IMPROVING THE PROPERTIES OF PARTICLEBOARD BY TREATING THE PARTICLES WITH PHENOLIC IMPREGNATING RESIN[1]

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ABSTRACT

Laboratory produced phenolic-bonded particleboard of both splinter and flake-type particles was studied. The effect of adding a phenolic impregnating resin to particles was compared to that of increasing the bonding resin content to an equal level of total resin solids. The original strength and strength retention were found to be similar for boards with a combination of impregnating plus bonding resin as compared to boards with an equal total solids content of bonding-type resin. The dimensional stability of boards containing the combination of phenolic resins was found to be considerably better than those with bonding resin alone. The impregnating resin was found to be much more effective in reducing swelling and springback when applied to wet rather than dry particles.

INTRODUCTION

Most methods that have been proposed to improve the performance of exterior particleboard exposed to severe moisture conditions involve either pretreatment of particles or post-treatment of boards. In commercial practice the performance of boards has been improved through process modification such as increased resin levels, modifications of the furnish, and control of forming and pressing operations. The adoption of some pre- or post-treatment by industry will probably depend upon the cost-effectiveness ratio of the treatments and the importance of improved durability in capturing new markets. In studying treatment methods, we felt is desirable to consider the treatments in relation to specific end uses. This study was conducted considering a combination siding/sheathing product as the ultimate goal. Although such particleboard products are now being produced, the potential of this market is just being scratched, particularly for manufactured housing and mobile homes.

Heebink (1967) points out that there are two types of uses for exterior particleboard, each with unique physical requirements. One class of use is in structural products where strength retention is of primary concern, and the other is in products where the uniformity, smoothness, and integrity of the surface are critical. Both strength retention and stable surface characteristics are important in products such as siding or underlayment designed to be used directly over framing members under severe moisture conditions. Particleboard products find much wider acceptance in industrialized housing systems when suitable for single-panel floor or wall construction. These systems generally do not use sheathing plus separate siding. The primary marketing competition in this application is and probably will continue to be plywood. Therefore, it may be advantageous to produce particleboard for this market that has engineering properties somewhat similar to those of plywood. Allowable design stresses cannot accurately be determined for particleboard until complete research results on long-term mechanical behavior of particleboard are available. It is likely that the time effect will be more severe in particleboard than in plywood. However, in designing with particleboard, the entire cross-sectional area will be considered rather than only the area of the parallel plies.

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Boards of 50 lbs per cubic foot were used in this study since we believe that the allowable stresses of such boards will be found to be similar to those of group 4 softwood plywood.

REVIEW OF LITERATURE

Two methods of post-treatment of boards have been shown to reduce significantly thickness swelling and springback. Heebink and Hefty (1969) describe treating boards with saturated steam at 360 F for from 2 to 20 min. Boards thus treated exhibited 30 to 50% less initial thickness swelling and 60 to 70% less thickness springback than unsteamed boards. A loss of up to 20% in strength resulted from the post-treatment, but the loss of strength during subsequent moisture cycling was only 30% for treated boards as compared to a 50% loss for untreated boards. The post-steaming treatment was not found to affect the linear stability of the boards.

Heat treatment of exterior particleboard was studied by Suchsland and Enlow (1968) and later confirmed by Heebink and Hefty (1969). They found that a 2-hr treatment at 425 F gave effective results that were quite similar to post-steaming for 10 min at 360 F.

Numerous methods of improving the properties of boards by treating particles before the boards are formed have been studied. These methods include heat treatment, steam treatment, acetylation, addition of polyethylene glycol, and addition of phenolic impregnating resin. Of these, the latter has been found to be the most effective and has been the one most often studied.

In an early study in this regard Maxwell et al. (1959) treated dry particles with 10, 30, and 50% levels of impregnating resin. They found that after six cycles of accelerating aging, the bending strength retention in these boards was not outstanding. In another early publication, Talbott (1959) produced a flakeboard with a high, i.e., 35%, phenolic-impregnating resin solids content. The properties of this product were somewhat similar to compreg. Talbott discussed the use of a range of impregnation levels to achieve any desired degree of stabilization. Lehmann (1964) tried a number of methods of stabilization, including the use of phenolic impregnating resin on particles. He did not use a bonding type of resin in addition to the impregnating resin, however, and a rather low strength board resulted. He, and many others, have studied the effect of different levels of phenolic-bonding resins and have shown a general improvement of board properties as resin levels increase.

