DIMENSIONALLY STABILIZED, VERY LOW DENSITY FIBERBOARD[1]

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ABSTRACT

In this study, fiberboards with a specific gravity ranging from 0.2 to 0.5 were made using acetylated, steam-treated, and untreated fiber. In all boards, dimensional stability increased as specific gravity decreased from 0.5 to 0.2. Fiberboards made from acetylated fiber were more dimensionally stable than boards made from steam-treated fiber at all specific gravity levels tested. Steam-treated fiberboards resulted in a 15% weight loss of hemicelluloses and some loss of lignin and extractives. Boards with a specific gravity of 0.2 had a low modulus value, which was probably due to poor adhesion between fibers.

Keywords: Low density, fiberboard, acetylation, steaming, dimensional stability, thickness swelling, physical properties.

INTRODUCTION

Fiberboards with a specific gravity ranging from 0.8 to 1.28 are usually referred to as high density hardboards and are generally used in products where surface hardness and high levels of strength are important to the performance of the product (McNatt and Myers 1993). Fiberboards with a specific gravity ranging from 0.5 to 0.88 are designated as medium density fiberboards (Forest Products Laboratory 1987). These boards have a wide application for both structural and nonstructural uses.

Fiberboards with a specific gravity ranging from 0.16 to 0.5 are referred to as low density fiberboards, commonly called insulation board, and are used for nonstructural applications, such as sound and thermal insulation (ANSI 1985). Fiberboards at the low end of this specific gravity range (i.e., 0.2 to 0.3), termed very low density fiberboards, could have applications for insulation, packaging, filters, or lightweight core materials (Myers and McNatt 1985). Very low density fiberboard technology

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lends itself to steam injection pressing or treating a fiberboard in a press with other types of gaseous chemicals. Recycled wood-based fiber and many types of agro-based fiber can also be used to produce very low density fiberboard. For example, Sellers et al. (1993) described the production of a very low density fiberboard (specific gravity 0.26) using kenaf core.

The Japanese have published extensive data on particleboards with a specific gravity ranging from 0.3 to 0.5 (Imamura et al. 1986; Kawai and Sasaki 1986; Kawai et al. 1986a, b). Their results showed that very low density particleboard improved dimensional stability, bending stiffness, bearing force, water resistance, thermal and sound insulation, and fire resistance when compared with medium density particleboard, specific gravity 0.7 to 0.8 (Kawai and Sasaki 1989).

Even greater levels of dimensional stability are possible through chemical modification technology (Yoshida et al. 1986) or steam treatment (Inoue et al. 1991, 1993) of the fiber before board formation. Dimensional stability, wet strength and stiffness, and water repellency are important in light-weight packaging and containers.

The purpose of this research was to produce very low density fiberboard using acetylation and steam treatments to improve dimensional stability and to determine physical properties of boards in dry and wet conditions.

EXPERIMENTAL

Acetylation

Oven-dry aspen fiber was reacted as described by Rowell et al. (1986) with the following modifications. The fiber was placed in a stainless steel mesh cylinder that was placed inside a stainless steel reactor; the reactor was closed; the container was rotated. Acetic anhydride, preheated to 120 C, was introduced into the reactor until the fiber was saturated with chemical. Excess anhydride was drained and returned to the holding tank. The treated fiber was rotated and heated at 120 C for 2 h, after which a vacuum was applied to the reactor for 3 h at 120 C. Excess acetic anhydride and byproduct acetic acid were collected from the bottom of this reactor. The acetylated fiber was removed from the mesh container and oven-dried again for 12 h at 105 C. The weight percent gain as a result of acetylation was calculated based on the weight of oven-dry unreacted fiber.

Acetyl content on untreated and acetylated fiber was determined by gas chromatography of acetic acid produced by deacetylation of ground and mixed samples with sodium hydroxide solution.

Steaming

Steam treatment was conducted as described by Inoue et al. (1993) with the following modification. Steaming was done on aspen fiber in an autoclave that was preheated to 200 C. High pressure steam was introduced into the autoclave at 16 kPa for 4 min. The pressure was reduced for 1 min; then the fiber was removed.

