THE SIMULTANEOUS DRYING AND DENSIFICATION OF SAPWOOD[1]

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ABSTRACT

A process for densifying wood while simultaneously drying it in a platen press is described. The effect of various pressure-time functions on the density distribution of the final product is discussed as is the effect of these functions on the dimensional stability characteristics of the product. Low density wood of high permeability, generally sapwood, is applicable to this process. A product with the most uniform density distribution and the best stability characteristics is obtained by rapidly compressing the material after the center has reached 212 F. Springback of such material after soaking for three weeks amounts to 10 to 15%. More stable material can be produced by steeping green wood in phenol formaldehyde impregnating resin prior to drying and densification. Springback after soaking can then be reduced to 1 to 2%. The bending strength properties of the densified material was found to be proportional to the density in a range from 0.60 to 1.00 gm per cm^3. Some estimates of cost of the process are presented.

Densified wood has been produced for at least fifty years in various forms for a number of uses including printing blocks, handles, textile shuttles, flooring, airplane parts, gears, and electrical insulators. Patents on methods of densifying wood date back to 1900. Almost all processes used to densify wood are based upon the fact that wood can be compressed in the transverse dimension and densified without producing rupture if the compression is carried out under conditions which plasticize the wood. Heat, and in some cases moisture or wood swelling resinoids, are the plasticizing agents usually employed.

The two methods of densification best known in the United States are the "Compreg" (Stamm and Seborg 1944) and "Staypak" (Seborg, Millett, and Stamm 1945) processes developed by Stamm and Seborg. The compreg process consists of impregnating solid wood or veneer with a water-soluble phenol formaldehyde resinoid, drying the material at a temperature low enough to avoid pre-cure, and then compressing the material under temperatures which will cure the resin. For maximum dimensional stability a resin solids content of about 30% and a specific gravity of 1.3 to 1.4 are recommended (Seborg, Tarkow, and Stamm 1962). However, compreg can be produced at lower resin contents and specific gravities. The strength properties of compreg are generally proportional to the specific gravity, with the exception that impact properties are affected detrimentally by the phenolic treatment. Almost all applications of compreg today are in veneer products.

Staypak differs from compreg mainly in the fact that the wood is not impregnated with a resin. Staypak is produced by compressing wood, at a moisture content equal to or below that which it will have in service, under temperatures from 300 F to 360 F. Pressures of 1,500 to 2,500 psi are generally required where a final specific gravity of 1.3 is desired (Stamm 1964). One of the problems encountered in making staypak results from the fact that the material must be cooled in the press. Because lignin is thermoplastic and because the moisture content of the wood is only slightly less after compression than prior to pressing, considerable springback or loss of compression will occur if the product is removed while still hot. This necessity places a severe handicap on efficient commercial production of this product. Staypak does have the advantage over compreg of possessing a higher impact strength. It is, however, much less dimensionally stable. There has been no commercial application of stay-

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pak in the United States, although there has been production (Seborg et al. 1962) of similar products in England and Germany.

One of the primary problems experienced with most types of densified wood products (the exception being those with high resin contents such as compreg) is the lack of dimensional stability. When soaked in water or exposed to high relative humidity, they tend to exhibit non-reversible swelling or springback. These products also, of course, exhibit reversible swelling as does normal wood. Since the density of these products is higher, they often exhibit a greater coefficient of reversible swelling than does the wood from which they are produced. The reversible or normal swelling characteristics do not present the potential problems in use that are presented by springback. Thickness springback is a serious problem in any situation in which these products may be subjected to high equilibrium moisture content conditions.

THE METHOD FOR DENSIFICATION OF GREEN WOOD

A method of densifying and simultaneously drying green sapwood which appears to have some distinct advantages over previous densification processes has been developed.[2] This method will be briefly outlined, and the research results regarding this product and process will then be presented.

The products produced by this process would generally have a specific gravity range of 0.60 to 1.00, although higher density material could be produced if desired. The objective of the process is to produce from a relatively low density species a product similar in strength and appearance to a high density wood. This is of course quite different from material produced in the compreg or staypak processes, which have specific gravities of 1.20 to 1.40.

Green wood (above the fiber saturation point) is placed in a press with platen temperatures from 290 F to 360 F. A nominal pressure of 25 to 75 psi is applied to provide maximum heat transfer. When the center of the wood reaches about 212 F, the pressure is increased to compress the wood rapidly to the desired thickness. This provides approximately uniform densification throughout the thickness of the specimen. For most types of products, uniform densification is preferable to a density gradient of some type. If, however, a product with relatively high surface density is desired, the press should be closed to the desired final thickness without the preliminary warmup period. The wood must be dried in the press until the moisture content is below 1%. The time required varies, depending on the original and final thickness and pressing cycle used and is generally from 75 to 120 minutes for material with an original thickness of one inch. After pressing, the product is conditioned under moderate relative humidity conditions to the desired final moisture content.

This process appears to be generally applicable to the sapwood of relatively low density species such as yellow poplar, aspens, gums, pines, and spruces. Heartwood is often too impermeable to be successfully dried in this manner. Increases in density can be varied according to the hardness or strength level desired in the final product.

Densified wood produced in the above manner is more dimensionally stable than wood produced under the other types of press cycles studied. However, it does exhibit some springback if subjected to high humidity (1 to 2% springback) or liquid water (10 to 15% springback). For products which will be subjected to extreme moisture conditions, a method of treating with a phenol formaldehyde impregnating resinoid was developed. This treatment is based on the fact that the resin can be diffused into the cell structure of wood in the green condition, and that subsequent drying and densification cure the resin and bulk the cell walls and in some other manner retard the recovery of collapsed cells. This treatment appears quite effective in reducing springback.

The treatment can be accomplished by

[2] U. S. Patent applied for under Serial No. 760,870.