More recently Brown et al. (1966) and Lehmann (1968) have studied more closely the effects of adding to the particles an impregnating phenolic resin. Brown impregnated dry particles with 10% solids using a patented process. In addition, 5% bonding phenolic resin was used. This product exhibited only about one-half the thickness swelling and one-half the springback of a control board containing only the 5% bonding resin solids. He found all springback to be eliminated at 25% impregnating resin solids content. Lehmann, in an extensive evaluation of weathering effects on commercial boards, also looked at a board with 4% phenol formaldehyde (PF) plus 2% impregnating phenol formaldehyde (IPF) resin. The addition of the IPF resin to a standard board of 4% PF produced improvement in all board properties after all types of exposure.

In a study of solid wood, Haygreen and Daniels (1969) found that when an IPF resin was added to green wood prior to simultaneous densification and drying, a very large reduction occurred in thickness and linear springback as compared to densified wood with no resin. Aspen treated with 8% IPF solids and densified to 0.70 specific gravity exhibited 1% thickness springback during a water soak cycle as compared with 16% for untreated controls. This great an effect would not be expected from cell-wall bulking provided by 8% resin solids. They believed that this effect was due to an internal restraint that prevents collapsed cells from returning to their initial cross-sectional shape when re-wet. Reversible swelling was found to be reduced about 25% by treatment with 8% IPF resin. This is about what would be expected as a result of cell-wall bulking. Linear springback under these conditions was negative, which is also the case with particleboard. The IPF-treated wood exhibited –0.4% as compared with –1.8% for untreated material.

OBJECTIVES

The effectiveness of phenolic impregnating resins in controlling swelling and springback of simultaneously compressed and dried solid wood (Haygreen and Daniels 1969) suggested that a similar effect might be found in particleboard when the impregnating resin was applied to wet particles. Preliminary tests showed this to be true (Haygreen 1969). To evaluate this means of stabilization, two series of tests were run, the first with splinter-type particleboards and the second with flake-type particleboards. There were three major questions that we hoped to answer:

1. Do particleboards containing phenolic impregnating resins perform better than boards containing equal amounts of resin solids exclusively of the bonding resin type?
2. Are the beneficial effects of the impregnating resin in proportion to the amount of resin used or are greater proportional effects obtained from a small amount of resin?
3. Does the moisture content of the particles at the time of application influence the effectiveness of the impregnating resin?

The board properties studied that we considered to be important to an exterior siding/sheathing board were:

Strength
- Modulus of rupture (MOR)
- Modulus of elasticity (MOE)
- Internal bond (IB)
- Loss in MOR, MOE, and IB due to a wetting cycle

Dimensional Stability
- Thickness swelling .... 50% relative humidity (RH) to 90% RH
- Thickness swelling .... 50% to wet
- Linear swelling .... 50% to 90% RH
- Linear swelling .... 50% to wet
- Thickness springback .... 50% to 90% to 50% RH
- Thickness springback .... 50% to wet to 50% RH
- Linear springback .... 50% to 90% to 50% RH
- Linear springback .... 50% to wet to 50% RH

Although surface roughness, impact strength, panel shear, and nail pull-out are also important for this type of product, we did not evaluate these characteristics.

PROCEDURE

All boards in this study were produced of aspen in our laboratory. The particles used for the homogeneous splinter boards were made of barkfree wood first chipped and then run in two passes through a 12-inch single disk refiner equipped with spike tooth plates. All fines generated in the process were utilized in the boards. The material for the homogeneous flakeboard was produced in a laboratory disk flaker and run through a hammermill to reduce width. Flakes averaged 0.015 inches thick and one-half inch long. The specific gravity of green aspen used for flakes and splinters ranged from 0.34 to 0.38.

It is apparent that the types of particles used were different from furnish found in any commercial product. Our aim was not to predict what the effect of the treatments would be if applied to a commercial board, but to obtain some basic information about the relative effectiveness of the treatments applied in two boards with radically different particle geometries.

