SPACEBOARD II STRUCTURAL PANELS: FORMING APPARATUS AND METHODS

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ABSTRACT

Novel methods and a patented apparatus have been developed to fabricate Spaceboard II, a new unique structural board of pulped wood fiber. Like the earlier Spaceboard I, the board has flat, high-density faces and a core of rectangular cells defined by high-density cell walls formed integrally with the faces. The board is assembled from two asymmetrical panel halves joined cell to cell. The panels are formed (molded) at low bulk density and subsequently compacted to a unique shape and uniform high density. Spaceboard II is formed by the porous mandrel method, which allows fabrication of much thicker panels than was possible with the original Spaceboard I method. A variety of wet or dry (adhesive-coated) fiber furnish may be used, with either air or water as the forming vehicle. The boards are being investigated for use in light frame and commercial construction; for packaging, palletizing, partitions, and furniture; and for other uses. In the present study, a total of 55 panels, 635 by 1,244 by 38 mm thick, were made by wet- and dry-forming methods in a Forest Products Laboratory patented apparatus.

Keywords: Paperboard, fiber, forming, wet-forming, dry-forming.

BACKGROUND

In 1985, Vance Setterholm, of the U.S. Department of Agriculture, Forest Service, Forest Products Laboratory (FPL), introduced a unique concept for fabricating panels molded of pulped wood fiber (Setterholm 1985). He envisioned a high-density flat face on one side of the panel and an integrally molded grid, defining rectangular "cells," on the other side. Two such panels joined cell to cell would create a rigid "spaceboard" with smooth surfaces on both sides and a lightweight core. Setterholm reasoned that such a configuration was structurally advantageous, vis-à-vis corrugated board, because there was only one glueline (located at the neutral axis in bending) and because the walls, which define the cells in the core, could be integral with the face. Moreover, the cell walls could be specifically shaped to most efficiently transfer load between core and face. Setterholm and Hunt (1987) conceived a simple technique for forming, compacting, and drying the panels on a wire screen overlaid with a pattern of spaced, deformable, silicone-rubber nubbles. Spaceboard I panels of thickness from 3 to 10 mm have been made on such a screen in a manner similar to that used to wet-form hardboard or to make handsheets in

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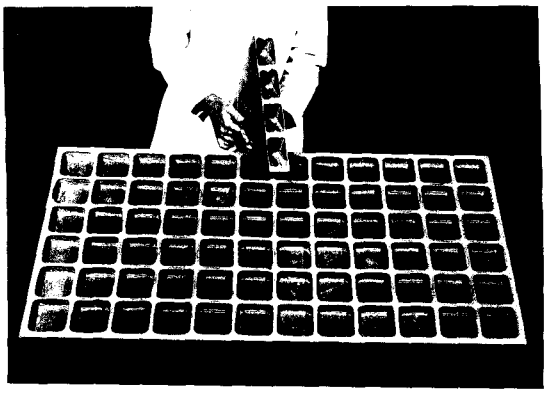

FIG. 1. Molded fiber panel (shown cell side up) and section of assembled Spaceboard II, showing flat faces and interior open cells.

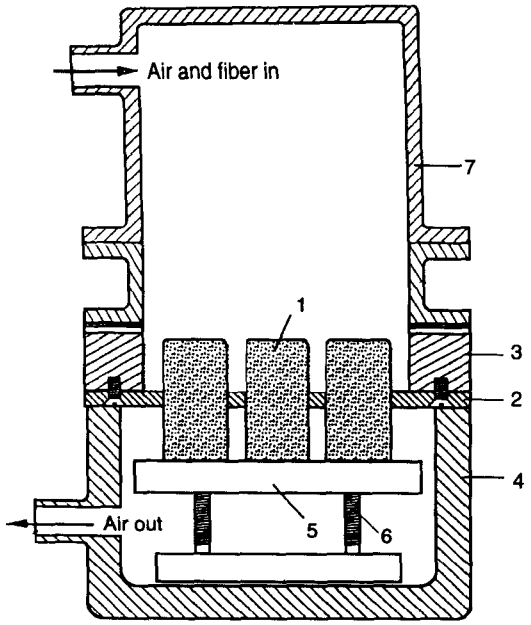

FIG. 2. Schematic of apparatus: (1) porous mandrel, (2) perforated plate, (3) casing, (4) lower enclosure, (5) moveable plate, (6) jack screw, and (7) upper enclosure.

a British Sheet Mold. A slurry of water and fiber contained in an open tank above the nubbled screen is drained through the screen, depositing the fiber between and over the top of the nubbles. When subsequently pressed between heated platens, the fiber mat (on the nubbled screen) is compacted and dried. Lateral deformation of the rubber nubbles efficiently compacts (densifies) the thin walls that create the cells.