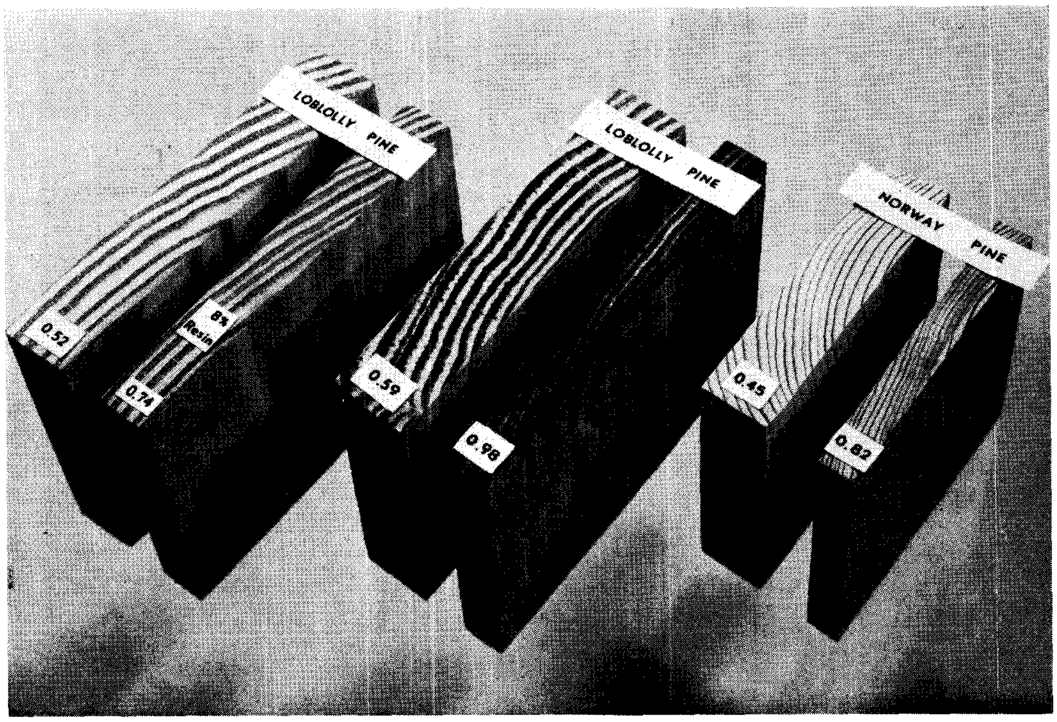

FIG. 1. Samples of densified pine with matched undensified controls. The left sample of each pair shows the thickness prior to densification. A phenolic resin treated loblolly pine sample is included. The specific gravity of the samples is shown.

soaking green sapwood in undiluted, low advanced, water-soluble phenol formaldehyde resin[3] for about one day. In this study, a sixteen-hour soaking period provided a resin solids pick-up of from 6 to 15% based on dry weight in green sapwood of aspen, Norway pine, and loblolly pine. The material is then stored to provide a period for further diffusion of the resin into the center of the board and presumably into the cell wall structure. Five days of storage was found adequate. Much of the effectiveness of the treatment is lost if the storage period is omitted. After the storage period, the material is simultaneously dried and densified, using the procedure described for untreated wood.

Fig. 1 shows resin-treated and untreated densified pine samples and samples of the size and type from which produced. The remainder of this paper describes the research conducted regarding the mechanics of the process, the properties of the material, and some of the economics involved.

THE EFFECTS OF PRESSING PROCEDURES

It was recognized that the pressure-time function, i.e. press cycle, could have an important influence on the density distribution through the product thickness and on resulting physical properties. Five distinct press cycles, shown graphically in Fig. 2, were studied. In cycle A, the press was closed immediately to the desired thickness, which was then maintained until the wood was dry. In cycle B, the press was closed to final thickness as soon as the center heated to 212 F. The pressure during cycle C was gradually increased to provide continuous densification throughout the cycle. Cycle D consisted of closing to thickness when the temperature ¼ inch from the

[3] In this study, "Tybon 951" resin provided by Pacific Resins and Chemicals, Inc. was used.

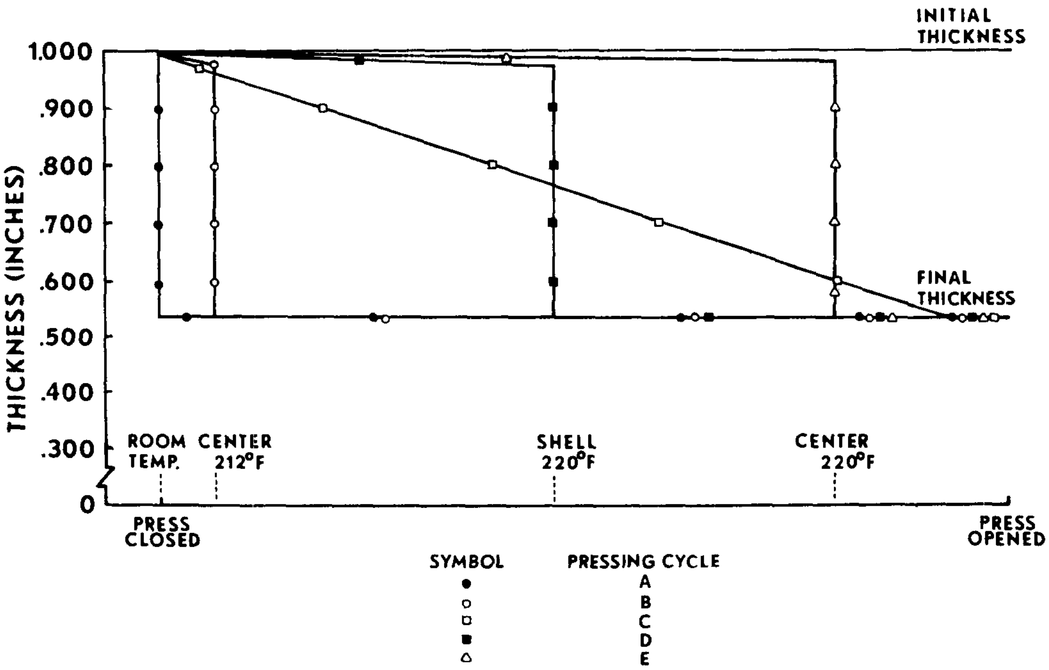

FIG. 2. Diagram of the five press cycles studied, showing the thickness of the specimens during the press cycle. For initial thicknesses other than one inch, the vertical axis should be considered as relative only.

surface reached 220 F, indicating that the surface has dried to below the fiber saturation point. In cycle E, the press was closed after the center reached 220 F, indicating that the entire piece was below the FSP.

The temperature in the center of aspen sapwood during the five types of press cycles is shown in Fig. 3. This figure is for material with a final thickness of from 0.52 to 0.59 inches with a platen temperature of 340 F. Similar but lower curves resulted from tests at a platen temperature of 290 F. Note that in cycles A and B, the temperature is higher throughout the pressing period than in the other cycles. This provides greater plasticization and faster drying.

Drying times can be expected to vary with original thickness, final thickness or degree of densification, initial moisture content, and the drying characteristics of the species. Times required for a variety of species and degrees of densification are shown in Table 1. The times shown in the table were obtained from tests which for some species included only ten pieces, while for other species included several hundred specimens. The press time required with a platen temperature of 290 F is about double that shown in the table for 340 F.