Fiberboard production

Untreated, acetylated, or steam-treated aspen fiber (air-dried laboratory moisture content, approximately 30% relative humidity [RH]) was sprayed with an isocyanate resin adhesive. A 20% acetone (based on resin solid weight) was added to the concentrated resin to reduce its viscosity. Each batch of fiber was put into a drum-type rotary blender, and the adhesive was applied by means of an airless spray. All acetone evaporated from the fiber before hot pressing. The final resin content of the mixture was 10% resin solids per dried fiber on a weight basis.

Each type of fiber was hand-formed into fiber mats and pressed for 2.5 min at 160 C. Top and bottom surfaces of the mat were covered with glass-fiber, reinforced Teflon[2] sheets

[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

to prevent the boards from sticking to the platens. Thickness was held constant at 7 mm by placing steel spacers between the platens. The mass of fiber for each board was adjusted so that the finished board had a final specific gravity of approximately 0.2, 0.3, 0.4, and 0.5. Each board was approximately 350 by 400 by 7 mm, which was cut down to approximately 300 by 350 mm for testing.

Bending tests

A static bending test (dry) was conducted according to American Society of Testing Materials Standard D1037 (1993) on six specimens of each treatment type. Specimen size was 25 by 7 by 125 mm. The span of the bending specimen was 100 mm, loading speed was 10 mm/min at 60% RH and 20 C. Modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated.

Six specimens of each type were placed in boiling water for 2 h. The wet specimens were then subjected to the bending test previously described, and wet MOE and MOR were calculated.

Internal bond tests

The internal bond test was done according to Japanese Industrial standards (A5908) on specimens of 50 by 50 by 7 mm at 60% RH and 20 C. Five specimens were tested for each type of treatment, and the results were averaged.

Equilibrium moisture content

The equilibrium moisture content (EMC) of untreated and acetylated fiberboards was determined by placing weighed fiberboards in constant humidity rooms at 30%, 65%, and 90% RH and 27 C. After 21 days, the fiberboards were reweighed, and EMC was determined based on the original oven-dry weight. Duplicate specimens were run and values averaged.

Thickness swelling

Six measured specimens of each type were placed in a water bath (20 C) for 24 h or in boiling water for 2 h, and the increase in thickness was measured while the specimens were hot. The percentage of thickness swelling was calculated based on the original oven-dry thickness.

Water swelling

Each oven-dried fiberboard specimen (51 by 51 mm) was weighed; the thickness was measured; and the specimen was placed in a 10- by 10-cm container, 5 cm deep. The container was on a flatbed micrometer, and each specimen was held down using a 20-g stainless steel ring 3 cm in diameter. Water was added to the container, and thickness was recorded as a function of time. Measurements were taken every 15 min for the first hour, every hour for 6 h, then once a day for 5 days. After 5 days, specimens were oven-dried and weighed, and the thickness was measured. Calculations were based on the original oven-dry weight and thickness. Water tests were done in duplicate.

Water extraction

Two board samples (10 by 10 cm) made from steam-treated fiber were extracted in 250 ml of nonagitated, distilled water for 2 days at room temperature. The water was poured off and collected. Fresh distilled water (250 ml) was added, and the samples were soaked for an additional 2 days. This procedure was repeated three times. All water collected was combined and concentrated, under vacuum, to dryness. Weight loss of the board was determined, and the dry concentrate was subjected to infrared analysis and hydrolyzed to determine sugar content.

RESULTS AND DISCUSSION

Because of the limited number of specimens per individual test or treatment, statistical analysis of the data was not possible. The results presented here should be considered as indicative of trends, and a larger, statistically valid experiment should be done to confirm these results.