Conceivably, this method could be used to mold panels on any scale, encompassing a wide range of facing thickness, panel thickness, and cell size. Practically, however, the challenge of forming and densifying the walls between the cells becomes much more difficult as panel thickness increases and cell walls become thicker and higher. Whether the furnish is borne by air or water, the bulk density of the fiber mat formed in the mold by the Spaceboard I method is inherently below that required for the finished product. The successful forming apparatus and process must be capable of compacting the molded fiber mat by a ratio of 20× to 30× after the mat is initially formed in the mold. Compaction of that order is accomplished with relative ease in panels of uniform cross section but can be very difficult to accomplish in sections of varying thickness—as in the cellular structure of spaceboard panels. Attempts at the FPL to form panels 38 to 51 mm thick using the Setterholm/Hunt method have been relatively unsuccessful because it has not been possible to deposit enough fiber in the gap between the nubbles and to deform the nubbles sufficiently to develop sound, uniform cell walls in thicker panels.

In the study reported here, thick spaceboard panels were made using the porous mandrel method (Fig. 1). The report describes the forming apparatus and fabrication process.

OVERVIEW OF POROUS MANDREL METHOD

The patented porous mandrel method (Gunderson 1986; Gunderson and Gleisner 1992) was developed to provide three attributes essential to forming thick spaceboard panels: ample space for depositing cell-wall fiber, high compaction ratios (implies large compaction deformation in thick sections), and greater drainage area for faster forming. The method and apparatus are schematically illustrated in Figs. 2 to 4. Three porous mandrels (vertical columns) are attached to a moveable plate and pass through a perforated plate (Fig. 2). Above

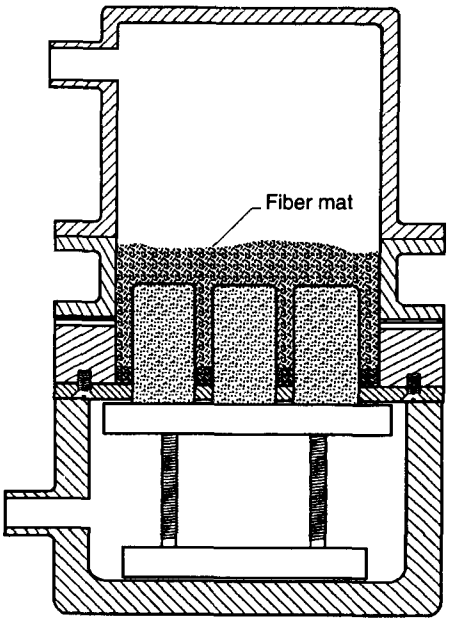

FIG. 3. Schematic of apparatus showing fiber mat formed in spaces between mandrels and as continuous mat over top of mandrels.

the perforated plate is a closed chamber with an inlet port and below the perforated plate a second closed chamber with an outlet port. The moveable plate is supported by jack screws such that the plate and mandrels can be raised and lowered with respect to the perforated plate, causing the mandrels to extend more or less into the upper chamber. The mat forming process begins with the mandrels extended fully into the upper chamber. A vacuum drawn in the lower chamber causes air to be drawn through the porous surface of the mandrels, into their hollow interior, and then into the lower chamber to be exhausted at the outlet port. In like manner, water entering the upper chamber is drawn along the same path. Fiber entering the upper chamber, whether borne by air or water, is separated from the carrier fluid at the porous mandrels to form a fiber mat that fills the spaces between the mandrels and covers their tops (Fig. 3). Fiber in the space between the mandrels forms the ribs that define the cell structure; fiber covering the tops of the mandrel forms the flat face of the panel.