All particles were dried at room temperature to about 5% moisture content. (MC). When necessary, the moisture level was increased by a water spray. Both bonding phenol formaldehyde (PF) resins and impregnating phenol formaldehyde (IPF)

TABLE 1. *Characteristics of the ½-inch-thick, homogeneous, phenolic, aspen particleboards studied*

Board designation	Particle type and size	Particle cutting by	Board density	Resin solids (% of dry weight) Total	Bonding[1] (PF)	Impregnating[2] (IPF)	% Moisture content of furnish when resin applied Impregnating resin	Bonding resin	Pressing conditions MC of furnish	Press temp	Time-to-stops (min)	Press time (min)
1				5	5	0	—	6 to 7	9–10	340 F	1.0–1.1	15
2		Labora-		10	10	0	—	5 to 6	10–11	340 F	1.0–1.1	15
3	Flake	tory		10	5	5	10	5 to 6	10–11	340 F	1.0–1.1	15
4	½″ ×	Flaker	50 lb	10	5	5	30	5 to 6	10–11	340 F	1.0–1.1	15
5	0.015″	and	per cu	10	5	5	85 (green)	5 to 6	10–11	340 F	1.0–1.1	15
6	by ran-	Ham-	ft	15	15	0	—	5 to 6	10–12	340 F	1.0–1.1	15
7	dom	mermill		15	5	10	10	5 to 6	10–12	340 F	1.0–1.1	15
8	width			15	5	10	30	5 to 6	10–12	340 F	1.0–1.1	15
9				15	5	10	85 (green)	5 to 6	10–12	340 F	1.0–1.1	15
10	Splinters plus fines	Single	45 lb	6	6	0	—	6 to 7	8–11	325 F	1.1–1.3	14
11	Max splinter size	disk refiner	per cu ft	12	12	0	—	6 to 7	8–11	325 F	1.1–1.3	14
12	⅝″ × 0.095″			12	6	6	112 (green)	6 to 7	8–11	325 F	1.1–1.3	14

[1] Bordens HL-69.
[2] Pacific Res. and Chem. Tybon 951.

resins were applied in a laboratory blender. The amount of water in the bonding resin formulation was adjusted so that the moisture content of the furnish was 10 to 11% when it entered the press. The 18 × 18 inch boards were not prepressed. No wax size was used in the manufacture of the boards since wax has generally been found to affect mainly the time of swelling but not the ultimate equilibrium conditions. In a commercial board containing an IPF resin, it probably would be beneficial to use a wax.

The IPF resins were sprayed on particles that were either green, at 30%, or at 10% moisture content. The 30% moisture content was obtained by spraying water onto dry particles and allowing it to diffuse for at least 30 min. After application of the IPF, the particles were bagged and stored overnight prior to being placed on screens for drying. In a commercial operation drying would need to be done at accelerated temperatures, but under time-temperature conditions that would not precure the resin. This obviously would require some careful design and control in the drying system. After the particles containing IPF resin were dried, the PF resin was applied.

Six per cent PF resin was used as the basic resin level in the splinter boards. Three 18 × 18-inch boards were made using 6% PF, 12% PF, and 6% PF plus 6% IPF resin applied to green particles for a total of nine boards. The only properties studied for these boards were MOR, MOE, thickness swelling, and thickness springback.

Five per cent bonding PF resin was used for all the flakeboards containing IPF resin. The amount of IPF resin added was either 5% or 10% solids. In this way, all boards contained either 5, 10, or 15% total (PF + IPF) resin solids. In addition, boards containing only 10% or 15% PF resin were made for comparison to the boards with combined PF plus IPF resins. Two boards were made of each of the board types 1 through 9.

The pressing conditions are shown in Table 1. We used the relatively short time-to-stops of about 1 min because, in a board for the purposes visualized here, we felt MOR to be of greater importance than internal bond and uniform density distribution. The press cycle was somewhat longer than necessary to cure the PF resin, but we felt it desirable to provide additional time for the IPF resin. Tests of IB in oven-dried samples showed a slightly higher strength than samples not oven-dried. This probably indicates that even the 15-min cycle was not adequate for complete cure.

The boards were conditioned to 50% relative humidity prior to cutting of test specimens. The equilibrium moisture content (EMC) of the boards at 50% RH and 72 F varied from about 5½% MC for boards with 5% resin to about 3½% for boards with 15% resin. The EMC at 50% RH was slightly higher after humidity or vacuum-pressure-soak cycling. Four specimens were used to determine each of the properties for each flakeboard type.