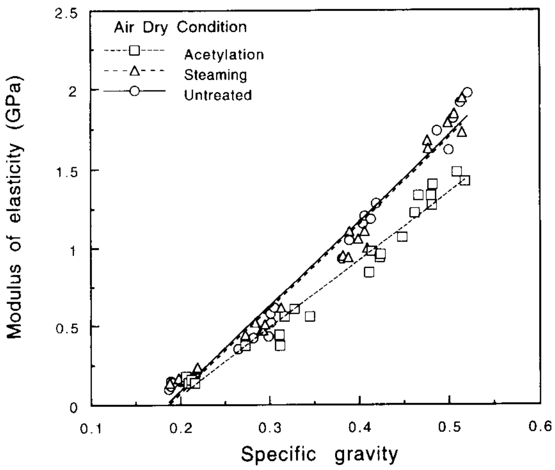

FIG. 1. Modulus of elasticity of aspen fiberboards at 60% RH and 20 C.

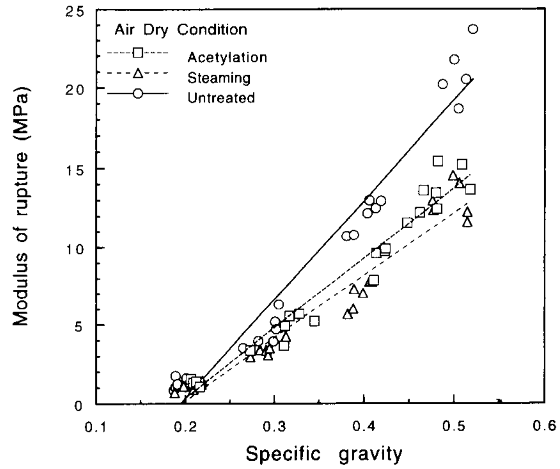

FIG. 2. Modulus of rupture of aspen fiberboards at 60% RH and 20 C.

Fiber and fiberboards

The aspen fiber was acetylated to an oven-dried weight gain of 17%. A slight darkening of the fiber followed reaction. Steaming at 200 C caused the fiber to change to a dark-brown color, but no physical damage to the fiber was observed. Pressing the fiber into boards of various specific gravity levels resulted in no color change.

Bending

Results of the three-point bending test on dry boards are shown in Figs. 1 and 2. The MOE as a function of specific gravity can reasonably be fitted by a straight-line relationship (based on computer best line fit) for all types of fiber (Fig. 1). The MOE values for each specific gravity were essentially the same for untreated and steam-treated boards but less for acetylated boards, except at a specific gravity of 0.2.

Figure 2 shows more scatter in the data for MOR as a function of specific gravity than in the data for MOE. Untreated boards gave the highest values of MOR at all specific gravity levels, except at 0.2, where all types of boards had the same MOR value. Boards made from acetylated fiber had slightly higher values for MOR compared with steam-treated fiberboards.

The MOE values after the 2-h boil test are shown in Fig. 3. Boards made from acetylated fiber gave significantly higher MOE values at all specific gravity levels compared with both untreated and steam-treated boards. The MOE values were higher for steam-treated boards than untreated boards at all specific gravity levels except 0.2, where the values were the same.

The MOR values (Fig. 4) show a very large difference between boards made from acetylated fiber compared with untreated or steam-treated fiber. The values for acetylated were more than double those of untreated or steam-treated boards after the 2-h boil test. At all specific gravity levels tested, the MOR values for untreated and steam-treated boards showed no apparent difference.

Internal bond

Results of the internal bond tests are shown in Fig. 5. Boards made from untreated fiber showed a slightly greater internal bond strength than did acetylated or steam-treated boards, which showed no difference between internal bond strength.

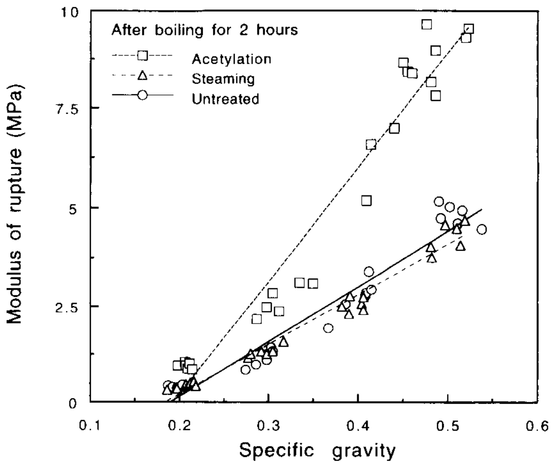

FIG. 3. Modulus of elasticity of aspen fiberboards after 2 h in boiling water.