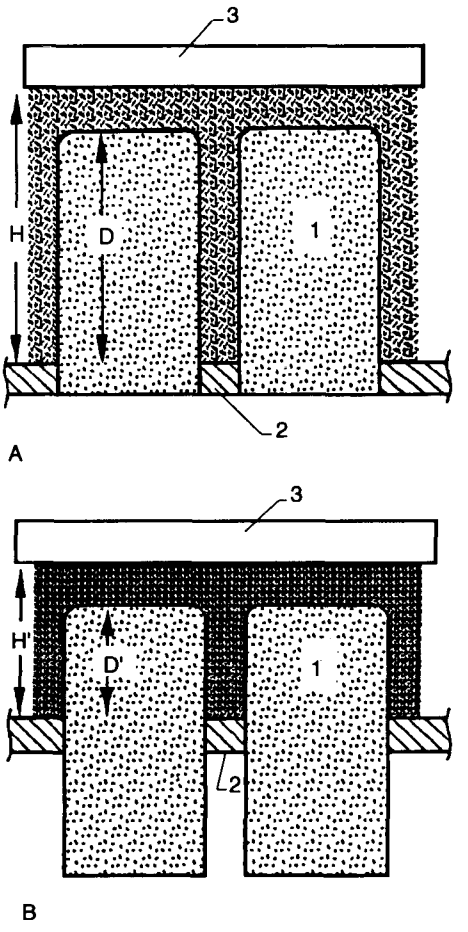

FIG. 4. Schematic of mat compaction in the mold: A, formed mat before compaction; B, compacted mat. Perforated plate (2) is stationary as mandrels (1) retract and pressing plate (3) compacts the mat. H and D are original height and thickness of rib and facing, respectively. H' and D' are reduced dimensions.

Once formed, the mat is compacted in the mold before it is cured or dried. Compaction is illustrated in Fig. 4, which shows two mandrels, the perforated plate, and a pressing plate (added after the forming process). Figure 4A shows the mat prior to compaction, with mandrels fully extended into the forming chamber; Fig. 4B shows the compacted mat. In Fig. 4B, both the facing and ribs of the mat have been compacted by coordinated movement of the pressing plate and mandrels. The original height of the rib between the mandrels (D) is reduced

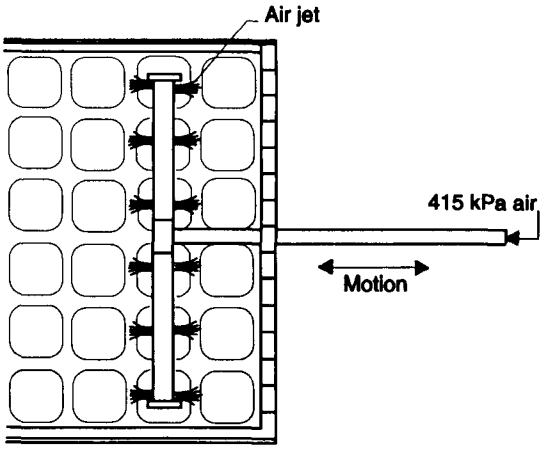

FIG. 5. Air jet bar. Jets of air emitted in plane parallel to mandrel tops prevent flocculation and bridging of fibers over spaces between mandrels.

to (D'); the original thickness of the facing (H-D) is likewise reduced (to H'-D'). By controlling the movement of both pressing plate and mandrels, the extent to which both rib and face are compacted can be independently controlled.

Although the volume of the fiber mat within the mold has thus been greatly reduced and the bulk density of the mat has been significantly increased, the task is not complete. Whether the mat has been wet- or dry-formed, an additional step is necessary. The mat formed of dry fiber (dry-formed) must be heat-cured to activate the adhesive coating that will bond fiber to fiber; the wet-formed mat must be dried to develop the hydrogen bonding between fibers; and both wet- and dry-formed mats must be further compacted to develop greater strength, strength that increases exponentially with increasing density. In a final step, two panels must be joined with an adhesive, cell to cell, to create the double-sided, flat-faced spaceboard.

Our research has developed forming methods depending upon the carrier vehicle used: air or water. In the following section, we first discuss aspects common to both methods, then describe the dry-forming apparatus and process, and finally describe the wet-forming process by differentiating it from the dry-forming process.