Strength tests were conducted using standard ASTM methods with only minor exceptions. A bending test width of 2¾ inches was used. Two-inch-square steel blocks and a hot melt adhesive were used for the internal bond tests. Samples were equilibrated to 50% RH before testing. For the strength retention tests, strips located adjacent to strips originally tested for strength were run through one wetting cycle and then oven-dried and reconditioned to 50% RH prior to testing.

Two types of moisture cycling tests were employed. In the first, samples were cycled once from an equilibrium at 50% RH to 90% RH to 50% RH, allowing equilibrium to occur at each step. In the second, samples were conditioned at 50% RH and then treated with one vacuum-pressure-soak (VPS) cycle. Samples were then oven-dried and reconditioned to 50% RH. Endicott and Frost (1967) and Heebink (1967) discuss use of the VPS test. The VPS test consists of a 22-inch vacuum for 30 min, followed by submerging in water under 40 psi for 22 hr. Other studies (Heebink and Hefty 1969; Jokerst 1968; Lehmann 1964) have utilized a series of humidity or VPS cycles in evaluating board properties. In most cases, however, the relative per-

TABLE 2. *Strength of particleboard before and after a VPS cycle*

Board designation	Total resin solids (%)	Impreg. resin (IPF) solids (%)	Particle MC when IPF applied (%)	Strength @ 50% rel. hum.			Per cent of strength lost during VPS	
				Modulus of rupture (psi)	Modulus of elasticity (10^6 psi)	Internal bond (psi)	Modulus of rupture (psi)	Modulus of elasticity (10^6 psi)
1	5	0	—	6720	0.887	145	29*	31*
2	10	0	—	7020	1.084	131	16*	22*
3	10	5	10	7170	0.995	195	18*	22*
4	10	5	30	6790	1.032	168	18	22*
5	10	5	green	6400	0.999	141	9	14*
6	15	0	—	8380	1.110	231	(2)	8
7	15	10	10	7790	1.125	226	2	9
8	15	10	30	6900	1.124	217	2	8*
9	15	10	green	6520	1.131	222	(3)	7*
10	6	0	—	3196	0.468			
11	12	0	—	4445	0.572			
12	12	6	green	4426	0.685			

( ) Indicates a gain in strength.
* Indicates that the loss is statistically different from 0 at the 95% level of confidence.

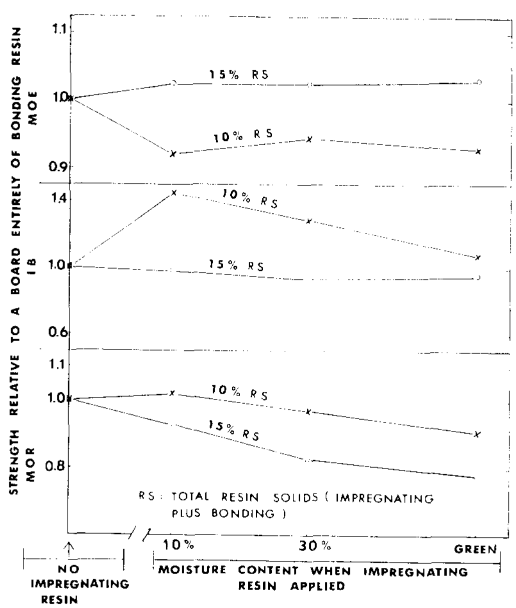

FIG. 1. The relative strength of boards produced with combination of bonding and impregnating resin as compared to boards only with bonding resin. Comparisons are at constant total resins levels. Note that the values plotted on the left vertical axis are for boards containing only bonding resin, i.e., no impregnating resin. Each plotted value is the average from 4 tests.

formance of various treatments after one cycle has not been shown to change greatly after subsequent cycling.

The dimensional characteristics of the splinter board were evaluated, utilizing a humidity cycle and a 3-hr boil test. No linear measurements or strength loss tests were made on the splinter board.

RESULTS

The results of the strength tests are shown in Table 2. In Fig. 1 a comparison between the initial strength of boards made exclusively with PF resin and those made with a combination of PF and IPF resin is shown. The results for boards containing both 10% and 15% total resin solids are included. Note that the 10% total solids boards were produced from 5% PF and 5% IPF resins, while the 15% total solids boards contained 5% PF and 10% IPF resins.

