A comparison of hardboards manufactured by semidry-, dry-, and wet-formed processes

Gary C. Myers

Abstract

The semidry-formed process was investigated as a possible alternative to the wet- and dry-forming processes of manufacturing hardboards. The objective was to improve performance and/or reduce the amount of resin required. A single wood species, aspen, was fiberized in a small pressurized refiner and used for all hardboard manufacturing trials. In addition to producing water-felted fiber mats, other mats were air felted at 65, 35, and 5 percent moisture content (MC). Fiber mats entering the hydraulic hot-press were either water saturated or had 65, 35, 25, or 5 percent MC. Mats felted and pressed from fibers with high MCs did have some liquid effluent from the hot-press, but nowhere near the quantity expelled from a wet-formed and wet-pressed fiber mat. No problems were encountered in air felting fibers with higher MCs, which also eliminated the dust hazard common to all dry-forming operations. At certain fiber MCs, there was a problem with the hardboard sticking to cauls and wires during hot-pressing. Sticking was not a problem with the wet- and dry-formed fiber mats. Strength properties of the semidry-formed hardboards fell somewhere between the wet- and dry-formed hardboards. Semidry-formed hardboards had resin requirements higher than needed for wet-formed hardboards, but lower than needed for dry-formed hardboards. A powdered phenolic resin was also tried with the semidry-formed hardboards, but the properties were poorer than hardboards manufactured with liquid phenolic resin.

The semidry process for manufacturing hardboard has not been the subject of much research (7, 10, 11). Only one plant was built (about 1950) for manufacturing semidry-formed hardboard (2, 4), and it has recently closed for economic reasons.

Z.F. Rachmat researched the semidry-process as part of his master's degree program at the University of Wisconsin, and had very encouraging results (9). Unfortunately, he used dry fiber which had to be rewet in order to obtain a higher mat moisture content (MC), a condition which would not be encountered in a hardboard plant. He also used an impregnating-type phenolic resin manufactured specifically for dry-formed hardboard production.

The semidry-formed process offers several potential advantages over other processes. The large volumes of water necessary for wet forming will not be required, eliminating expenses for handling and cleaning this water before discharge. A higher fiber MC should reduce the dust and explosion hazard that is always present with dry fiber. It might also be possible to shorten hot-pressing time by taking the fiber directly from the pressure refiner cyclone, felting a mat, and sending it into the hot-press without any additional drying, and minimal fiber cooling. Heat retained by the fiber should speed up heat transfer to the hardboard interior.

The objective of this study is to examine a wide range of MCs, resin contents, and resin types for the manufacture of high-density hardboard by the semidry process, attempting to reduce the amount of phenolic resin needed to produce an acceptable quality hardboard.

Materials and methods

Pulpwood processing

Aspen (*Populus tremuloides* Michx.) pulpwood was the raw material. All bark was removed and the pulpwood chipped in a commercial-sized four-knife chipper. Chips were screened and all materials greater than 1-1/2 inches or less than 1/4 inch were discarded. The chips were placed in polyethylene-lined barrels and stored at 40°F until needed for fiberizing.

Fiber preparation

Aspen chips were fiberized in an 18-inch, single-disk pressurized refiner equipped with coarse plates. Chips were steamed for 10 minutes at 302°F, refined at

---

The author is a Research Forest Products Technologist, USDA Forest Serv., Forest Prod. Lab., One Gifford Pinchot Dr., Madison, WI 53705. This paper was received for publication in June 1985.

Forest Prod. J. 36(7/8):49-56.

the same temperature, blown from the refiner, and dropped into a polyethylene-lined barrel. Plate gap was adjusted to produce fiber with approximately a 25-second drainage rate. No water was added to the fiber during or after refining. Fiber was stored at 40°F until needed for hardboard manufacture.

Resins

Three commercially available phenolic resins were used in manufacturing hardboards. One was a high molecular weight liquid resin which had been specifically developed for the manufacture of wet process hardboard. The second was a slightly alkaline, medium-advanced, liquid resin designed for the dry and semidry hardboard process. This resin was used to manufacture all of the dry- and semidry-formed hardboards. The third was a finely pulverized, modified phenolic powdered resin developed especially for use as a binder in the molding of wood-flour and sawdust. This resin was only used in the manufacture of the semidry-formed hardboards.