METHODS

Common features of wet- and dry-forming methods

The forming area of the mold is 635 by 1,247 mm. Seventy-two mandrels are arranged in a rectangular array (6 × 12) spaced 102 mm center to center. The gap provided for rib formation is 13 mm between mandrels and 18 mm between outside mandrels and mold perimeter. The mandrels are hollow, porous, sintered bronze columns 89 mm square by 203 mm high. Outside corners are radiused to 12.7 mm. There is a 5° taper on the upper 38 mm of the mandrel to facilitate its removal from the panel. The mandrels are mounted on a common moveable plate supported by eight jack screws driven by a single, variable speed, direct current motor (Fig. 2). The mandrels pass through a stationary perforated plate that carries the pressing force during mat compaction and is used to lift the compacted mat from the mold and support it during curing (dry-forming process only). The area beneath the perforated plate, enclosing the jack screws and moveable plate, is fully enclosed and sealed as schematically represented in Figs. 2 and 3. However, the actual apparatus has four 50-mm-diameter ports into this area. A manifold connects the ports to two 51-mm inside diameter (ID) flexible hoses that lead to the vacuum source: a 0.33-m^3/sec vacuum pump and 0.45-m^3 surge tank. The high volume capacity of the vacuum source is essential for the dry-forming process but exceeds demand in the wet-forming process. During the forming process, most furnishes tend to flock and bridge across the tops of the mandrels, resulting in poor fiber distribution in the mat sections. To preclude this problem, an air jet bar (Fig. 5) is moved back and forth over the tops of the mandrels (Gleisner and Gunderson 1992). Jets of air at 415 kPa, emitted from holes oriented parallel to the plane of the mandrel tops, create local turbulence preventing flocculation and bridging.

Beyond these elements of commonality, many other aspects of apparatus and process are at least subtly different for dry- and wet-forming methods.

Dry-forming process

Figures 2 and 3 are schematically correct representations of the upper portion of the mold for the dry-forming process. However, in the actual apparatus, the inlet is centrally located on the top surface of the upper chamber and is attached to a 51-mm ID hose. As a whole, the dry-forming apparatus could be viewed as functionally analogous to a large vacuum cleaner, with porous mandrels serving as the collection bag. When the vacuum is turned on, a measured quantity of fiber is simply drawn in through the inlet. Within the upper chamber, a baffle disperses and directs the incoming flow of air and fiber to achieve a uniform distribution at the mandrels.

Commercially produced, pressure-refined aspen mechanical fiber was used for the first run of dry-formed panels. The method described by Myers (1986) was used to apply a commercial phenolic resin to the fiber. Dispersed in water at 51% to 53% solids, the resin was sprayed on the fiber at a rate of 11% by weight (oven-dry basis) while the fibers were tumbled in a rotating drum. Following resin application, the fibers were run through a 203-mm-diameter single rotating disk refiner with knobby plates set at 19-mm gap to break up fiber bundles that formed during the tumbling process and to create more fiber-to-fiber rubbing, which assists resin spread.

The mandrels were fully extended into the mold at the beginning of the forming process. With vacuum active (nominally 6.5 to 10 kPa in the lower chamber), an initial charge of coated fiber (3,300 g with resin) was fed into the inlet hose while the air jet bar was moved back and forth over the mandrel tops. The initial charge should have filled the spaces between the mandrels to become the cell walls. Actually, it was necessary to manually tamp the fiber in the spaces between the mandrels to facilitate acceptance of the full initial charge. For the furnish in our study, the mandrels for dry-forming should have been approximately 50 to 70 mm higher. Next, with the air jet bar removed, a second charge of 3,500 g of fiber was fed to the inlet to form the facing. Forming time was about 3 min. Prior to compaction, the mat was approximately 355 mm thick; the rib bulk density was 60 kg/m^3 and facing density was approximately 30 kg/m^3.