The density distribution through the thickness resulting from the different press cycles is shown in Fig. 4. The board compressed immediately shows high surface densification. The board heated to 212 F and then compressed shows relatively uniform densification. The boards pressed after the surfaces had dried to any degree showed relatively high densification in the center, as would be expected. These latter types of press cycles would, therefore, not be desirable for most types of products. These tests were conducted on aspen sapwood with a green thickness of 1.00 inches and final thickness of 0.56 inches. In species such as loblolly pine with great differ-

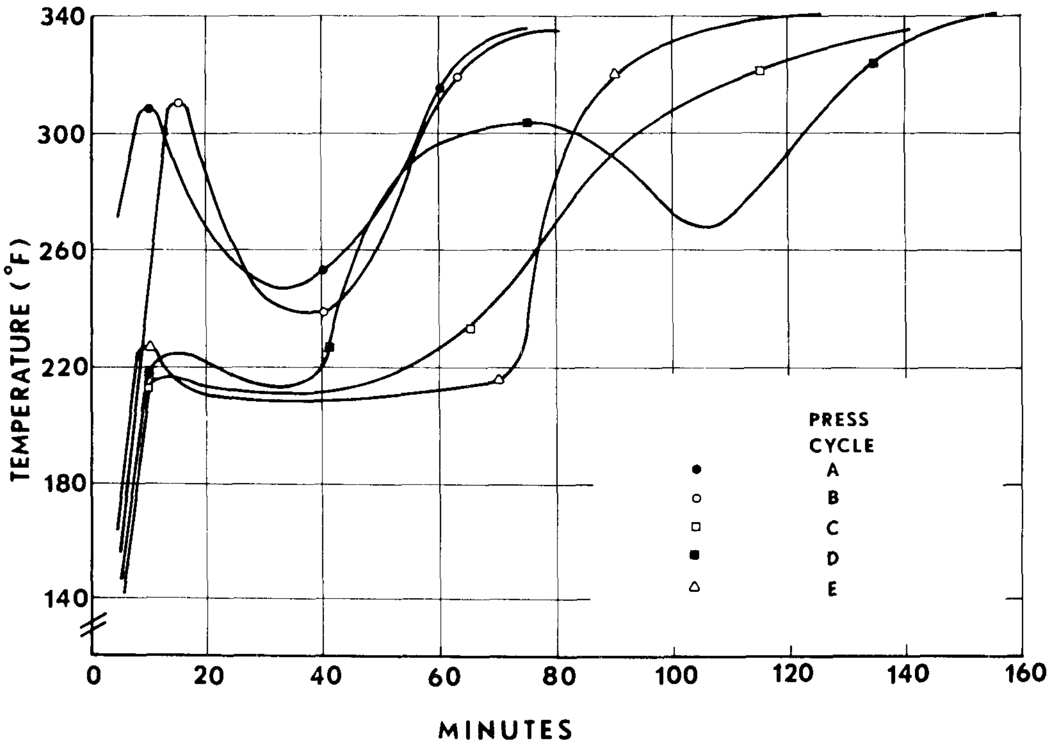

FIG. 3. Typical time-temperature curves for aspen samples dried and densified with platens at 340 F. Initial thickness was 1 inch and the final thickness 0.55 inches.

ences between the density of earlywood and latewood, almost all densification occurs in the earlywood.

SORPTION AND DIMENSIONAL STABILITY CHARACTERISTICS

Tests were run to determine the effect of a series of humidification cycles on the dimensional stability of material produced by the five press cycles previously described. The samples were first conditioned to 43% relative humidity from the nearly oven-dry condition existing after pressing. The oven-dry dimensions were used as a base for the per cent of swelling calculations. Two humidification cycles were then

TABLE 1. *Drying times required: from green sapwood to less than 1% M.C. using press cycle A or B with a caul temperature of 340 F*

Species	Ave. green M.C. (%)	Initial thickness (inches)	Final thickness (inches)	Ave. press time (min.)
Aspen	100	1.00	0.55	75
Baldcypress	85	0.75	0.50	90
Jack pine	138	0.60	0.38	75
Jack pine	117	0.80	0.40	90
Loblolly pine	102	0.75	0.50	65
Loblolly pine	95	1.00	0.75	110
Norway pine	145	0.60	0.36	40
Norway pine	152	0.80	0.40	70
Tupelo	65	1.00	0.75	125
Yellow poplar	105	0.75	0.50	90

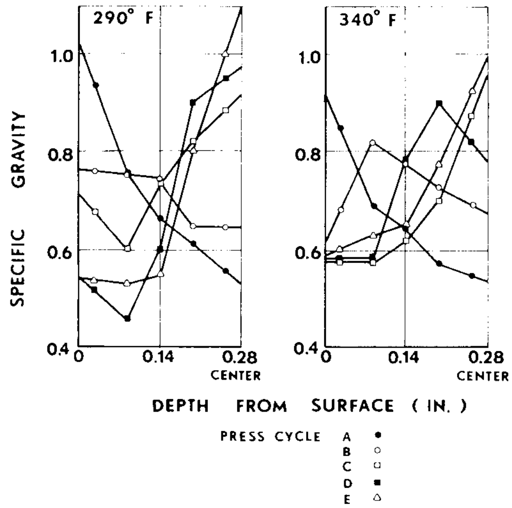

Fig. 4. Specific gravity distribution through the thickness of densified aspen produced at two platen temperatures. The density of five layers of each half-thickness was determined.

carried out in which, in both cases, the samples were equilibrated to 85% relative humidity and then brought back down to equilibration at 43% R.H. The difference between the initial and the final dimension at 43% R.H. was used as the measure of springback.

A single soaking cycle was also run on aspen produced by the different press cycles. In this case the specimens were equilibrated to 43% R.H., soaked for three weeks, oven dried, and reconditioned to 43% R.H. The difference between dimensions at 43% R.H. was considered as springback.