Resin application

Each type of phenolic resin required a different application procedure. For wet-formed hardboard, enough fiber for a single hardboard sample was weighed out, placed in a container, and diluted with soft, cold water. While stirring the pulp slurry, we added the proper amount of liquid phenolic resin and 314 percent wax emulsion and mixed thoroughly. The next additions to the slurry were 1 percent alum and enough sulfuric acid to lower the slurry pH to between 3.5 and 4.0, which caused the acid-sensitive phenolic resin and wax to precipitate onto the fiber. For damp and dry fiber, enough liquid phenolic was weighed out to give the desired amount on an ovendry fiber basis, and this was sprayed onto the fiber as it tumbled in a rotating drum. Tumbling was continued for 5 minutes after resin application to enhance dispersion on the fiber. The same rotating drum was used to apply powdered phenolic resin. The powdered resin was dumped into the treating drum and mixed with the damp fibers for 15 minutes. After resin treatment, the damp and dry fibers were vacuumed from the treating drum, which effectively dispersed fiber balls formed during tumbling.

Fiber drying

Whenever fiber MC had to be reduced prior to forming a fiber mat, the loose fiber was poured into a drying frame, placed in a convection oven heated to 250°F, and dried to a desired MC. Whenever mat MC had to be reduced after forming and prior to pressing, the prepressed fiber mat was placed on a wire-covered metal frame, which was placed in a convection oven heated to 220°F, and dried until a predetermined mat weight was reached. This lower temperature was chosen to avoid curing out the resin while removing excess moisture.

Mat formation

Two different procedures were utilized to form fiber mats for wet-formed, and for semidry- and dry-formed hardboards: 1) wet-formed hardboards were formed by dumping the fiber-water slurry into a 20- by 20-inch screen-bottomed metal forming box, where the water was drained away and a fiber mat formed on the screen; 2) semidry- and dry-formed fiber mats were formed on a mechanized banjo former, which consists of strings placed 114 inch apart over a 14- by 14-inch box. Resin-treated fibers placed on the mechanically agitated strings were physically separated and air felted into a mat.

Cold- and hot-pressing

All fiber mats were cold-pressed prior to hot-pressing, using the same pressure and pressing time - 100 psi on the mat surface for 1 minute. Effluent squeezed from the wet-formed and high MC semidry-formed hardboards was drained to the sewer.

The fibrous mat was consolidated, dried, and resin cured in a steam-heated platen press. To eliminate one variable, we pressed all hardboards with the same temperature (375°F) and pressure cycle (500 psi mat for 1 min., 100 psi mat for 2 min., and 500 psi mat for 3 min.). After hot-pressing, we heat-treated hardboards for 1 hour in a convection oven heated to 320°F.

Six 1/8- by 20- by 20-inch hardboards were manufactured for each wet-formed condition evaluated, and six 118- by 14- by 14-inch hardboards for each semidry- and dry-formed condition. We cut each set of 6 wet-formed hardboards to yield 24 specimens for strength testing and 48 specimens for evaluating dimension and weight change. Because of the smaller hardboard size, each set of 6 semidry- and dry-formed hardboards yielded only 15 specimens for strength testing, and 30 specimens for evaluating dimension and weight change.

Hardboard evaluations

Evaluations of static bending, tensile strength perpendicular to surface, and tensile strength parallel to surface were made after the hardboards were conditioned for 30 days at 50 percent relative humidity (RH) and 73°F, using test procedures specified in ASTM Standard D 1037-72a (1). The only exception to the ASTM standard was dimensional stability, which was determined on 1/2- by 6-inch specimens conditioned for 30 days at 50 percent RH and 73°F, followed by exposure to one of the following: 1) conditioning at 90 percent RH and 80°F for 30 days, 2) immersing in water for 30 days, and 3) drying in an oven at 220°F for 72 hours. Length, thickness, and weight changes were determined before and after exposure to each condition.

Statistical analysis

An analysis of variance was performed to determine if the means for strength and dimension change were the same for the 24 sets of hardboard samples made for this study.

Results and discussion

Presentation of results

Resin content, resin type, fiber MC at time of forming a mat, and fiber MC at time of hot-pressing were intentionally varied during hardboard manufacture (Table 1). Other variables in the boardmaking operation were held constant whenever possible. Obviously, different forming procedures had to be used for wet-formed and for the semidry- and dry-formed fiber mats.