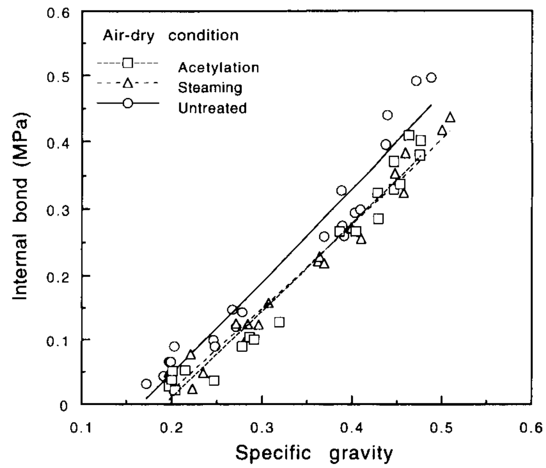

FIG. 5. Internal bond strength of aspen fiberboards at 60% RH and 20 C.

Equilibrium moisture content

The EMC and swelling that occurred at 30%, 65%, and 90% RH are given in Table 1. As expected, the EMC for each type of board was independent of the specific gravity of the board. However, thickness swelling increased as specific gravity increased. The EMC of boards made from acetylated fiber was about half those of steam-treated boards at 30% and 65% RH and about one-third those of untreated boards at 30%, 65%, and 90% RH. The highest EMC was obtained at 90% RH for the steam-treated fiberboards and was twice that of untreated boards. These very high EMC values may be due to the sorption of moisture with the hemicelluloses made accessible during the steam treatment. The reason for this very high EMC is currently under further investigation.

Thickness swelling

The extent of thickness swelling after 24-h liquid-water soaking at room temperature is

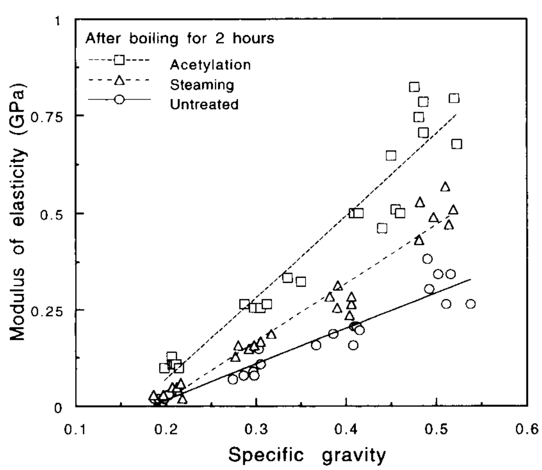

FIG. 4. Modulus of rupture of aspen fiberboards after 2 h in boiling water.

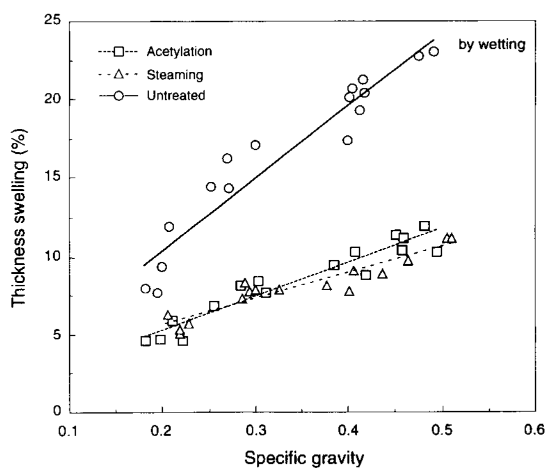

FIG. 6. Thickness swelling of aspen fiberboards after water soaking.