It is recognized that heat treatments generally reduce the hygroscopicity of wood. The difference between the equilibrium moisture content (EMC) of the densified aspen and normal air-dried aspen is shown in Fig. 5. All data points are for material conditioned to 43% R.H. A portion of the difference at the first 43% R.H. condition after pressing is due to hysteresis, the densified wood adsorbing to this point and the normal wood desorbing. That press cycle D affects the EMC more than the other cycles may reflect the fact that this cycle required the longest drying time, 150

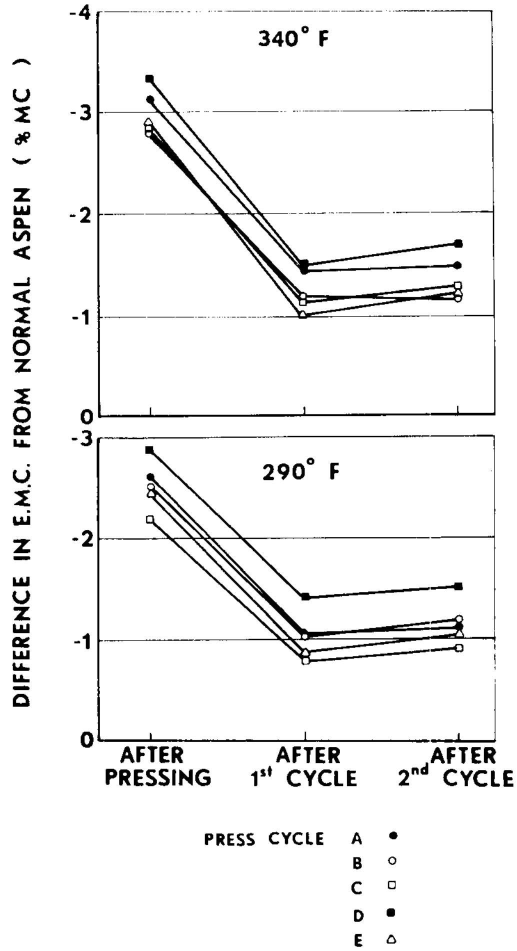

Fig. 5. The difference in equilibrium moisture content between densified aspen samples and controls for material produced with two platen temperatures. All points are equilibrated at 43% relative humidity.

minutes at 340 F. This is compared to 73 minutes for cycle A and 75 minutes for cycle B. After cycling, there was a 1 to 2% lower EMC for the densified material than for the controls.

The swelling in thickness and width which develops in densified aspen when conditioned to 43% R.H. and then subjected to two humidity cycles is shown in Fig. 6. Differences between the dimensions at the three 43% R.H. conditions will be termed springback, though it should be recognized that a portion of the difference

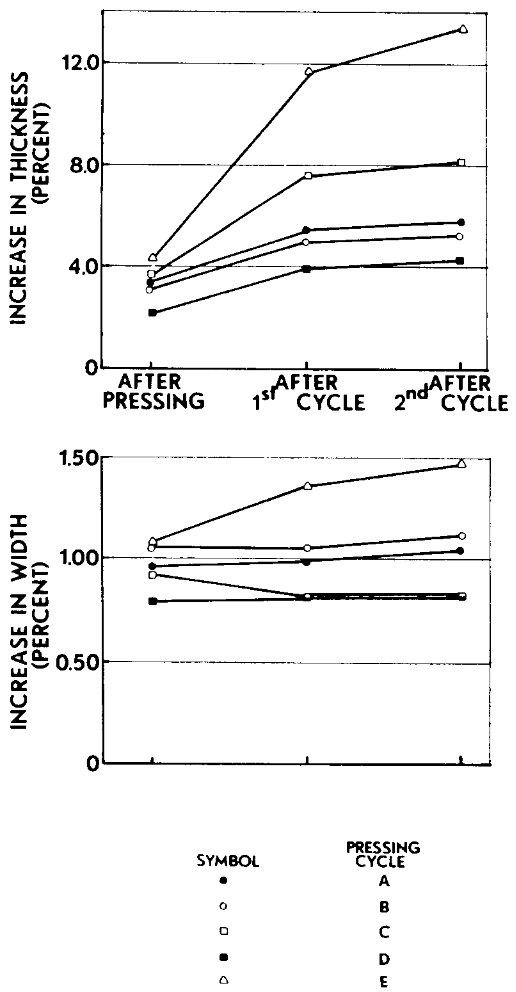

Fig. 6. Swelling of densified aspen samples produced by the five-press cycles with a platen temperature of 340 F. The per cent increase in dimension is based upon the initial oven-dry condition after pressing. All points are at equilibrium with 43% relative humidity.

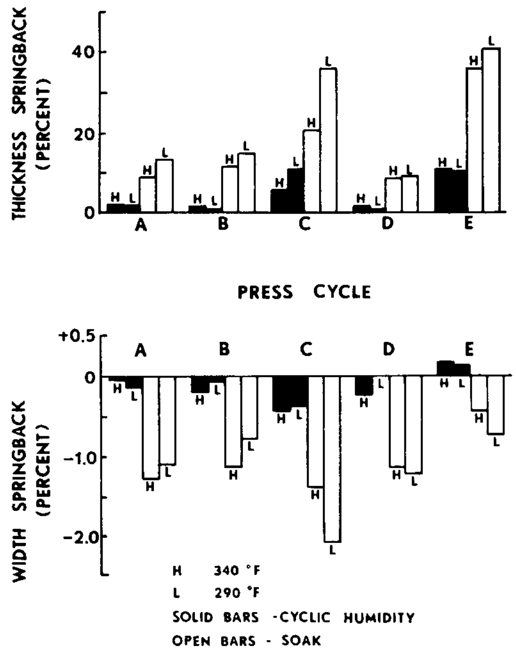

Fig. 7. Thickness and width springback of densified aspen samples subjected to cyclic humidity and soak treatments. The samples were densified from a thickness of 1.00 inches to 0.55 inches.

results from the change in EMC as shown in Fig. 5. Materials produced by cycles A, B, and D behave in a similar manner, while cycles C and E produce material which is much less stable. Results for material pressed at 290 F are similar to those shown in Fig. 6 for 340 F.

The most serious dimensional problem in a densified wood product is springback. The amount of springback in thickness and width exhibited by aspen when subjected to a water soak and to cyclic humidity is shown in Fig. 7. In width the springback is generally negative, i.e., the board becomes narrower, presumably because of the relaxation of set produced during drying. There is a pronounced difference between the dimensional stability produced by the different press cycles. Cycles A, B, and D produce the most stable product. Cycle D is not, however, a practical cycle for most applications because of the relatively low surface density produced. There is not a great deal of difference between the stability of boards produced at 340 F and those produced at 290 F.