TABLE 1. – *Boardmaking variables, hardboard thickness, and basis weight.*

Resin		Fiber MC at		Hardboard	
Content	Type	Forming	Pressing	Thickness	Basis weight
(%)		------------ (%) ----------		(in.)	lb./1,000 ft.^{2}
0		Slurry	Saturated	0.127	611
1	Liquid	Slurry	Saturated	.126	619
1	Liquid	65	66	.120	571
1	Powder	64	65	.118	574
2	Liquid	65	66	.119	574
2	Powder	64	66	.121	587
1	Liquid	65	35	.112	569
1	Powder	65	35	.113	547
2	Liquid	65	35	.113	571
2	Powder	63	35	.114	557
1	Liquid	65	25	.110	577
1	Powder	64	25	.112	569
2	Liquid	64	25	.111	580
2	Powder	64	25	.117	580
1.5	Liquid	34	34	.113	586
1.5	Powder	35	35	.115	576
3	Liquid	34	34	.112	577
3	Powder	34	34	.112	577
1.5	Liquid	33	25	.116	563
1.5	Powder	36	25	.114	576
3	Liquid	34	25	.112	562
3	Powder	33	25	.110	568
2	Liquid	5	5	.148	564
4	Liquid	6	6	.129	564

Regardless of forming procedures, all hardboards were prepressed, hot-pressed, and heat-treated the same. Screens were used during hot-pressing for all but the two driest fiber mats.

Average hardboard properties for each of the 24 sets are presented in Figures 1 through 7, as bar graphs, to facilitate comparisons between hardboard sets. These figures contain more information than just the physical property. Along the *x* axis is information on MCs at time of forming and pressing. Above the MCs are listed resin contents (in weight percent). Results are also separated by resin type (liquid and powdered phenolic).

Several statistical analyses were performed on the results. One-way analysis of variance showed that the means for each property (density, modulus of rupture, modulus of elasticity, tensile strength parallel to surface, internal bond, linear change between 50% and 90% RH, and thickness change between 50% RH and water soak) could not be considered statistically equal for the 24 sets of hardboards ($p < 0.0001$ for each property). Tukey's multiple comparisons (8) were used to determine which sets were different. Because there were unequal sample sizes in each set, the results could not be easily tabulated. Summaries of the results are given in the appropriate section. The error used to compare sets was the board-to-board variation, if this was larger than within-board variation. Multiway analysis of variance was used to determine which underlying factors (resin type, resin percent, or MC at pressing) might influence property values for two groups of data (MC at forming –65% and MC at forming –35%). This was not successful because there were significant second and third order interactions for many variables. Some of these interactions might be due to an unbalanced experimental design.

Hardboard manufacturing observations

There were three noteworthy occurrences when manufacturing wet-, semidry-, and dry-formed hardboards: 1) effluent flow during hot-pressing; 2) sticking to cauls and wires; and 3) ease and cleanliness of forming a fiber mat.

Hot-pressing wet-formed hardboards always produces a heavy flow of contaminated water from the fiber mat as the press closes to thickness. A much lighter water flow issued from fiber mats pressed at 65 percent MC. The semidry-formed hardboards did leave a residue coating the cauls, wires, and hot-press platens. This coating was, immediately thought to be phenolic resin which migrated from the fibers during hot-pressing, since the resin had not been precipitated as done in wet-forming. A film of cured phenolic resin would have been very difficult to remove, but this residue was hot-water soluble and easily washed from the metal surfaces. Apparently this residue was water-soluble sugars generated during fiber preparation (5, 6) and never washed from the fibers. This aspen fiber was analyzed to contain 70 percent total sugars.

Certain semidry-formed hardboards stick to the cauls and wires after hot-pressing (5). This problem did not occur routinely with all hardboards, but seemed to be especially severe for hardboards hot-pressed at 35 percent MC, and occurred with both liquid and powdered resins. Except for isolated instances, sticking did not occur with any regularity at any other MC.

Forming (air felting) fiber mats with 35 and 65 percent MCs proved advantageous. We could form fiber mats in the laboratory without handling the large volumes of water required for wet-forming, or generating the dust that occurs during air-forming. It was possible to work in the laboratory without wearing a respirator and without having everything covered with a layer of fibers. Greater problems were anticipated in our efforts to air-felt high MC fibers. Surprisingly, the high MC fibers were no problem in forming mats in the banjo former. They readily separated on the vibrating strings and fell in snowfall fashion into a fiber mat.