TABLE 1. *Equilibrium moisture content (EMC) and thickness swelling (TS) of very low density fiberboards made from untreated, steam-treated, acetylated fiber at different relative humidity (RH) levels.*

Specimen	Specific gravity	Percentage at 30% RH EMC	30% RH TS	65% RH EMC	65% RH TS	90% RH EMC	90% RH TS
Untreated	0.2	4.0	1.1	8.5	3.3	25.9	12.3
	0.3	4.1	1.4	8.6	4.1	25.9	12.7
	0.4	4.0	1.5	8.6	5.0	25.9	14.4
	0.5	3.8	1.5	8.3	5.5	25.3	15.4
Steam-treated	0.2	2.5	0.3	6.7	1.8	54.7	5.4
	0.3	2.6	0.4	6.3	1.8	54.1	5.9
	0.4	2.4	0.4	6.4	2.4	52.3	5.4
	0.5	2.3	0.8	6.4	3.3	49.2	7.6
Acetylated	0.2	1.7	0.0	3.7	0.0	8.9	3.4
	0.3	1.4	0.0	3.7	0.0	8.9	3.9
	0.4	1.5	0.0	3.6	0.3	9.0	4.5
	0.5	1.4	0.0	3.5	0.3	8.7	4.6

shown in Fig. 6. Boards made from acetylated or steam-treated fiber swelled less than one-third that of untreated boards. Thickness swelling after the 2-h boil test is shown in Fig. 7. At all specific gravity levels, boards made from acetylated fiber swelled less than 3%, and boards made from steam-treated fibers swelled about 5%. Thickness swell increased to about 15% at a specific gravity of 0.5; boards made from untreated fiber swelled to a greater extent than did steam-treated or acetylated boards.

The rate and extent of thickness swelling in liquid water are shown in Figs. 8 and 9. The fastest rate of swelling was observed in untreated boards with the highest specific gravity (0.5). Rate of swelling decreased as specific gravity decreased. After 15 min of water swelling, untreated boards with a specific gravity of 0.5 swelled more than 8% in thickness, and boards made from acetylated fiber at the same specific gravity swelled less than 2%. There was a large difference in the rate of swelling of untreated boards as specific gravity decreased. Untreated boards with a specific gravity of 0.2 swelled less than half those at specific gravity

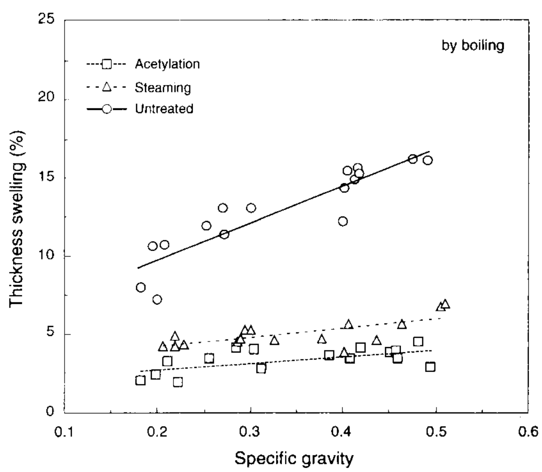

FIG. 7. Thickness swelling of aspen fiberboards after 2 h boiling.

TABLE 2. *Permanent thickness swelling and weight loss after 5 days of water soaking and redrying of fiberboards made from untreated, steam-treated, and acetylated fiber.*

Specimen	Specific gravity	Permanent thickness swelling (%)	Weight loss (%)
Untreated	0.2	9.8	1.1
	0.3	11.8	1.1
	0.4	18.4	1.2
	0.5	20.7	1.3
Steam-treated	0.2	−7.2	16.0
	0.3	−4.2	15.3
	0.4	−1.0	14.2
	0.5	−0.9	14.1
Acetylated	0.2	0.0	0.6
	0.3	0.8	0.4
	0.4	1.0	0.2
	0.5	1.0	0.1