The next step, compaction in the mold, is depicted in Figs. 6 and 7. With upper chamber cover removed, a rigid metal pressing plate was positioned on the mat prior to compaction. Once again, vacuum was drawn in the lower chamber, consequently reducing pressure in the mold volume below the pressing plate. As a result, atmospheric pressure (Fig. 7F) pushed the pressing plate down. At the same time, the mandrels were slowly lowered (withdrawn) under control of the jack screws and motor. When the mat was compressed to a thickness of 89 mm, the compaction process was stopped and the pressing plate was locked to the casing (Fig. 7). In this configuration, the mat was held and supported by the mechanical assembly consisting of the pressing plate, perforated plate, and casing. Although the mat was significantly more dense than in its previous state (prior to compaction), an additional processing step was necessary to further compact the mat and heat-cure the phenolic adhesive. The mat, with supporting mold components, was removed from the mandrels. Composite spacers (Fig. 8), 89 mm square by 57 mm high, with a solid base and silicone rubber top were inserted into each cell through the openings in the perforated plate. The assembly (Fig. 9) was placed in a heated platen press. The pressing plate was unlocked (Fig. 10), a gradually increasing force was applied by the platen press, and the mat was further compacted. Initially, the "action" in the mat was vertical compression, which displaced the solid portion of the spacers into the holes in the perforated plate. However, when the spacers "bottomed-out" and pressure increased (to a maximum of 760 kPa), the silicone blocks deformed (Fig. 11), compressing vertically and

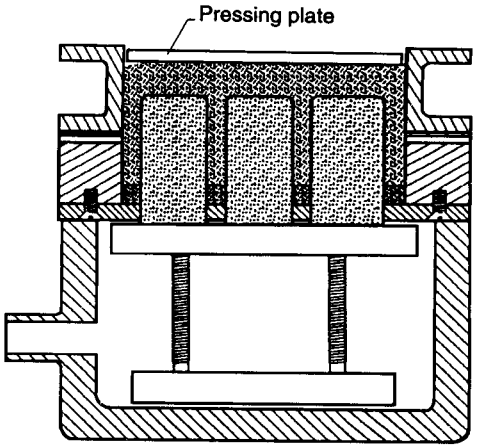

FIG. 6. Mat in mold prior to compaction, with pressing plate placed over top of mat.

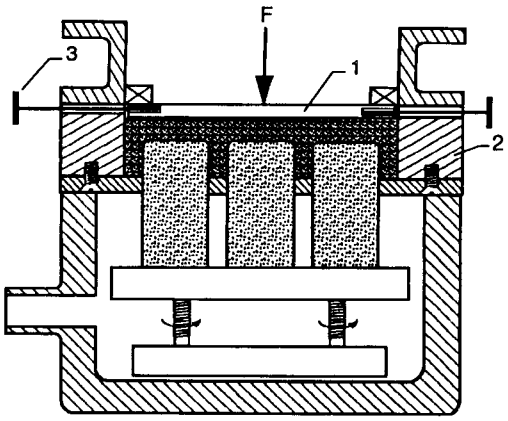

FIG. 7. Mat compacted in mold. Mandrels are retracted and pressing plate (1) is locked to casing (2) with pins (3). F represents force of atmospheric pressure on pressing plate compacting mat facing.

expanding horizontally to create an almost uniform, near-hydrostatic compression force within the mat. The panel was pressed for 40 min at 170 C platen temperature to assure adequate curing of the bonding adhesive (107 C/10 min). At the completion of the curing cycle, the rib had been compacted by a ratio of 7:1 vertically and 1.4:1 horizontally from its state prior to compaction, to produce a bulk density of 500 to 600 kg/m^3. The facing had been compacted by a ratio of 24:1, resulting in a bulk density of 600 to 700 kg/m^3.

In the current study, 27 panels were produced using the dry-forming process. Target specifications were weight, 6.8 kg; thickness, 38 mm; and facing thickness, 6.4 mm. The range and means of weights and thicknesses are shown in Table 1.

Wet-forming process

Panels may also be formed of a high consistency slurry of fiber in water. In the wet-forming operation, the closed upper chamber depicted in Figs. 2 and 3 is replaced by an open rectangular tank or vat. The furnish can be simply poured or pumped into the open vat. With mandrels raised (extending into the forming area), the water "carrier" drains through the porous mandrels and forms the fiber mat, as in the dry-forming process. Use of the air jet bar prevents formation of bridges and aids cell-wall formation. Vacuum drawn in the lower chamber accelerates the drainage rate to reduce forming time. The compaction following formation is similar to that for dry-formed mats (see Figs. 6 and 7) except that an

TABLE 1. *Spaceboard II measurements.*

Panel type and value	Weight (kg)	Total thickness (mm)	Facing thickness (mm)
Dry-formed			
Range	4.63–6.90	33.8–34.3	4.8–6.9
Mean	6.24	34.2	6.0
Standard deviation	0.51	0.16	0.61
Wet-formed			
Range	5.0–7.08	31.8–33.5	2.03–3.56
Mean	5.83	32.9	2.7
Standard deviation	0.52	0.65	0.43