Hardboard density

Hardboard densities differed little, except for dry-formed hardboards. Although not statistically significant, Figure 1 shows a very slight increase in hardboard density as MC at time of pressing decreases. This is not the same as Byrd (3) found with papermaking fibers, where paper density increased as MC at time of pressing increased. These differences are probably the result of fiber differences. Papermaking fibers have most of their lignin removed during pulping, have more flexibility, and have a greater affinity for water than do the lignin-encased hardboard fibers.

Few statistically significant differences in hardboard density exist, but dry-formed hardboards have significantly lower density than all other hardboards. The apparent cause of this lower density dry-formed hardboard was the higher caliper caused by excessive springback after hot-pressing (Table 1). Possibly the lower board density affected the dry-formed hardboard's

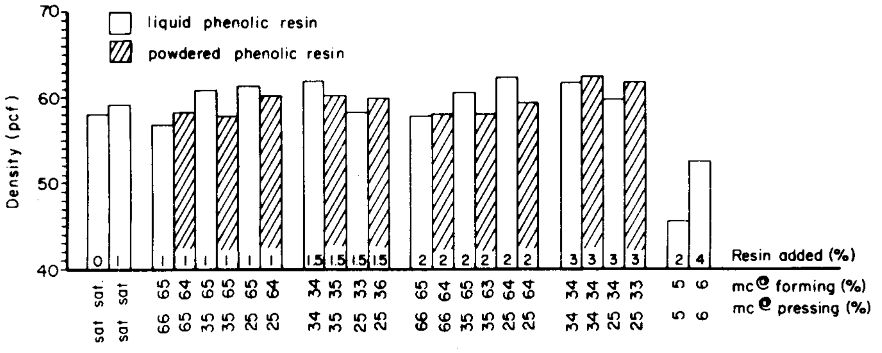

Figure 1. – Hardboard density.

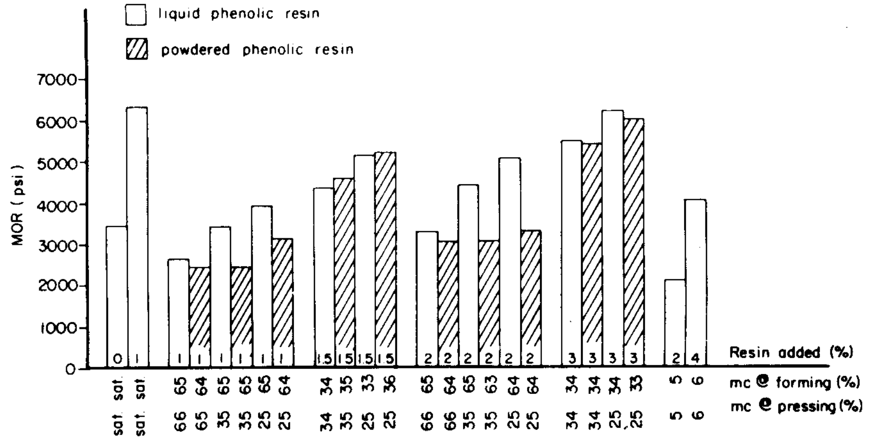

Figure 2. - Modulus of rupture (values not adjusted for density).

performance and should be kept in mind when examining other properties.

When examining the results presented in Figure 1, I question if increasing density is the result of decreasing MC alone, or does the increasing resin content have an effect? Because of a statistically significant interaction between resin content/resin type/MC at pressing, it is impossible to identify which variable is more important in determining hardboard density.

Modulus of rupture

When examining the modulus of rupture (MOR) results in Figure 2 (values not adjusted for density), observe that 1) wet-formed hardboards made with 1 percent resin content have the highest value and dry-formed hardboards made with 2 percent resin content have the lowest value (these values are statistically different from those of nearly all other hardboards); and 2) MOR increases as MC at time of forming and pressing decreases. When the MOR values for hardboards formed at 65 percent MC and those formed at 35 percent MC are examined as two distinct groupings, there is a gradual increase in MOR as MC decreases within these groupings at time of pressing. Differences between these two distinct groupings are significant.