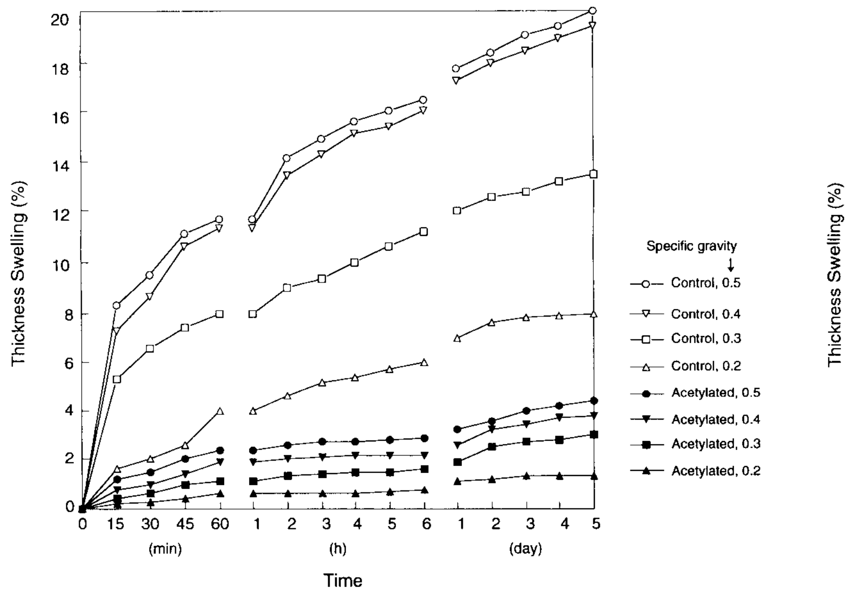

FIG. 8. Thickness swelling of untreated and acetylated aspen fiberboards in water.

of 0.4 or 0.5. All acetylated boards at all specific gravity levels swelled less than 4% after 5 days.

A comparison of Figs. 8 and 9 shows that the rate of swelling of boards made from steam-treated fiber was faster than for acetylated boards at the same specific gravity levels but much less than for untreated boards. Little additional swelling occurred in steam-treated boards at all specific gravity levels tested after about 4 h in liquid water.

Table 2 shows the permanent increase in

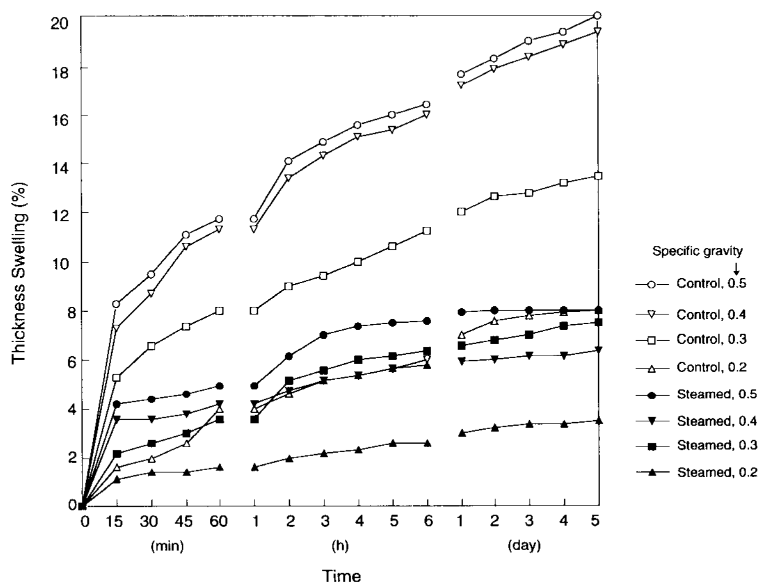

FIG. 9. Thickness swelling of untreated and steam-treated aspen fiberboards in water.

thickness after each set of boards was oven-dried after the 5-day liquid-water swelling test. Permanent swelling increased in untreated boards with an increase in specific gravity. Boards made from steam-treated fiber were thinner after the swelling test than before the test, probably as a result of the loss of wood substance during soaking. Oven-dry weight loss by leaching of the steam-treated boards was about 15%. Oven-dry weight loss as a result of leaching in untreated boards after the 5-day test was about 1%, compared with about 0.5% for acetylated boards.

Water leachate analysis

The leachate from the hot water extraction of the boards made from steam-treated fiber was analyzed for sugar and lignin content. Of the total leachables removed from the board (about 15% by weight), about 80% by weight was extracted sugars. The remaining 20% was a combination of degraded lignin and other extractives as seen by infrared analysis. The percentage of simple sugars extracted follows:

Weight loss	16.5%
Arabinose	3.8
Galactose	13.4
Glucose	17.7
Xylose	11.3
Mannose	53.8
Rhamnose	Trace

The preponderance of mannose, xylose, galactose, and arabinose extracted shows that the hemicelluloses were being degraded to extractable molecular weight during the steam treatment.

