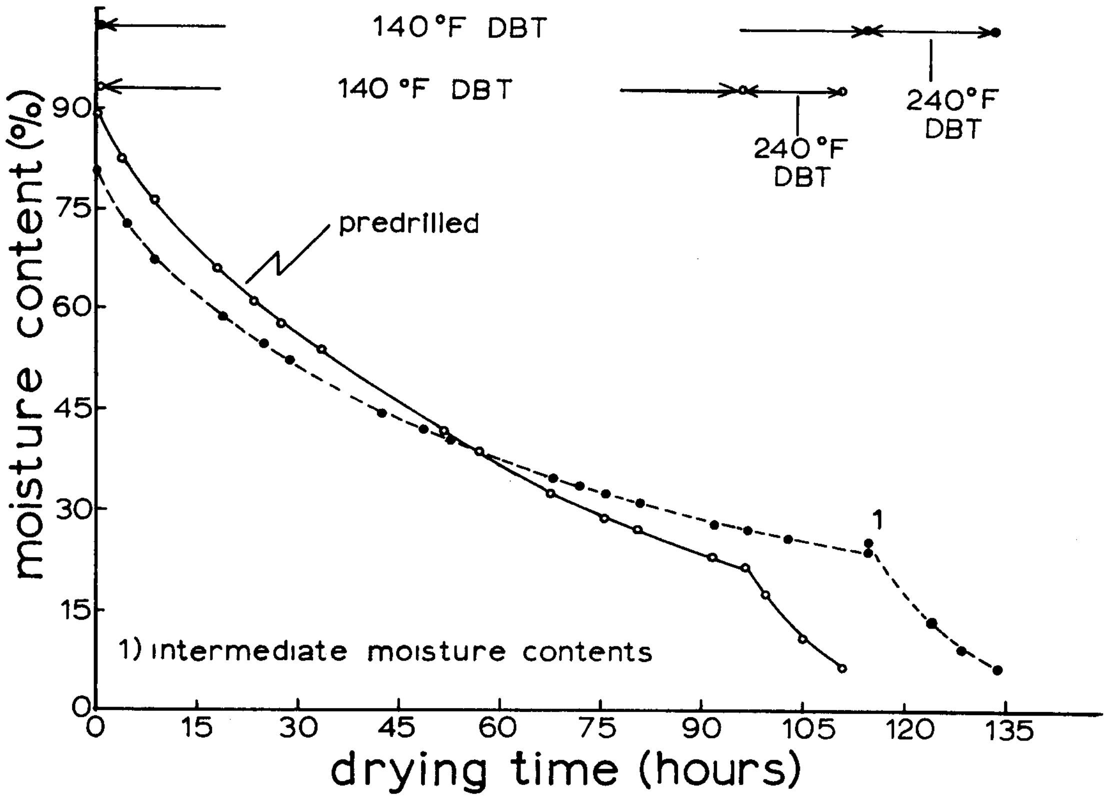

Figure 1. Comparative drying rates for the predrilled and undrilled studs. (See Table 1 for further explanation.)

I. Intermediate MC determinations were made for sample boards just before the start of high temperature drying. For undrilled studs a slight adjustment upward was required following the intermediate MC determinations.