Differences exist between hardboards manufactured with liquid and with powdered resins, especially for those formed at 65 percent MC. Hardboards formed at 35 percent MC have smaller differences between the liquid and powdered resins. Apparently the higher MCs at forming and pressing have an adverse effect on developing a high MOR. This seems to be caused by resin location on, or in, the fiber. High fiber MC probably wet the powdered resin enough to cause lumping, resulting in a poor distribution over the fiber surface. Since the liquid resin is soluble in eater, the high MC probably enhanced penetration into the fiber, leaving a resin-starved surface. Both conditions would have an adverse effect on developing high strength properties. Regardless of MC at time of forming or pressing, increasing the amount of liquid or powdered resin in the hardboard also increases the MOR, as expected.

The most obvious question has to be what caused this increase in MOR. Is it due to a decreasing MC either at time of forming or pressing, or is it entirely due to a change in the resin content? The presence of statistically significant interactions between resin content/MC at pressing, and also between resin contentiresin type/ MC at pressing makes it impossible to answer this question.

Because density is significantly lower for dry-formed hardboards, the MOR values for all hardboards were adjusted to a 60 pound per cubic foot (pcf) density. As would be expected, the biggest MOR change occurred in the dry-formed hardboards. The adjusted values were

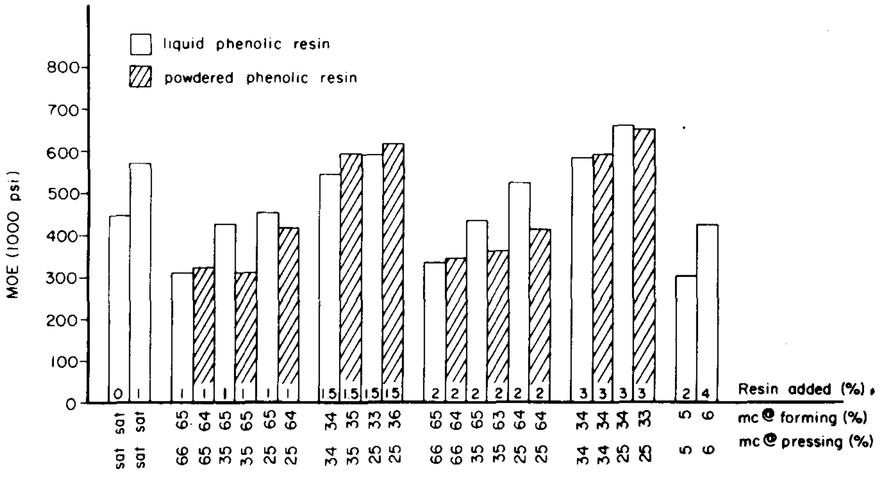

Figure 3. – Modulus of elasticity (values not adjusted for density).

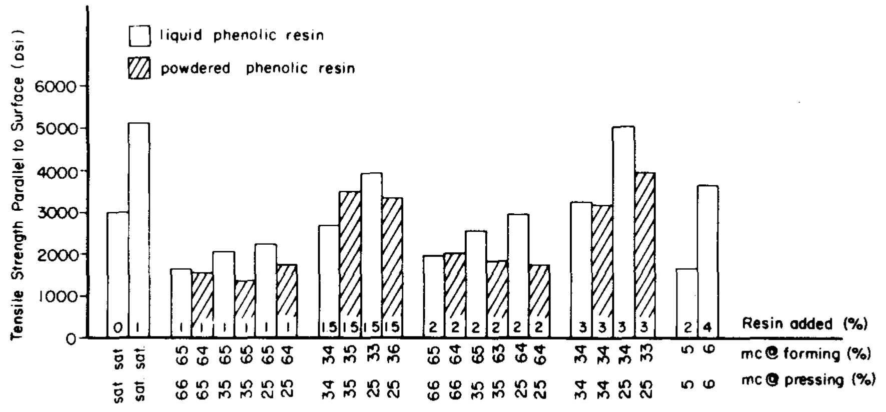

Figure 4. – Tensile strength parallel to surface.

submitted to statistical analysis, and no difference was found between the original and adjusted results.

Modulus of elasticity

Modulus of elasticity (MOE) increases as MC, at time of forming and pressing, decreases (Fig. 3) (values not adjusted for density). Some of the hardboards have MOE properties that are significantly greater than other hardboards. Nearly all of the hardboards formed at 35 percent MC and pressed at 35 and 25 percent MC have significantly greater MOE than do other hardboards. Hardboards formed at 65 percent MC with 1 and 2 percent liquid resin contents and pressed at 35 and 25 percent MC also have significantly higher MOE. The wet- and dry-formed hardboards fall between the extremes of semidry-formed hardboards, and are significantly different from nearly all of the semidry-formed.