CONCLUSIONS

It is possible to make fiberboards with specific gravity levels of 0.2 or less. Although having very low modulus values, these boards would be strong enough to be used for insulation, packaging, and light-weight core materials. The properties of boards with a specific gravity of 0.2 were probably controlled by poor adhesion between fibers because little pressure is applied when the board is formed to cause the fibers to come close enough together for good bonding. At all specific gravity levels tested in this study, fiberboards made from acetylated fiber were more dimensionally stable than boards made from steam-treated fiber. Dimensional stability increased as the specific gravity decreased in all types of boards. This was probably due to both internal (interstitial) swelling and very little fiber compression (deformation) during pressing. Interstitial swelling allows swelling without causing the board to enlarge, and a low level of fiber compression means that almost no fiber stress is released during water wetting. Experiments are presently underway to make fiberboards with a specific gravity of less than 0.2.

REFERENCES

American National Standards Institute (ANSI). 1985. American National Standard, Cellulosic Fiberboard. ANSI/AHA A194.1, Palatine IL.

American Society for Testing and Materials (ASTM). 1993. ASTM D1037. Standard test methods for evaluating properties of wood-base fiber and particle panel materials. American Society for Testing and Materials, Philadelphia, PA.

Forest Products Laboratory. 1987. Wood handbook: Wood as an engineering material. Agric. Handb. 72. rev. U.S. Department of Agriculture, Washington, DC. 266 pp.

Imamura, Y., K. Nishimoto, Y. Yoshida, S. Kawai, T. Sato, and M. Nakaji. 1986. Production technology for acetylated low-density particleboard. II. Decay and termite resistance. Japan J. Wood Res. 73:35–43.

Inoue, M., M. Norimoto, Y. Otsuka, and T. Yamada. 1991. Surface compression of coniferous wood lumber II: Permanent set of compression wood by low molecular weight phenolic resin and some physical properties of the products. Mokuzai Gakkaishi 35(3):227–233.

———, ———, M. Tanahashi, and R. M. Rowell. 1993. Steam or heat fixation of compressed wood. Wood Fiber Sci. 25(3):224–235.

Kawai, S., and H. Sasaki. 1986. Production technology for low-density particleboard. I. Forming a density gradient and its effect on board properties. Mokuzai Gakkaishi 32(5):324–330.

———, and ———. 1989. A challenge to lower the density of particleboard. Proc. 23rd Particleboard/Composites Materials Symposium, April, Pullman, WA.

———, ———, M. Nakaji, S. Makiyam, and S. Morita. 1986a. Physical properties of low-density particleboard. Japan J. Wood Res. 72:27–36.

———, H. SUDA, M. NAKAJI, AND H. SASAKI. 1986b. Production technology for low-density particleboard. II. Effects of particle moisture content and resin content on board properties. Mokuzai Gakkaishi 32(11):876–882.

MCNATT, J. D., AND G. C. MYERS. 1993. Selected properties of commercial high-density hardboards. Forest Prod. J. 43(4):59–62.

MYERS, G. C., AND J. D. MCNATT. 1985. Fiberboard and hardboard research at the Forest Products Laboratory: A 50-year summary. Gen. Tech. Rep. FPL-47. USDA, Forest Service, Madison, WI. 40 pp.

ROWELL, R. M., A.-M. TILLMAN, AND R. SIMONSON. 1986. A simplified procedure for the acetylation of hardwood and softwood flakes for flakeboard production. J. Wood Chem. Technol. 6(3):427–448.

SELLERS, T., G. D. MILLER, AND M. J. FULLER. 1993. Kenaf core as a board raw material. Forest Prod. J. 43(7/8):69–71.

YOSHIDA, Y., S. KAWAI, Y. IMAMURA, K. NISHIMOTO, T. SATOU, AND M. NAKAJI. 1986. Production technology for acetylated low-density particleboard. I. Mechanical properties and dimensional stability. Mokuzai Gakkaishi 32(12):965–971.