The amount of springback in A, B, and D resulting from humidity cycling is small enough to be of little practical significance for many interior uses. Springback resulting from 43% to 85% humidity cycling is less than 2% in thickness and 0.2% in width. Under severe moisture conditions including soaking, however, the amount of thickness springback would be prohibitive for many

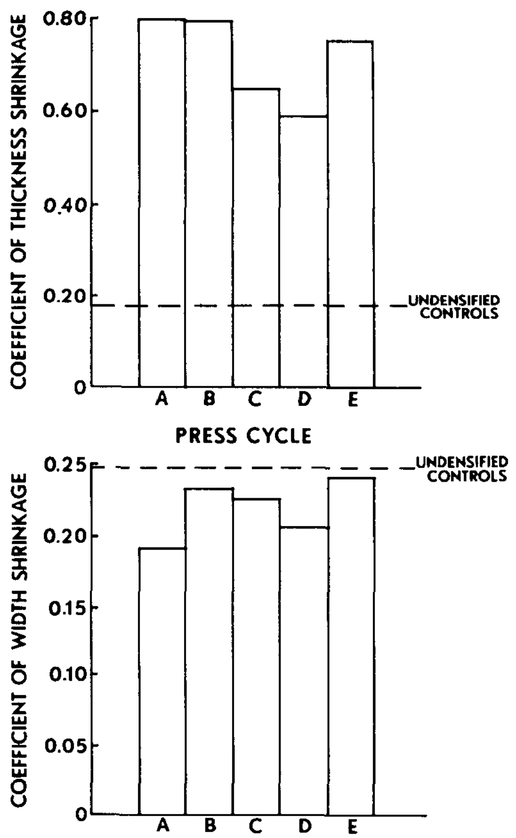

FIG. 8. Coefficient of shrinkage for densified aspen produced by the five press cycles with a platen temperature of 340 F.

applications. Thickness springback from soaking ranges from 9% for material A to 40% for material E. Width springback, even after soaking, is generally less than 1½%.

A coefficient of shrinkage (% dimensional change per % moisture content change) was determined from the shrinkage of the specimens during the final desorption cycle of 85% R.H. to 42% R.H. This is essentially normal reversible shrinkage since most of the springback has been removed by this time. The results of these tests are shown in Fig. 8. In thickness, the coefficient of shrinkage is about four times as high for the densified material as for the matched undensified aspen used as controls. The specific gravity was less than doubled in producing these particular samples, being increased from 0.38 for the controls to 0.70 for the densified samples. In the width direction, the coefficient of shrinkage for the densified wood is slightly less than that of the matched undensified aspen controls.

EFFECT OF TREATMENT WITH PHENOL FORMALDEHYDE RESIN

In an attempt to improve the dimensional stability of the product, the addition of a resinoid was investigated. Phenol resin of a molecular size small enough to enter the cell wall is known to act as a dimensional stabilizer because of bulking and perhaps cross-linking. It was felt that when present in small quantities, it might be even more beneficial in reducing springback because of a physical restraint effective in preventing the recovery of collapsed cells.

Green aspen sapwood samples were end-coated and soaked in undiluted phenol formaldehyde resinoid for 16 and 72 hours. In a sample containing 10 specimens, the 16-hour treatment resulted in a resin solids content, based on dry wood weight, of 6.1 to 10.7% with an average of 8.0%. The 72-hour treatment with matched samples resulted in a resin solids from 9.3% to 15.3% with an average of 12.4%. Resins solids content was determined from the change in the oven-dry density of the sample. Weight gain during soaking does not provide a good measure of the resin pickup because of loss of moisture by diffusion. After soaking, one-half of the samples were immediately densified, using cycle A and a platen temperature of 340 F. The other samples were wrapped and stored at room temperature for 120 hours prior to densification.

Samples treated in the above manner and also end-matched, untreated, densified controls were run through a soak test and one humidification cycle in the same manner as described for untreated aspen. The springback resulting from these conditions is shown in Fig. 9. Note the appreciable reduction in thickness springback caused by soaking resulting from the resin treatment. Resin treatment without storage

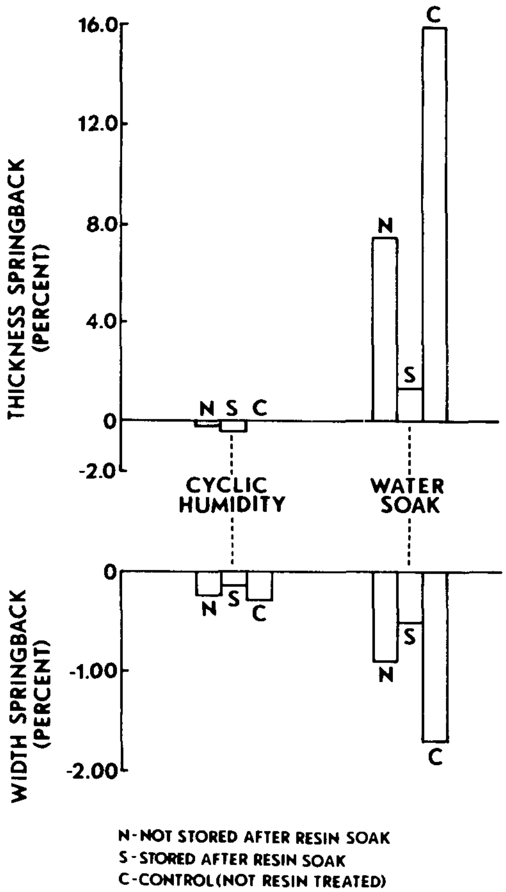

FIG. 9. Springback in aspen impregnated with phenolic resin prior to drying and densification.

reduced thickness springback to about 50% of that in untreated material. The combination of resin treatment plus storage was much more effective, reducing thickness springback from water soak by over 90%. Resin treatment had a less pronounced effect on width springback resulting from a soak. The results in Fig. 9 are averages for samples from both the 16- and 72-hour soak. Since the correlation between resin content level and reduction of springback was found to be statistically insignificant, values for all resin content levels in the 6.1% to 15.3% range were combined.

The resin treatment had much less effect upon springback resulting from humidity cycling than upon that from

FIG. 10. Matched undensified and densified aspen samples. Note the defect which developed as a result of impermeable tissue. The specific gravity is shown.

the soak test. It had a moderate effect upon the amount of reversible shrinkage determined from the desorption cycle 85% R.H. to 43% R.H. The results in Table 2 show about a 25% reduction in shrinkage due to a resin content averaging 10.2%.

Soak tests to determine the effect of resin treatment on springback were also run on Norway pine and loblolly pine. Results are shown in Table 3. The effectiveness of 8% resin in reducing springback is very pronounced, as it was in aspen. The results at the two density levels in Norway pine show the increase in springback as the degree of densification is increased. The results with the pines compare closely with those found in aspen.