The MOE and IB varied with the total amount of resin used in the boards, but the form of the resin, i.e., PF or IPF, did not affect the strength greatly. The MOR for the 15% PF boards was somewhat higher than for the combination of resins. The

TABLE 3. *Some statistical comparisons*[1]

Property of the flake-type boards	Differences between resin levels 5% vs. 10% vs. 15%	Differences between bonding resin only (BR) and a combination of PF + IPF (CR) (applied at all moisture contents)—at the same total resin levels	Differences due to MC of particles when IPF applied (in boards made with combination of bonding and impregnating resins) @ 10% Total resin solids: 10% MC vs. 30% MC vs. green	@ 15% Total resin solids: 10% MC vs. 30% MC vs. green
Thickness swelling				
50% RH–90% RH	5 > 10 > 15	BR > CR	10 > 30 < green	10 > 30 > green
50% RH–VPS	5 > 10 > 15	BR > CR	10 = 30 = green	10 > 10 > green
Linear swelling				
50% RH–90% RH	5 = 10 = 15	BR > CR	10 > 30 = green	10 = 30 = green
50% RH–VPS	5 < 10 = 15	BR = CR	10 = 30 = green	10 = 30 = green
Thickness springback				
50–90–50	5 > 10 > 15	BR = CR[3]	10 > 30 = green	10 > 30 = green
50–VPS–50	5 > 10 > 15	BR > CR	10 = 30 = green	10 > 30 > green
Linear springback				
50–VPS–50	5 > 10 < 15	BR > CR	10 > 30 = green	10 > 30 > green
Original MOR	5 = 10 < 15	BR = CR[3]	10 = 30 = green	10 = 30 = green
Original MOE	5 < 10 < 15	BR = CR	10 = 30 = green	10 = 30 = green
Original IB	5 = 10 < 15	BR = CR	10 = 30 = green	10 = 30 = green
Loss in MOR from VPS	5 > 10 > 15	BR = CR	2	2
Loss in MOE from VPS	5 > 10 > 15	BR = CR	2	2
Loss in IB from VPS	5 > 10 = 15	BR > CR	2	2

[1] In this table ">" indicates that the adjacent board types are significantly different and the direction of the difference, while "=" indicates no significant difference in adjacent groups at the 95% level of confidence. Significant differences between groups not adjacent, for example 10% MC vs. green, or between combinations of groups, for example 10% MC vs. 30% + green are not shown.
[2] Sample size inadequate for meaningful statistical comparison.
[3] At 15% resin level only BR > CR.

statistical significance of differences between the various treatments is shown in Table 3. Analysis of variance combined with Scheffe's test for comparisons was used. The third column in this table compares the boards made exclusively of PF with those of PF plus IPF at all three MC levels of IPF application. These comparisons are at the same total resin levels. The only statistically significant differences in original strength are in modulus of rupture at the 15% total solids level. Here the specimens of 15% PF are stronger than those containing 5% PF plus 10% IPF. The

TABLE 4. *Dimensional changes in the splinter-type particleboards resulting from humidity cycling and a 3-hr boil*

Board designation	Total resin solids	Impregnating resin (IPF) solids	Changes in thickness: Humidity cycling (50% RH–90% RH–50% RH): % Swelling[1] (50–90)	% Springback[1]	3-hr boil test (O.D.–Wet–O.D.): % Swelling[1] O.D.–Wet	% Springback[1]
10	6	0	20.5	10.8	34	20
11	12	0	17.3	7.8	25	12
12	12	6	9.0	1.2	12	2.0

[1] The means in these columns are significantly different at the 95% level of confidence.

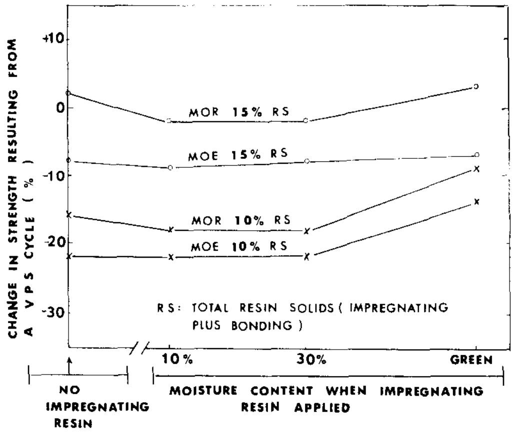

FIG. 2. The change in strength that results from one VPS cycle for boards with a combination of bonding and impregnating resins and with bonding resin alone.