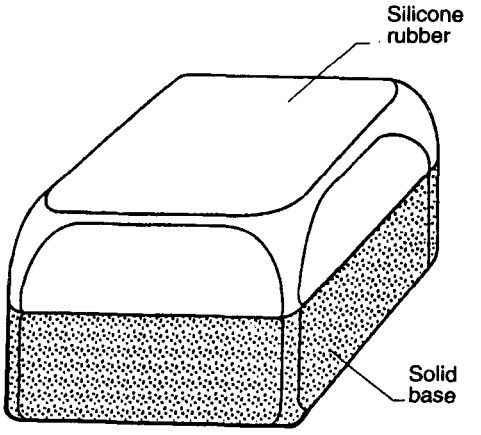

FIG. 8. Composite spacer. Silicone rubber top and solid (aluminum) base, 89 by 89 mm square, 57 mm high (22 mm solid, 35 mm silicone rubber).

externally applied pressure in excess of 100 kPa is required to dewater and compact the wet-formed mat in the mold. As with dry-forming, a (modified) off-mold secondary compaction and drying step follows initial compaction.

For the initial run of wet-formed panels, a kraft pulp composed of three parts northern red oak to one part loblolly pine was prepared. The Canadian standard freeness (CSF) value of the furnish was 700. Mandrels were set to extend 178 mm into the mold. An initial charge of slurry (3,000 g of oven-dry fiber at 2% consistency) was pumped into the mold vat. With a vacuum of 60 to 66 kPa in the lower mold chamber, the time to form the cell-walls was approximately 5 min. A second charge, sufficient to form the panel facing (3,200 g of oven-dry fiber at 2% consistency), was then added. The time to drain the second charge was an additional 7 to 8 min. Prior to compaction, the mat was approximately 200 mm thick. The mat was then compacted and dewatered in the mold. The vat was removed and a pressing platen placed over the mat (Fig. 6). With vacuum in the lower chamber at 30 kPa and a mechanical force of 548 kN applied to the pressing platen, the mandrels were withdrawn until the mat thickness was reduced to 51 mm and mat solids content reached 20% to 25% (Fig. 7). Because the mechanical integrity of the wet-formed mat was much greater than that of the dry-formed mat at this stage, final processing was somewhat simplified. For final compaction and drying, the pressing plate was removed and the mat was lifted from the mandrels on a parting screen (not shown in figures). Silicone rubber blocks (89 by 89 by 35 mm) were placed into the open cell cavities, and the mat was placed in a frame that constrained dimensions in length and width. The mat was transferred to a heated (177 C) platen press and pressed to 760 kPa. Wire screens placed between mat and platen on both sides of the mat drained liquid water from the compacting mat and then vent steam as the mat dried. Drying time under these conditions was nominally 2 to 3 h.

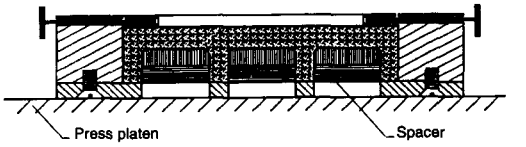

FIG. 10. Vertical compaction of mat under increasing force (F′) of pressure plate. Composite spacers have "bottomed-out" in perforated plate.

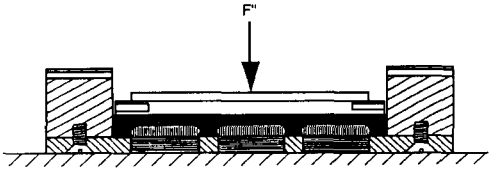

FIG. 9. Compacted mat supported by pressing plate, perforated plate, and casings. Composite spacers inserted in each cell. Assembly rests on press platen.

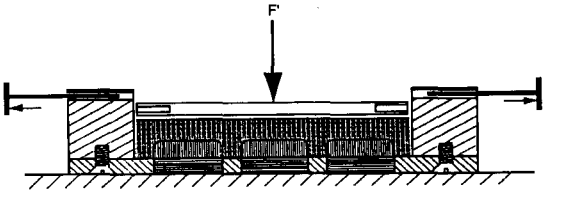

FIG. 11. High pressure compaction and heat-curing of mat. Silicone rubber portion of spacer compresses vertically and expands horizontally to create near-hydrostatic compaction force (F″) within mat.