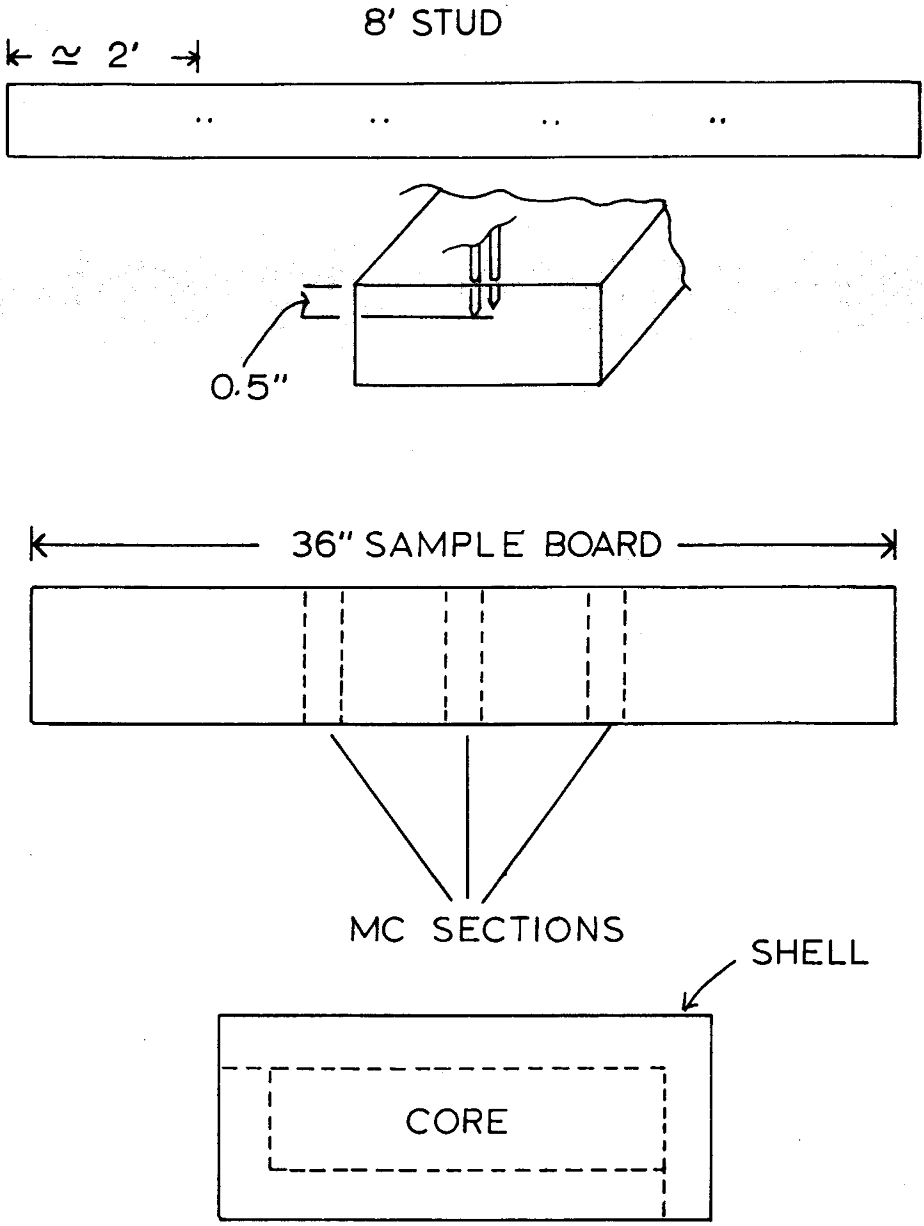

Figure 2. Illustration of the locations of the four moisture meter readings attempted on each stud and the depth to which the needles were driven. Also, an illustration of how shell and core MC sections were obtained from the sample boards at the end of drying.

Table 2. Summary of crook and moisture content data.

	Predrilled	Undrilled
Total Number of Studs	96	98
Average Initial MC - 5 Sample Boards	90%	81%
Average Final MC - 5 Sample Boards	6.5%	6.6%
No. Of Green Studs With Crook In Excess of 1/4"	4	2
No. Of Dry Studs With Crook In Excess of 1/4"	21	14
Average Dry Crook For The 21 Predrilled	12/32"	
Average Dry Crook For The 14 Undrilled		16/32"
Number of Dry Studs Registering On Meter	8	51
Total Number Of Meter Readings Attempted	384	392
Total Number of Meter Attempts Registering	10	136
Average For The Registering Values	6.8%	11.9
Range Of The Registering Values	6%-9.5%	6%-50%

Table 3. Summary of moisture content data for sample boards.

	Predrilled	Undrilled
Final Ovendry MC Of All Sample Boards	7.3%	8.4%
Average Shell MC	4.9%	4.6%
Average Core MC	9.2%	12.4%
Average MC For "Whitewood" Samples	3.5%	4.3%
Average Shell MC For Whitewood	3.9%	3.4%
Average Core MC For Whitewood	3.5%	5.6%
Average MC For "Darkwood" Samples	13.1%	14.5%
Average Shell MC For Darkwood	6.5%	6.4%
Average Core MC For Darkwood	17.6%	25.3%

Table 4. Change in crook during drying for those studs that showed greater than 1/4" of crook in the green condition.