APPEARANCE AND OCCURRENCE OF DEFECTS

The method of simultaneous drying and densification appears to work well on highly permeable sapwoods. The species

TABLE 2. *Shrinkage from EMC at 85% R.H. to 43% R.H. Aspen densified to 0.70 sp. gr. using cycle A*

	Thickness	Width
Untreated densified aspen	4.2%	1.2%
Resin treated, not stored	3.6%	0.9%
Resin treated and stored	3.3%	0.9%

studied[4] were aspen, Norway pine, jack pine, loblolly pine, baldcypress, yellow poplar, and tupelo. In species where heartwood is sometimes not easily detected, defects often developed if heartwood was accidentally included in the stock being densified. The sapwood of the species tested was consistently dried and densified without defect except in aspen. Fig. 10 shows such an aspen sample with an impermeable zone which became defective. Occasional pieces of white aspen which appear in every way to be sapwood do develop defects. A considerable number of tyloses were noted in many of these defective pieces. The heartwood of loblolly and Norway pine, tupelo, yellow poplar, and aspen can sometimes be compressed without defect; however, the per cent of success is generally rather low.

[4] Acknowledgment is made to Georgia Pacific Corp., Savannah, Georgia and Russellville, South Carolina for providing the southern species.

The type of defect which develops in heartwood appears similar to honeycomb. It is generally accompanied by a darkening of the wood evidently due to the high temperatures developed in these impermeable zones. On some occasions, the impermeable wood which may still be wet when the press is opened will partially recover to the original thickness. If the same piece is dried until the moisture content is below 2%, serious honeycomb but little recovery develops.

The material used in this process must be clear and relatively straight grained. In this study, the largest pieces produced were six inches by twenty-four inches. Thickness of the boards produced ranged from 0.30 to 0.75 inches. In drying and densifying these largest pieces, it is important that they be left in the press until below 1% moisture content. If they are removed at a higher moisture content, cup or bow will often develop. Care must also be taken to cool the samples uniformly from both surfaces to avoid cupping. Cupping appears to be no problem on material less than 3 inches wide, although 6-inch widths will remain flat if the above precautions are taken.

There is occasionally some brown staining developed in pine samples when dried and densified at 340 F. This problem was

TABLE 3. *Springback resulting from a 14-day soak*

	Ave. Green M.C.	Ave. % Resin solids[2]	Ave.[3] specific gravity	Ave. % springback[1] Thickness	Ave. % springback[1] Width
	Loblolly pine				
Untreated control	92%		.76	14.3	−1.1
End matched resin treated samples (with storage period)	93%	8.2	.81	2.0	−0.2
	Norway pine				
Medium density untreated control	145%		.55	20.2	−0.6
Medium density resin treated (with storage period)	150%	8.5	.59	0.8	−0.6
High density untreated control	138%		.80	40.5	−0.9
High density resin treated (with storage period)	142%	8.1	.86	4.2	−0.3

[1] Springback determined from O.D. dimension before and after soaking.
[2] Treatment was by a 24 hour soak.
[3] Ave. green Sp. Gr. of the loblolly pine—0.50.
Ave. green Sp. Gr. of the Norway pine—0.39.

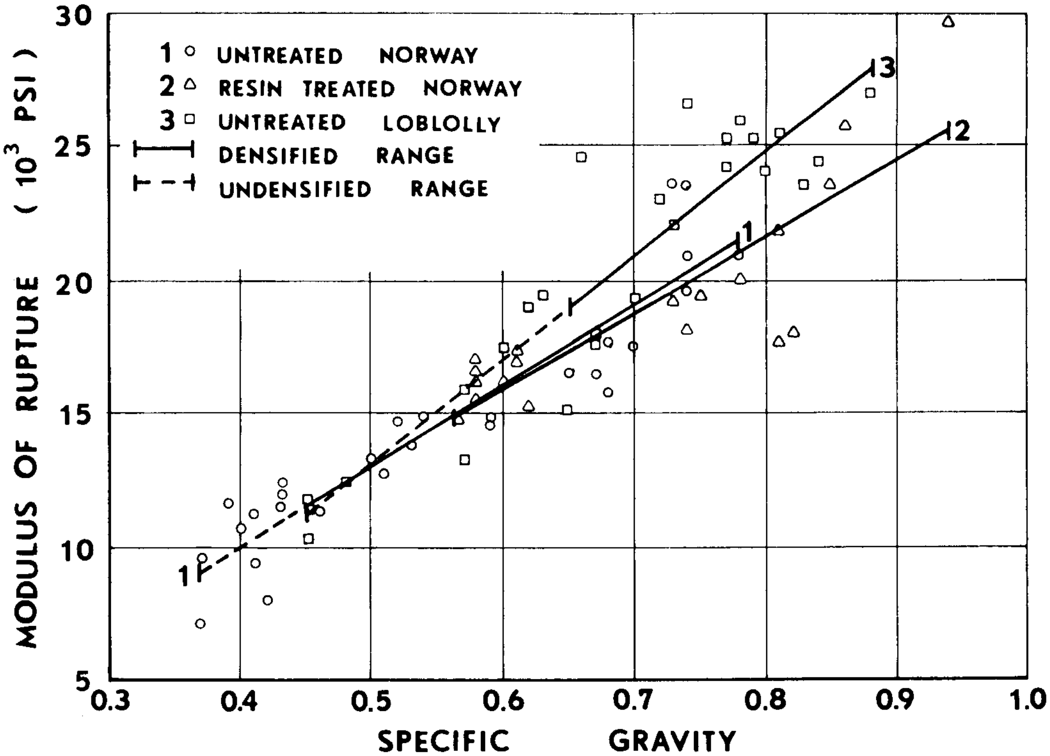

FIG. 11. Modulus of rupture of densified and undensified Norway and loblolly pine as related to specific gravity.

overcome by using a press temperature of 290 F. There is slight darkening of untreated wood, which is primarily a surface effect removable by light sanding. Treatment with the phenolic resin seems to eliminate any browning or darkening of the wood. The samples which were resin treated remained brighter in all species than did the samples which were not treated. The phenolic treatment gives the sample a light yellowish cast which, after sanding, is not greatly different from untreated wood. The resin-treated samples have a hard glossy surface when removed from the press.

MECHANICAL PROPERTIES OF DENSIFIED WOOD

Most strength properties of compreg and staypak have been shown (Seborg et al. 1962) to be approximately proportional to the increase in specific gravity. An exception to this is with phenolic resin-treated material which generally has (Stamm 1964) a lower Izod impact strength and toughness than untreated material of a similar density. In some cases, impact strength of resin-treated densified material has been found to be even less than that of the undensified wood.

A series of tests was run to determine the effect of simultaneous drying and densification on the bending strength and hardness of Norway pine and loblolly pine. Ten end-matched Norway pine test specimens were cut from each of five boards. From each board two bending samples were cut from undensified wood, four from densified wood, and four from resin treated densified wood. The level of resin treatment was 8% solids. The specific gravity of the densified stock varied from 150% to 200% of that when green. In loblolly pine, bending specimens were cut from eight boards.