TABLE 2. *Brief summary of mechanical properties.*

	Wet-formed panel	Dry-formed panel
Tensile strength of facing	36.6 MPa	10.5 MPa
Deflection due to concentrated load—91 kg on 1.2-m span	1.93 mm	2.74 mm
Flat-crush stress, average over entire surface	503 kPa	827 kPa
Center-point bending		
Modulus of elasticity	6.5 GPa	2.1 GPa
Modulus of rupture	53.1 MPa	27.6 MPa

A total of 28 panels were produced using the wet-forming method. Target specifications were the same as those for the dry-formed panels. The range and means of weight and thickness are reported in Table 1. Rib shape was similar to that of the dry-formed panels but not as smooth and uniform. Surface grooves running parallel to the face were apparent in many cells, as were splits in corners of cells where rib and facing met. Both defects are assumed to be the product of uneven shrinkage during drying and might be correctable by altering either the as-molded shape or the shape and stiffness of the silicone rubber blocks.

Assembly into boards

Both wet- and dry-formed panels were surface-sanded in a 915-mm-wide belt sander to remove uneven edges caused by fiber squeezing between the mold casing and the pressing surfaces during drying and curing. Twenty-four panels of each type were matched in pairs to make twelve sets of boards each. The panels were coated, on the rib side, with a resorcinol adhesive at a rate of 290 kg/1,000 m^2, joined rib to rib, and pressed for 24 h at 190 kPa (facing pressure).

RESULTS AND DISCUSSION

Using the novel forming methods described here, we successfully fabricated panels with uniform density through rib and facing sections within the same panel. Both wet- and dry-forming concepts could be used. Briefly, our experience with the two approaches can be compared as follows:

Wet-forming process.—Longer forming time, simple compaction and handling of mat, no adhesive required, relatively long drying time, very dense rib and facing sections, and tendency to develop cracks and corner flaws in rib sections.

Dry-forming process.—Fiber precoated with adhesive, low bulk-density mat, more complicated compaction of mat, and relatively rapid heat-cure to highly uniform flaw-free panel with lower section densities.

Finished panels of the two types are of essentially equal gross density and have consistently flat, flaw-free faces. A variety of mechanical tests have been conducted to measure panel properties in accordance with methods and standards established by the American Plywood Association (APA) and the American Society for Testing and Materials (ASTM). The results of that investigation and discussion of the relative merits of this product vis-à-vis other structural panels are beyond the scope of the present report. However, Table 2 does provide a brief summary of results of the mechanical testing of both wet- and dry-formed panels.

The time required to dry the wet-formed panel, or to cure the adhesive in the dry-formed panel, is a particularly critical process parameter because the panel occupies the press throughout the drying/curing cycle. The press-time per panel can, of course, be significantly reduced by drying/curing a number of panels at the same time in a multiopening press. Nevertheless, the extended times reported for the present processes are seen as an obstacle to commercial acceptance of the process. There is reason to believe that both drying and curing times can be significantly reduced, however. In the case of the dry-formed panels, experiments have shown that the internal board temperature reaches the required cure temperature of 105 C in less than 20 min—at the platen temperatures and pressures previously stated. Given a nominal cure time of 10 min, it appears that overall press-time for dry-formed

panels could be reduced to "under" 30 min with little or no change to other parameters.

Reduction in the drying time for wet-formed panels is also thought to be possible, albeit through use of more advanced and probably more costly technology. At present it appears that the drying rate is limited by the rate at which we are able to conduct heat energy into the web—and that rate is limited by the relatively poor thermal conductivity of the "dry layer," which quickly develops in the panel at the surfaces in contact with the hot platen. In essence, the "still-wet" interior portions of the panel become insulated from the source of drying energy by the "already-dried" portions. If this interpretation is correct, there is reason to believe that drying rate can be greatly improved by introduction of radiofrequency or microwave energy using techniques developed, and occasionally used, for the drying of lumber. Given the dramatic results achieved with these techniques in the drying of wood (and other materials), it is not unreasonable to project that a "factor of 10" reduction might be achieved in the drying of spaceboard.

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