Stud	Type	Green Crook (inches)	Dry Crook (inches)
A69	Predrilled	26/32	10/32
A72	Predrilled	13/32	---*
A75	Predrilled	11/32	12/32
A76	Predrilled	17/32	12/32
19	Undrilled	9/32	10/32
42	Undrilled	16/32	34/32

*This does not necessarily indicate zero crook but rather that the crook was reduced to less than the 1/4" maximum allowed by the grading rules.

The average shell MC's for both "whitewood"[2] and "darkwood" sample boards were least for the undrilled studs. Conversely, the average core MC's for both types of wood were highest for the undrilled. This shows the effect of the holes upon the MC gradient. The holes apparently assisted in the more rapid transfer of water from the core to the shell, thereby accounting for both the higher shell MC and lower core MC.

Each stud was weighed individually prior to the start of drying and again at the end of drying. When the volume removed by predrilling was accounted for, the predrilled studs had an average final weight of 4467 grams with a standard deviation of 326 grams. The undrilled studs had an average final weight of 4560 grams with a standard deviation of 368 grams. The difference in final average weight of 93 grams (assuming the same specific gravity for drilled and undrilled studs), translates into a difference in average MC of just over two percentage points. Consequently, the actual difference in final average MC for the studs appears to have been greater than the 1.1% difference in MC given in Table 3 for the ovendry sections cut from the sample boards. It appears therefore that the undrilled studs at the end of drying actually had an average MC value at least 2 percentage points greater than that for the predrilled. Recognizing the steeper MC gradient for the undrilled studs, and the higher average MC, it is easy to see why the meter readings came out as they did. With a needle penetration equal to about one-third of the stud thickness, there was much greater opportunity for encountering high MC in the undrilled pieces. On the other hand, if we had used the recommended depth of penetration of 1/4 to 1/5 of the piece thickness, the average MC for the undrilled would probably have been no more, and conceivably less, than what would have been obtained for the predrilled. Obviously the shape of the MC gradient and the depth of needle penetration is quite critical in obtaining a correct estimate of average MC with the electrical resistance type of moisture meter.

In summary, predrilling not only shortened the total drying time by about 20%, it also produced a more favorable MC gradient in the studs. In this regard, the differential in core MC at the end of drying due to predrilling was greater for the impermeable darkwood than for the more permeable whitewood. This greater effect for predrilling in the context of low permeability suggests that predrilling would make a significant contribution to the dissipation of troublesome wet pockets.

Table 2 also summarizes the crook results. As indicated, only 14 of the 98 undrilled pieces had crook in excess of the allowable 1/4" while 21 of the 96 predrilled had crook in excess of 1/4". Part of this difference in favor of the undrilled can be accounted for by the difference in final MC. It is a well known fact that the lower the final MC, the greater the warp. Arganbright et al. (1) demonstrated a dramatic increase in crook for ponderosa pine studs as the average MC was reduced from 13.4 percent to 5.4 percent.

It is of some interest that the average crook for the predrilled studs was 1/8" less than that for the undrilled studs. This may or may not be a real difference. If real, it might be attributable to the fact that in conventional stacking there is the possibility of almost unlimited crook for a given stud under certain

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[2] "Whitewood" comes primarily from the outer perimeter of the logs and probably consists largely of sapwood. "Darkwood" originates more toward the log centers and often occurs in the form of streaks along the grain. There is a significant difference in drying rate for the two types of wood.

conditions. For example, consider the case of two adjacent studs on the edge of the unit. Let us assume they are both quartersawn and the third stud in from the edge is flatsawn. As the unit dries, the quartersawn studs will suffer reduced frictional contact with the stickers due to their higher thickness shrinkage. If both studs develop crook by becoming concave on the edge toward the unit's interior, there is really nothing to limit their movement. On the other hand, if these same two studs were vertically stacked and with adequate top load restraint, their ability to crook would apparently be quite limited. In this regard, three of the four predrilled/vertically stacked studs that had greater than 1/4" of crook in the green condition had less that 1/4" of crook after drying. This data is summarized in Table 4. Unfortunately there were only four predrilled and two undrilled that had crook in excess of 1/4" in the green condition. A larger sample will be required before any firm conclusions can be reached regarding the ability of vertical stacking to eliminate crook that exists in the green condition.