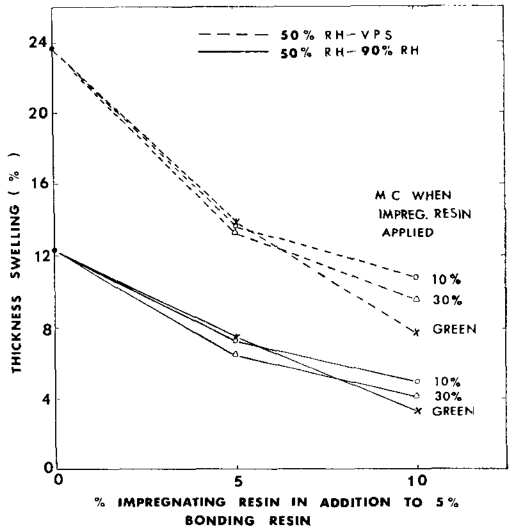

FIG. 3. The thickness swelling of boards with 5, 10, and 15% total resin solids. Each plotted value is the average of 4 specimens with 4 thickness measurements from each.

high degree of variability in the internal bond tests resulted in no significant differences, despite the fact that at the 10% total resin level the means for the boards containing a combination of PF and IPF are higher than the straight PF specimens. The fourth and fifth columns in Table 3 indicate the significance of differences resulting from the application of the IPF at different moisture contents.

The loss of MOR and MOE resulting from one VPS cycle is shown in Table 2 and Fig. 2. The asterisks indicate those cases in which there was a statistically significant change in strength. At 10% total resin solids, the boards containing IPF applied on green flakes showed considerably better strength retention than the other boards. At the 15% resin level, the loss in strength was about the same regardless of resin combination. As would be expected, the strength loss was dramatically reduced as resin content was increased. The internal bond (Table 3) was the only strength property tested in which the loss of strength for boards containing PF resin was significantly greater than for boards containing a combination of PF and IPF resin.

The thickness swelling and springback of the splinter boards are shown in Table 4. The boards with 12% resin, as would be expected, exhibited significantly less swelling and springback than the boards with 6% resin. Springback was taken as the difference between the initial and final dimension at 50% RH for humidity cycling or from oven-dry to oven-dry for the boil test. The important finding in these tests was the much greater effectiveness of the resin when applied as PF plus IPF resin, as compared to being applied entirely in the form of PF resin. The addition of 6% PF resin to a board already containing 6% PF resin reduced swelling by about one-fifth and springback by one-third, but addition of 6% IPF resin to green particles reduced swelling two-thirds and springback by nine-tenths. The MOE of the 12% PF + IPF board was greater than the 12% PF board, but the MOR was the same. No statistical comparison of the strengths was computed.

The dimensional behavior of the flake-type particleboard is shown in Figs. 3 through 7. The thickness swelling and thickness springback of boards containing 5, 10, and 15% total resin solids can be seen in Figs. 3 and 4. In all cases there is significantly more swelling and springback with 5% total resin than with 10%, and more at 10% than at 15% total resin. Also,

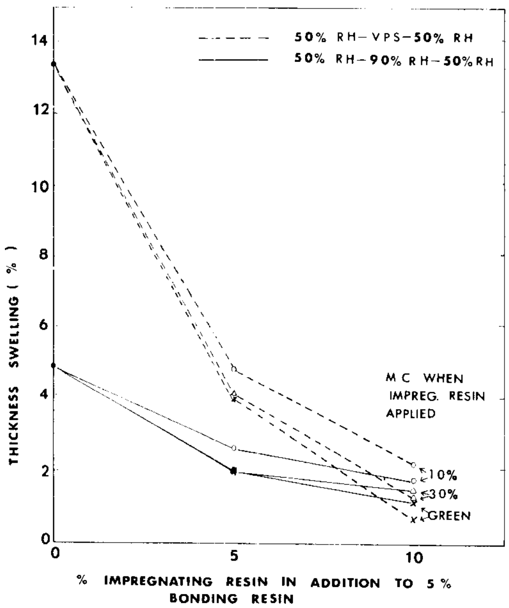

FIG. 4. The thickness springback of boards with 5, 10, and 15% total resin solids.