Increasing resin content also increases MOE, as expected. However, only with wet- and dry-formed hardboards is the effect of increasing resin content statistically significant. Differences between liquid and powdered resins are minimal, and the only significant difference between resin types occurs in hardboards formed at 65 percent MC and pressed at 35 percent MC.

It is impossible to know for certain if the increases in MOE are due to changes in MC or due entirely to increasing resin content, because there is a statistically significant interaction between resin content/MC at pressing.

Because of the low densities obtained with dry-formed hardboards, and the presence of statistical significance, the MOE values were adjusted to 60 pcf density. As found with the MOR results, adjusting for density made the biggest change in dry-formed hardboard MOE. However, it did not make any difference in the relative ranking of one hardboard against another, nor did it make any difference in the statistical analysis results.

Tensile strength parallel to surface

Tensile strength parallel to the surface of semidry-formed hardboards falls between the strongest wet-formed and the weakest dry-formed hardboards, with one of the semidry-formed hardboards nearly equal to the wet-formed hardboard (Fig. 4). As found with previous strength properties, tensile strength increases as MCs at times of forming and pressing decrease. Most of the hardboards formed at 35 percent MC and pressed at 35 and 25 percent MC have significantly greater tensile strength than those formed at 65 percent MC and

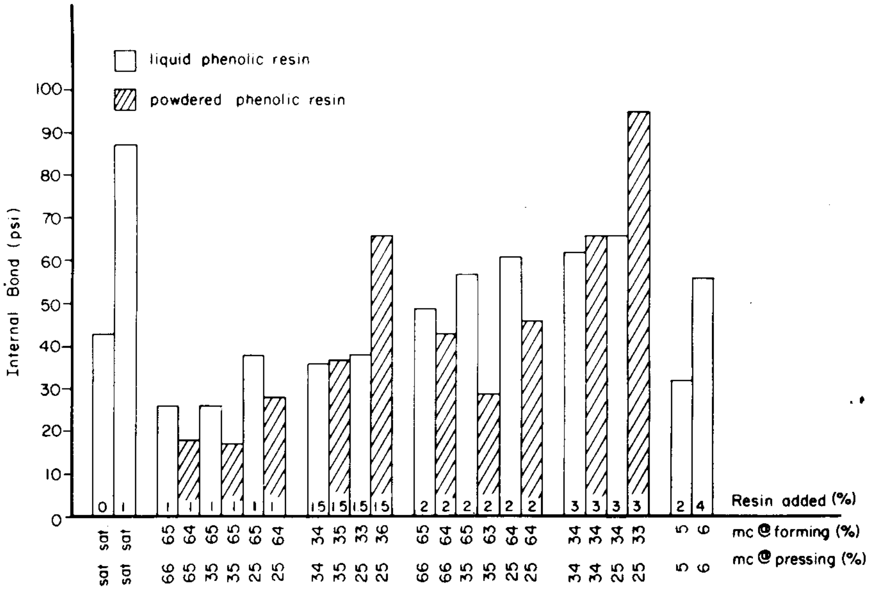

Figure 5. — Tensile strength perpendicular to surface (internal bond).

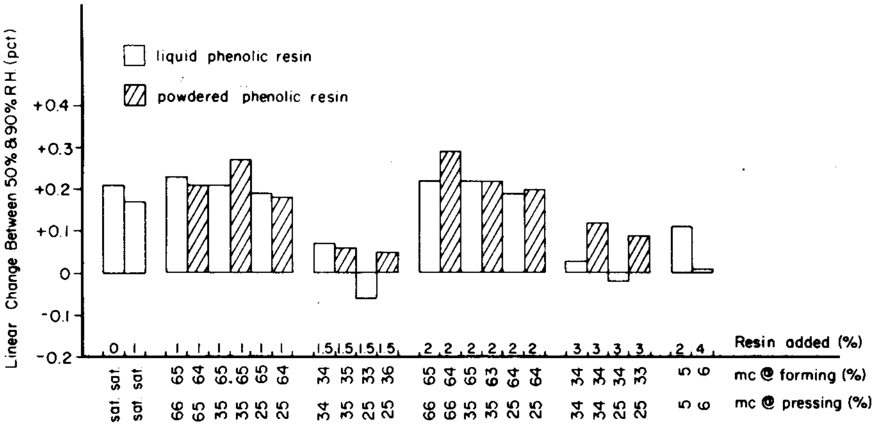

Figure 6. – Linear change between 50 and 90 percent RH.

pressed at 65, 35, and 25 percent MC.