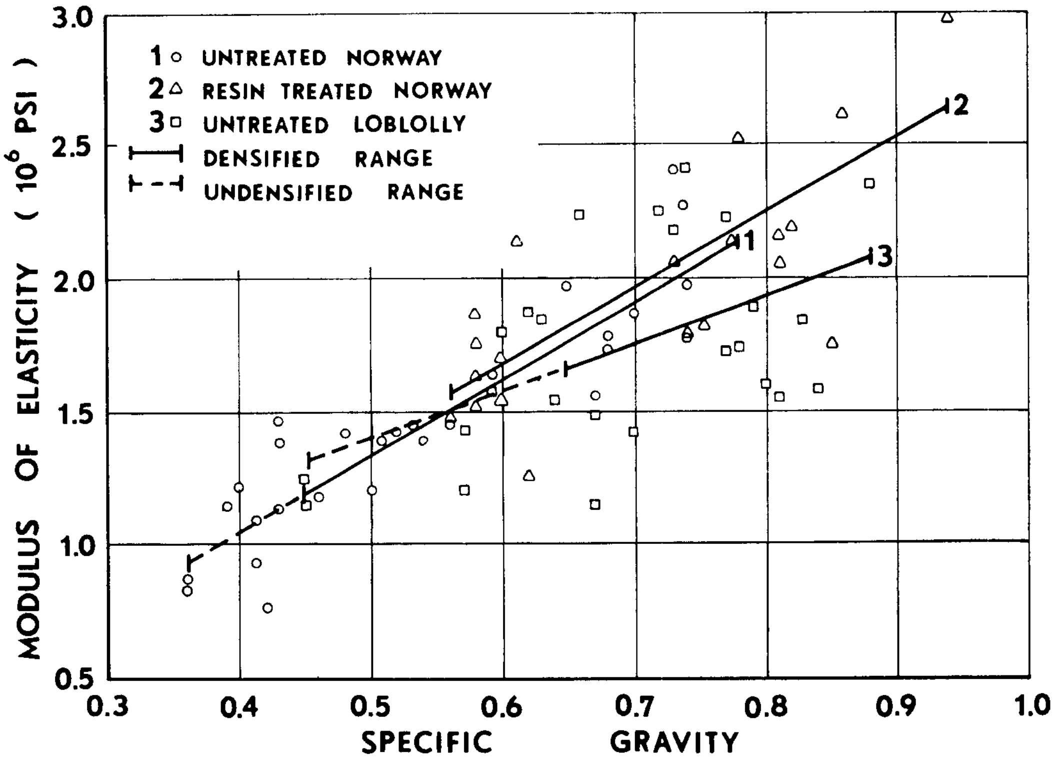

FIG. 12. Modulus of elasticity in bending of densified and undensified Norway and loblolly pine as related to specific gravity.

These were not end matched. Eight undensified specimens and sixteen densified specimen were tested. None of the specimens were resin treated, and the degree of densification varied from 150% to 200%.

All the densified material in these tests was produced under press cycle B with a platen temperature of 340 F. The material was conditioned to a constant relative humidity prior to testing. The moisture content of the densified material was thus lower than that of the air-dried undensified controls. This effect was previously discussed. The average moisture content of the controls was 9½%, as compared to 7% for the densified wood. The bending tests were conducted on small specimens 0.4 inches by 1.0 inches over a 5-inch span. A modified Janka hardness test was used, the modification being that the load was read after penetration of 0.200 inches rather than the customary 0.222 inches. Only side hardness was determined.

The modulus of rupture results are shown in Fig. 11. The range of density of the controls and the densified material is indicated. The data for both normal and densified wood were combined to establish the regressions for untreated material. Individual regressions for normal and densified wood appeared similar, though the small number of samples makes any statistical comparison of slopes of doubtful value. In all tests the strength-density relationship appeared to be linear. Note that at various specific gravity levels, there is little difference between the two species and little difference between the resin-treated and untreated samples. There is no statistically significant difference. A doubling of specific gravity more than doubles the modulus of rupture.

Modulus of elasticity in bending is shown in Fig. 12. The results here are similar to those regarding the MOR. The correlation coefficient between specific gravity and

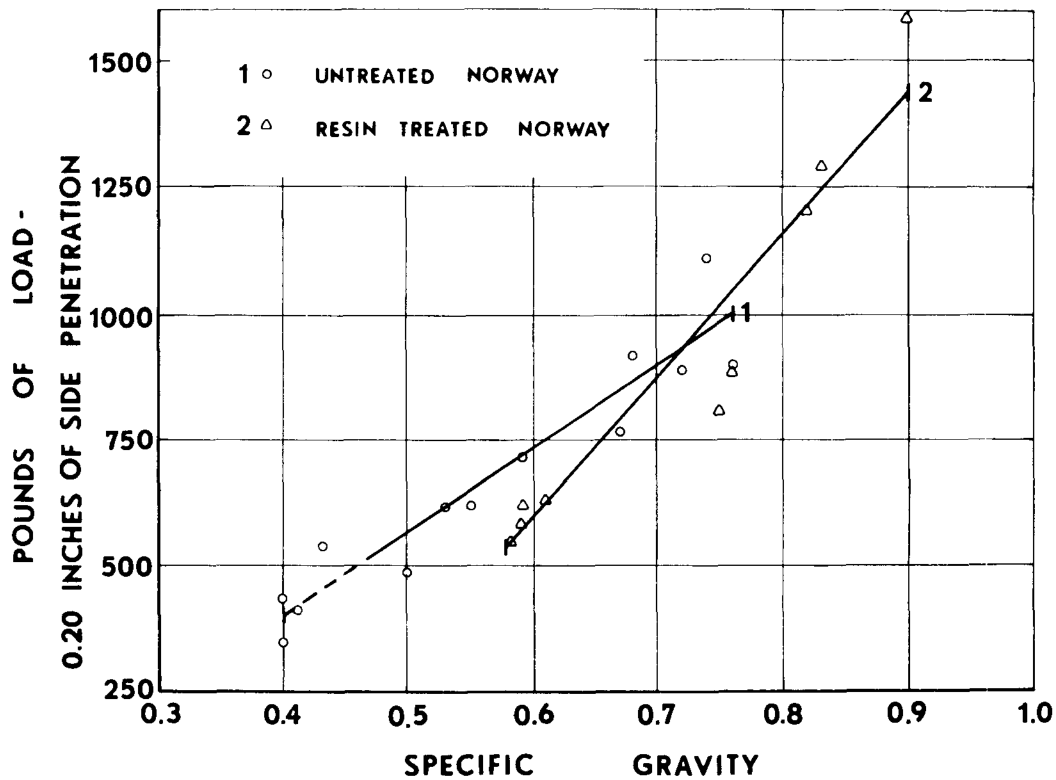

FIG. 13. Hardness of resin treated and untreated densified Norway pine. Obtained from a modified Janka test.