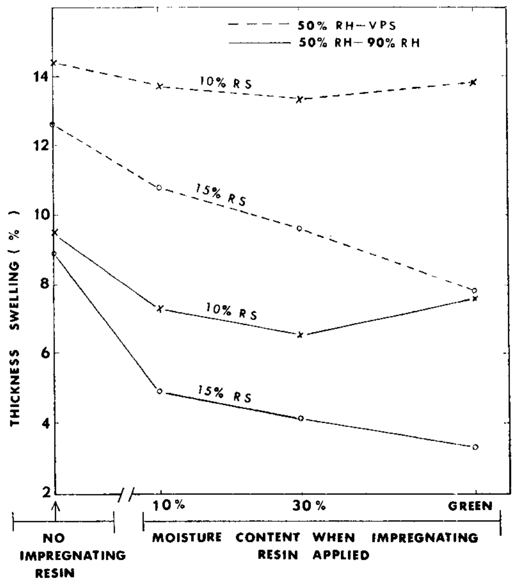

FIG. 5. Thickness swelling in boards with 10% and 15% total resin solids as a function of the type of resin and the moisture content at which the impregnating resin is applied.

the effect of the first 5% IPF resin (difference between 0 and 5% IPF) is considerably greater than the effect of the second 5% (difference between 5% and 10% IPF). This decreasing effectiveness of IPF as the resin level increases is more striking for springback than for swelling. It seems likely that if the IPF resin level were increased beyond 10%, the effectiveness in controlling thickness per unit of resin added would decrease further.

Thickness swelling for boards of 10% and 15% total resin content is illustrated in Fig. 5. In all cases the specimens containing only PF resin exhibited statistically greater swelling than boards containing a combination of PF and IPF resins. This was true regardless of the moisture content of the particles when the IPF was applied. In the specimens with 15% total resin, there was a significantly greater beneficial effect when the IPF resin was applied to green particles than when applied to particles at 10 or 30% MC. Further, the resin applied at 30% was significantly more effective than when applied at 10%. See Table 3 for the comparisons. At the 10% total resin level, the moisture content of the particles at the time the IPF was applied had little effect on the thickness swelling.

Springback was taken as the difference between the original and final thickness at 50% RH expressed as a per cent of the original thickness. The difference in thickness springback between PF boards and PF + IPF boards was much greater for samples run through the VPS cycle than for those subjected to humidity cycling. There was a statistical difference, however, for the 15% total resin specimens subjected to humidity cycling. For the three moisture content levels, the resin applied at 30% MC or green was significantly more effective in three of the four comparisons than when applied at 10% MC. The IPF resin applied to green particles was significantly more effective against springback in one of the four comparisons than when applied at 30% MC.

The linear swelling and linear springback of the flake-type particleboards are summarized in Fig. 7. A surprising result was that boards with 15% total resin did not always perform better in this respect than

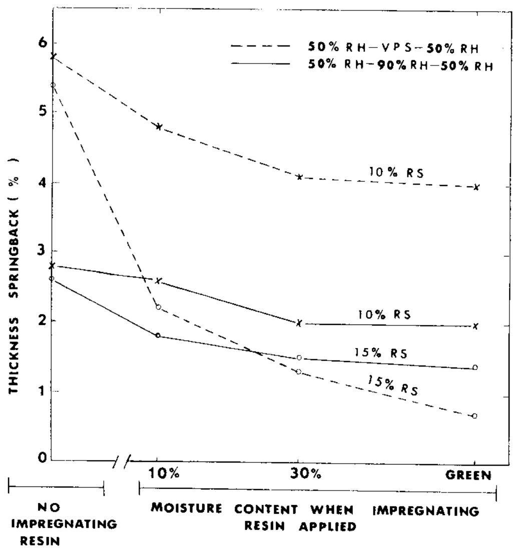

FIG. 6. Thickness springback in boards with 10% and 15% total resin solids as a function of the type of resin and the moisture content at which the impregnating resin is applied.