As MCs decrease at times of forming and pressing, added resin contents of the hardboards increase. However, in addition to the wet- and dry-formed hardboards, there are only two instances where the increased added resin contents are significantly different. In nearly all instances, switching from a liquid to powdered phenolic resin results in a strength decrease, five instances of which are significant.

What might have caused the increasing tensile strengths as MC declined? MCs at the time of hot-pressing appear to be the most probable cause. MC at time of forming might be important, because strength properties increase for hardboards that have similar MCs at time of pressing and resin contents. However, the statistical analysis found no significant board-making variables or interactions of variables. Tensile strength parallel to the surface is only one of two performance properties which have no significant board-making variables.

Tensile strength perpendicular to surface (internal bond)

An overall trend, discernible in Figure 5, is a slight increase in internal bond strength as MCs decrease at time of forming and pressing. Again, the dry-formed hardboards are lower. Maximum strengths occur in wet-formed hardboards with 1 percent resin content, and those hardboards formed at 35 percent and pressed at 25 percent MC with 3 percent powdered resin content. These two hardboard sets are significantly higher than any of the other hardboard sets. Of all the strength properties, internal bond has less significant differences between hardboard sets than any of the strength properties.

Looking closer at the results in Figure 5, hardboards made with the same amount of liquid or powdered phenolic resin show only a slight, or in some instances, no increase in strength as MCs decrease at forming and pressing.

There are some fairly obvious differences between

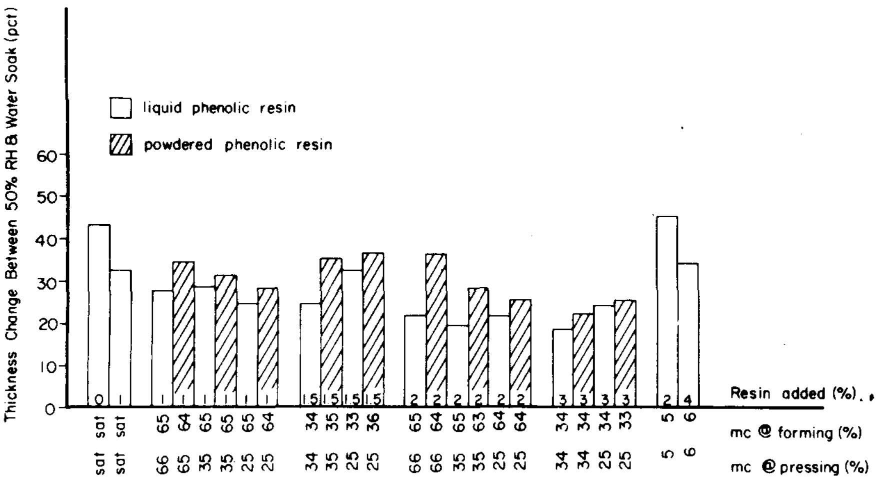

Figure 7. – Thickness change between 50 percent RH and water-soak conditions.

the liquid and powdered phenolic resins. Hardboards formed at 65 percent and pressed at 65 to 25 percent MC have higher internal bond strengths when liquid resin is used. However, just the opposite is true for hardboards formed at 35 percent MC, in which the powdered resin-bonded hardboards are the strongest. Statistically significant interactions occur between the boardmaking variables of resin content/MC at pressing, and resin content/resin type/MC at pressing.

Linear change between 50 and 90 percent RH

The magnitude of linear change decreases as MCs decrease at forming and pressing (Fig. 6). Hardboards with the most linear change were formed and pressed at 65 percent MC, and those with the smallest linear change were formed at 33 percent and pressed at 25 percent MC. Wet-formed hardboards have slightly less movement than the least stable semidry-formed hardboards, and dry-formed hardboards have slightly more movement than the most stable semidry-formed hardboards.