MOE was somewhat lower than between specific gravity and MOR. The relationship was linear, however. There is almost no difference between resin-treated and untreated samples at any density level.

The resin-treated sample exhibited brittle fractures, as compared to a normal type of fracture for the untreated-densified material. This fact is reflected in the work-to-maximum-load values for the three categories of Norway pine. These results were:

	specific gravity	in. lb./in.^{3}
undensified	0.41	12.2
densified—		
medium density	0.53	17.4
high density	0.71	25.0
resin-treated and densified—		
medium density	0.59	13.0
high density	0.81	15.8

No toughness or impact tests were conducted.

Results of the hardness tests on Norway pine are illustrated in Fig. 13. Again the treated and untreated stock shows similar characteristics at comparable density levels. It is likely that the hardness vs. density relationship is exponential, but because of the small number of tests a linear plot was used.

COST OF THE PROCESS

One feature of this process for densification of green sapwood is the potentially low manufacturing cost involved. It has been suggested (Haygreen and Turkia 1968) that under certain conditions, the cost of platen drying may be no higher, in some cases less, than the cost of kiln drying lumber which is to be cut into furniture dimension. This could be true only for species which can be platen dried without

TABLE 4. *Estimated costs of manufacturing based upon operation 8 hrs/day–250 days/yr. annual production of 800 M sq. ft. (95 minute press cycle)*

Equipment cost		
20 opening 4 × 8 press with automatic loaders and unloaders		$110,000.00
Caul transfer and unloading equipment		49,000.00
Steam plant		5,000.00
Humidity chamber equipped with controls		15,000.00
Stock transfer equipment		20,000.00
Installation of equipment		40,000.00
Total capital costs		$239,000.00
Operating costs		
Fixed		Annual
Insurance (.50/$100)		$ 1,195.00
Maintenance (2%)		4,780.00
Property taxes (2%)		4,780.00
Total annual fixed operating costs		$ 10,755.00
Variable		
Labor (4 men/shift)		$ 28,000.00
Power: electric (.50/M sq. ft.)		
steam (2.50/M sq. ft.)		
Total $3.00/M sq. ft.		2,400.00
Total annual variable costs		$ 30,400.00
Total annual operating costs		$ 41,155.00
Annual capital costs @ 8% interest & 10 yr. depreciation ($239,000 × capital recovery factor)		$ 35,618.00
Net annual cost		$ 76,773.00/year
Cost per M square feet of product $\left(\frac{\$76,773}{800}\right)$		$95.97/M sq. ft.

defect, and where high production levels result in low unit costs for capital investment. The costs of simultaneous drying and densification would be only moderately greater than for platen or kiln drying alone. The added cost would result from the higher pressure needed on the press and in some cases a slightly longer press cycle.

If a market existed for this product to the extent of 800 MBF per year, it is estimated (Table 4) that the manufacturing cost would amount to about $96.00 per M square feet. This does not include the cost of the wood or any overhead expenses. This estimate is based on the assumption that a 20 opening 4 × 8 press would be operated by four men for one shift a day with material that can be dried and densified in about 95 minutes. A 95-minute press time is adequate for most boards pressed to ½ inch final thickness or less when using a platen temperature of 340 F.

It is estimated that the unit manufacturing cost could be reduced to about $57.00 per M square feet if the press were operated three shifts per day. The normal cost of kiln drying aspen is about $40.00 to $45.00 per M square feet of cut-stock if a grade of lumber which provides a 50% yield is being dried.

The cost of the phenolic resin for treating the stock to an 8% solids content would amount to about $39.00 per M square feet. This estimate is based on the use of 300 pounds of resin with 62% solids per M square feet at a cost of $0.13 per wet pound.

The handling and equipment cost for treating should not exceed \$12.00 per M square feet. The total cost of the phenolic treatment would thus amount to approximately \$51.00 per M square feet. Some additional equipment maintenance costs might also be involved for clean-up of resin squeeze-out.

SUMMARY

1) A method of simultaneously drying and densifying green sapwood is described. The process to obtain uniform densification consists of:

a) Heating green sapwood in a platen press until the core temperature reaches 212 F.

b) Compressing to the desired final thickness and holding thickness until the moisture content is below 1%.

c) Conditioning the product under moderate humidity conditions to the desired final moisture content.

2) If high surface densification is desired, the press should be closed to desired thickness without the preliminary warm-up of the material.

3) If greater resistance to springback is desired than that possessed by untreated stock, a steeping treatment with a phenol formaldehyde impregnating resin is beneficial. The treatment should be followed by a storage period and then simultaneous drying and densification as described above.

4) Heartwood cannot be consistently compressed free of defects. Sapwood in aspen occasionally develops defects, but in other species tested the sapwood gave consistently good results.

5) Some of the dimensional stability characteristics of the simultaneously dried and densified boards are:

a) The product has slightly lower coefficient of reversible shrinkage across the width than does normal wood, but in the thickness direction the coefficient is several times as great as in normal wood.

b) Springback due to two humidity cycles from 43% R.H. to 85% R.H. amounts to 1 to 2% in thickness. Almost all springback is recovered on the first humidification cycle. A soaking treatment causes 10 to 15% thickness springback. There is also some slight negative springback in width.

c) A treatment with 8% phenolic resin followed by an adequate storage period prior to pressing reduces the springback from soaking by about 90%. There is a less pronounced effect on changes due to humidification.

d) The densified material has a 1 to 2% lower EMC than normal sapwood.

6) Boards with density levels from 0.60 to 1.00 can be produced to provide a range of strength properties.

a) The bending strength and bending modulus of elasticity of simultaneously dried and densified pine sapwood are about proportional to the density.

b) Pine which is treated with phenol formaldehyde resin prior to densification has about the same bending strength and hardness as untreated material of the same density.

c) Hardness increases more rapidly with increases in density than does bending strength.

7) Assuming it is possible to operate a multiopening press one shift per day on a 95-minute cycle, it was estimated that the cost of drying and densification would be about \$0.10 per square foot. This does not include the cost of wood or overhead. Higher production levels would lower the unit cost. The added cost of the phenolic treatment would be about \$0.05 per square foot.

8) It is important that the extent of defective material produced by simultaneous drying and densification be thoroughly studied for any type of wood being considered for this process.

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