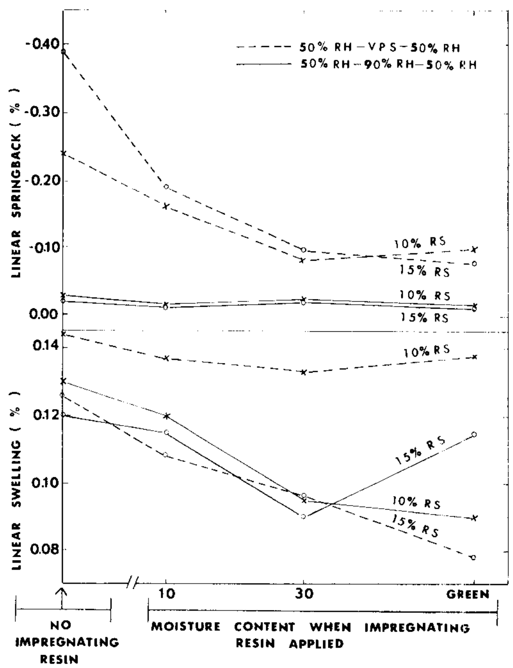

FIG. 7. Linear springback and shrinkage in boards with 10% and 15% total resin solids as a function of the type of resin and the moisture content at which the impregnating resin is applied.

those with 10% total resin. In fact, linear springback resulting from the VPS cycle was significantly higher for the 15% resin boards. The linear swelling of the PF samples was significantly greater than the PF + IPF samples when going from 50% to 90%. There was no such statistically significant difference, however, in going from 50% to wet (VPS). Linear springback from the VPS cycle was greater in the PF than in the PF + IPF samples. There was an advantage in applying the IPF resin to particles at 30% MC or green as compared to applying it at 10% MC.

SUMMARY

A well-known method of improving the behavior of exterior particleboard is to increase the amount of phenolic bonding resin used. In this study we found that if increased phenolic resin levels are used, there are advantages to utilizing a combination of bonding resin plus impregnating resin rather than bonding resin alone.

As far as original strength and strength retention are concerned, we found little difference between additional resin applied in the bonding and in the impregnating form. Additional PF resin may give a slightly higher initial strength than additional IPF, but the impregnating resin provides slightly greater strength retention during moisture cycling. In either form the additional resin provides a considerable increase in strength as compared to a board at a lower resin level.

The major difference between the PF and the PF + IPF boards at the same total resin level is in the dimensional stability of the product. As judged from the VPS cycle, the addition of 10% IPF to green particles in boards with 5% PF resin decreased thickness swelling by 86% and decreased thickness springback by about 95%. This compared to a reduction in thickness swelling of 45% and a decrease in springback of 67% when the same amount of PF resin was added. Differences were less dramatic at the 5% IPF resin level.

It appears that the effectiveness of IPF resin, per unit of resin, decreases as the resin level is increased. That is, the effect of increasing the amount of IPF from 0 to 5% is greater than when increasing it from 5 to 10%. Lehmann (1968) found significant advantages in adding only 2% IPF resin.

The moisture content of the particles at the time the IPF resin was applied was shown significantly to influence the dimensional stabilization that results. When it was applied to particles at 30% MC or green, the reduction in swelling and springback was greater than if applied on dry (10% MC) particles. There also appeared to be a slight advantage in applying the IPF resin on green particles as compared to particles at 30% MC.

There are some important differences between the effects of the pretreatment procedure studied here and post-steaming (Heebink and Hefty 1969) or post-heating (Suchsland and Enlow 1958). Addition of IPF resin increases strength to about the same extent as would be accomplished by using additional bonding resin. Post-steaming or post-heating results in a loss of strength. The use of IPF resins will provide greater strength retention during weathering than in a board of lower resin content. Post-steaming has also been shown to reduce the amount of strength lost because of weathering. It is impossible accurately to compare the dimensional stabilization resulting from IPF treatment with the results from post-treatment because of the differences in species, board density, and weathering conditions used in the various studies. Both pretreatment with IPF and post-treatment with steam or heat result in greatly improved thickness dimensional stability. The IPF treatment also has a beneficial effect on linear behavior.

The answer to the question of whether or not it will be practical to use either pretreatment or post-treatment to improve the behavior of particleboard will depend upon the effectiveness of the treatment, the cost, and the need for improved behavior. In this study we have tried to add to what is known about the effectiveness of pretreatment with IPF resins. We can offer little as to the costs involved. The main cost would be that of the additional resin. Manufacturing costs would be increased because of the necessity of an additional resin blender and a drying system capable of drying the treated particles without precure. However, the additional costs might well be justified if a specialty board was produced that was able to compete more effectively in the marketplace with plywood siding capable of use directly over studs.

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