Differences in linear change of the group of hardboards formed at 65 percent, and the group of those formed at 35 percent MC are significant. When observations are narrowed to hardboards formed at 65 percent MC, changing the MC at time of pressing improved linear change some, but not significantly. Doubling the resin content had mixed results, sometimes helping and other times hurting the linear movement. Basically the same observations made for hardboards formed at 65 percent MC can be made for hardboards formed at 35 percent MC, where there is only one statistically significant difference.

Results presented in Figure 6 suggest that MCs at forming and pressing, and perhaps resin content, might be significant in controlling linear change. However, the statistical analysis showed a significant interaction between the boardmaking variables resin type/MC at pressing.

Thickness change between 50 percent RH and water soak

Two things are immediately evident from Figure 7: 1) most of the movement was in wet- and dry-formed hardboards, and 2) except for a few isolated hardboards, not much difference exists between the semidry-formed hardboards. The least amount of movement is in hardboards formed at 65 percent and pressed at 25 percent MC and those formed and pressed at 35 percent MC. These two groups of hardboards have thickness change values that are statistically significant from most of the other hardboards. At a constant resin content, reducing the MCs at time of pressing yielded mixed results. Sometimes thickness change is decreased and other times it is increased.

Most of the significant differences appear to be the results of resin type and resin content. Generally speaking, liquid is much better than powdered resin for thickness stability. This is probably caused by resin location. Liquid resin will penetrate more readily into the fiber and stabilize it. The powdered resin is soluble in solvents other than water, so it remains on the surface where it cannot stabilize the fiber. Doubling the resin content at the same forming and pressing MCs definitely improves stability. Many of these hardboards are significantly different from the others. However, thickness change is another property (the other is tensile strength parallel to surface) that has no significant boardmaking variables.

Conclusions

The following conclusions are drawn as a result of this study:

1. Fibers with high MCs are readily dispersed and air felted into uniform fiber mats;

2. Semidry-forming hardboards minimizes the major problems of wet- and dry-forming hardboards - water and air pollution;

3. Because of retained water-soluble sugars, some of the semidry-formed hardboards stuck to cauls and wires at certain MCs;

4. Strength properties of semidry-formed hardboards are lower than wet-formed hardboards, but higher than dry-formed hardboards;

5. Semidry-formed hardboards are more stable (linear and thickness change) than wet- or dry-formed hardboards;

6. Semidry-formed hardboards require more phenolic resin than wet-formed, but less than dry-formed hardboards;

7. There is no advantage to using powdered resin, in place of liquid resin, for semidry-formed hardboard.

Literature cited

1. American Society for Testing and Materials. 1972. Standard methods for evaluating the properties of wood-based fiber and particle panel materials. ASTM D 1037-72a. ASTM, Philadelphia, Pa.
2. Anonymous. 1953. New hardboard process. Chem. Eng.60(1).
3. Byrd, V.L. 1974. How much moisture is needed to develop strength in dry-formed handsheets? Tappi 57(4):131-133.
4. Evans, H.R. 1950. Hardboards from wood semi-dry process. Proc., Vol. 4, Forest Prod. Res. Soc.
5. Jansson, M.B. 1982. Hardboard quality when produced in closed white water systems. Forest Prod. J. 32(6):39-46.
6. Koran, Z., B.V. Kokta, J.L. Valade, and K.N. Law. 1978. Fibre characteristics of masonite pulps. Pulp and Pap. of Can. 79(3): T107-113.
7. Liiro, O. 1959. Manufacturing hardboard by dry and semi-dry process. I. Papper och Trä. 41(3).
8. Olive, J.D., and V.A. Clark. 1974. Applied Statistics. Analysis of Variance and Regression. John Wiley & Sons.
9. Rachmat, Z.F. 1975. High density hardboards produced by a semi-dry formed semi-dry pressed process. M.S. thesis. Univ. of Wisconsin, Madison, Wis.
10. Sandermann, W., and O. Kunnemeyer. 1956. Present status of the new dry and semi-dry fiberboard processes and experiments on their water-soluble components. Das Papier 10(13/14):287-294. Abstr. Bull. of Inst. of Pap. Chem. 26:974.
11. Solechnik, N.Y., and A.P. Shishkina. 1962. Theory and technology of the semi-dry process for the manufacture of fiberboards. Theoretical basis for the semi-dry process and factors affecting semi-dry (sheet) formation. Nauch. Tr. Leningr. Lesotekh. Akad. 98:11-18. Abstr. Bull. of Inst. of Pap. Chem. 33:427.