The lack of crook in the green condition, plus the comparatively high recovery of stud grade pieces in the dry condition, suggests the use of atypical aspen. Normally there would be considerably more pieces with noticeable crook directly off the saw, and with conventional processing techniques perhaps stud grade recovery would be about only 50%. It was noted that these 2 by 4's were almost totally flatsawn. We learned that this developed from the sawing procedure employed. In fact, these flatsawn pieces had a greater tendency to show bow in the green condition than crook. A second reason for the higher than expected stud recovery for our conventional stacking process could be the green surfacing to a uniform thickness of 1.75" and therefore more effective sticker restraint.

Shrinkage Data

Each stud was measured in width to the nearest 1/32" prior to drying and at the end of drying. It was not necessary to measure thickness in the green condition since all studs were planed to a green thickness of 1-3/4". Each stud was measured in thickness at the end of drying to the nearest 1/32".

The shrinkage results are summarized in Table 5. Note that the predrilled and undrilled had identical thickness shrinkage of 0.12" (6.9%). However, the width shrinkage for predrilled was 0.17" while for the undrilled it was 0.24". This is a difference of just over 1/16". If the undrilled studs had dried to the same average moisture content as the predrilled, this difference would have been even more. It thus appears that the green target size for such predrilled studs could be at least 1/16" less than that for conventional, undrilled studs.

The difference in width shrinkage was due to the modification of the MC gradient and the associated drying stresses in the predrilled studs. The presence of the holes allowed drying of the interior parts of the studs concurrent with the drying of the external surfaces. This reduced the severity of the MC gradient and thereby reduced the severity of the stresses attributable to unequal shrinkage over the cross sectional area of the board. The net result was that less compression set developed in the predrilled board and this translated into reduced board shrinkage.

SUMMARY AND CONCLUSIONS

Green aspen 2 by 4's eight feet long were predrilled with 3/8" diameter holes perpendicular to the 2" face and through the full depth of the stud. The total cross sectional area of the holes generated was equal to that allowed by the grading rules, i.e. one 3/4" hole or the equivalent smaller per lineal foot. The predrilled studs were stacked for kiln drying with the wide face orientated vertically and top load weights were employed. Matched studs were processed in the conventional

Table 5. Summary of shrinkage data for the predrilled and undrilled studs.

	Avg. Green Width (in.)	Avg. Dry Width (in.)	Width Shrinkage (%)	Avg. Green Thickness (inches)	Avg. Dry Thickness (inches)	Thickness Shrinkage (%)	Estimated Final Avg. MC (%)
Predrilled	4.11	3.94	4.1	1.75	1.63	6.9	8*
Undrilled	4.11	3.87	5.8	1.75	1.63	6.9	10

*Based on a comparison of average stud weight at the end of drying, it is concluded that the final average MC for undrilled studs was at least two percentage points higher than that for undrilled studs. The absolute values of 8 and 10 percent given here are based on the assumption that the final average MC for full length studs was slightly greater than that estimated from the MC sections cut from the sample boards at the end of drying and recorded in Table 3.

drying and stacking manner for a comparison.

Predrilling reduced total drying time to about 8% MC by about 20% and the MC uniformity for predrilled studs was greatly improved. Stud grade recovery for conventional processing was approximately 86% while for the predrilled/vertically stacked studs the recovery was approximately 79%. The lower recovery for predrilled studs is believed due to two factors: 1) The predrilled were dried to an estimated 8.0% final MC while the conventional studs had a final estimated average MC of 10% or slightly greater. 2) Due to mechanical problems the top load restraint for the predrilled/vertically stacked studs was only partially effective.

The removal of allowable amounts of material by predrilling and the use of vertical stacking with effective load restraint is considered promising for the production of light framing studs.

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