Combined board properties of FPL spaceboard formed by a new method

John F. Hunt and C. Tim Scott

Three-dimensional forming consolidating and drying on a spaceboard screen gives a product with improved strength and stiffness compared to C-flute.

Spaceboard developed at Forest Products Laboratory (FPL) is a pulp-molded, three-dimensional. fiber or composite sandwich structure usually made of two identical sheets bonded together at the neutral axis of the combined board **(Fig. 1).** Setterholm (*1*) showed that this new concept could be used to form paperboards with higher edgewise compression strength than that of C-flute fiberboard. Originally. the individual sheets. 2.1 mm thick (0.08 in.), were formed on solid molds. Although this forming method was satisfactory for bench-scale experimentation and for conveying a new structural fiber concept. it did not easily lend itself to continuous production. Wedecided to improve themethod for forming spaceboard and to study the subsequent strength properties.

Here. we will (a) describe an improved forming method for spaceboard, (b) compare the edgewise compression strength of spaceboard formed by this new method to spaceboard formed by the previous method. and (c) evaluate the properties of spaceboard formed by the new method. We made linerboards in a series of varying linerboard weight and pressing pressure. We combined the linerboards and measured edgewise compression strength. bending stiffness. flat-crush strength, and burst strength. For comparison. we used previously reported spaceboard data (*1*), commercial C-flute data (*2, 3*). and data from a commercial C-flute fiberboard tested at FPL, designated as C-flute F1131.

Method for forming spaceboard

Previous method

In the previous method for forming spaceboard. we used specially shaped molds (*1*) made of either all metal or all rubber. The spaceboard webs were formed by the following steps. First, the mold was filled approximately one-third full of pulp slurry. The consistency of the slurry was approximately 3% (g of fiber/g of total fiber and water). A thin tool was used to press the pulp between the raised pads on the mold. A second layer of pulp or a preformed wet web was placed on top of the formed pulp. The combined wet web and spaceboard mold were pressed and dried at 70 kPa (10 psi).

Setterholm's (*1*) data showed that the strongest components were formed and pressed on the solid rubber mold. Although forming spaceboard on solid molds had been adequate for Setterholm's demonstration of the structural concept, we saw two areas that needed to be improved. First, a better technique was needed for placing fibers between the pads. Second, a method was needed for removing water from the solid mold and web. We developed a fabricated wire screen (4) to overcome these problems.

New method

The new forming method is similar to forming a flat web on a fourdrinier or cylinder machine, where the fibers are deposited on a screen while the water flows through. However. the fourdrinier wire screen used in forming spaceboard has silicone-rubber pads attached to it. This screen is called the "spaceboard screen." The pads direct the flow of water and fibers, forming a three-dimensional web **(Fig. 2A).**

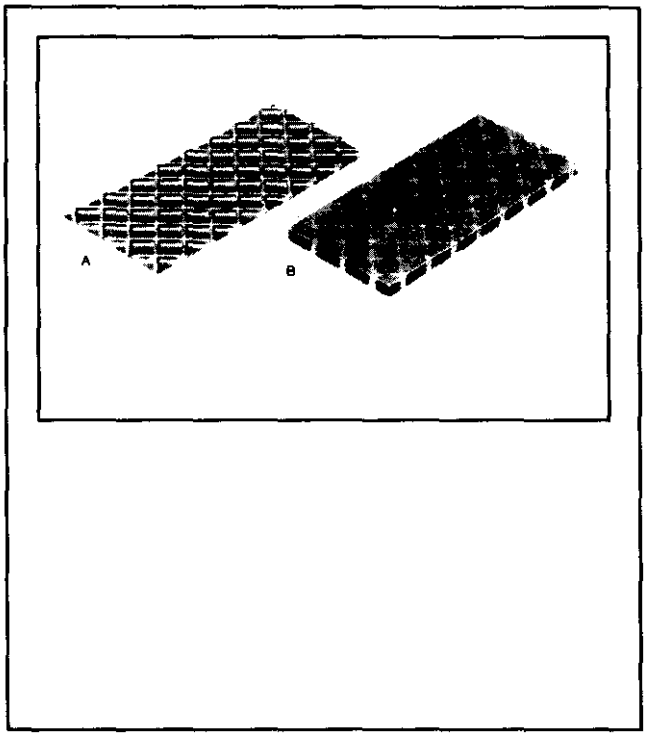
The silicone-rubber pads of the solid rubber mold and on the spaceboard screen are important for consolidating the three-dimensional web. Once the web has been formed, both the spaceboard web and the screen are placed in a wet press. The resilient pads compress vertically under the pressure while expanding laterally. This expansion packs the fibers that form between the pads more densely. Thus. by applying a normal force to the spaceboard web and screen. the web is made more dense in all directions **(Fig. 2B).**

After the web has been formed and consolidated, the web and screen are placed in a hot press. As in the wet press, the same vertical compression and lateral expansion of the pads also take place in the hot press to make the web more dense and to hold it as it dries. The pads are made of silicone rubber because silicone is resilient and does not readily break down in the presence of heat and moisture. The final sheet thickness is dependent on the normal force, the silicone properties, and the spacing between the pads.

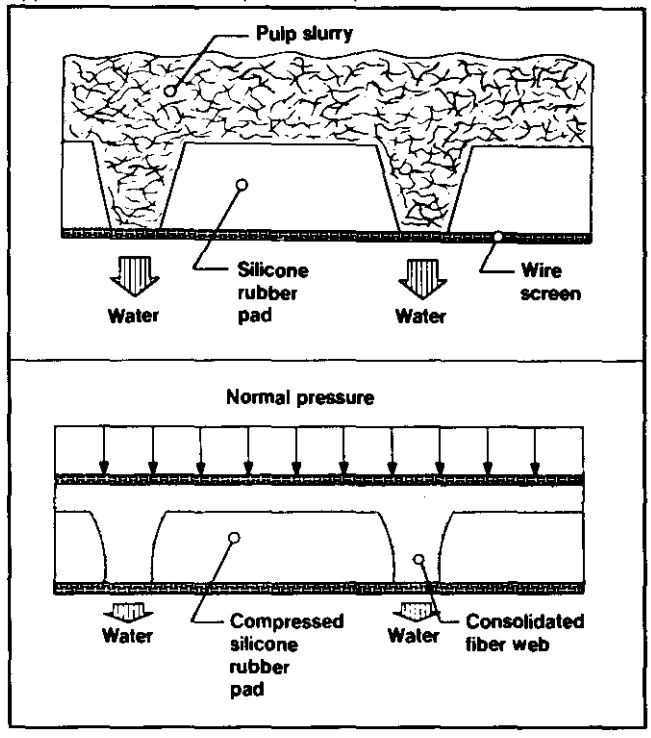
Finally, the half-thickness sheets are bonded rib-to-rib

Hunt is mechanical engineer and Scott is general engineer at the USDA Forest Service, Forest Products Laboratory, One Gifford Pinchot Dr., Madison. Wis. 53705-2398.

1. Construction of FPL spaceboard. A: one part of the "sandwich," with ribs facing up. B: two half-thickness sheets bonded together at the ribs.



2. Side view of me spaceboard screen. consisting of silicone rubber pads attached to a fourdrinier screen. Top: A fiber mal forms around the pads as water passes through the screen. Bottom: Normal force applied to the screen compresses the pads.



to form combined boards of spaceboard.

Combined board properties

The edgewise compression test (ECT) results are shown in **Fig. 3.** The ECT strength of spaceboard increased with greater static pressure and basis weight. At an equal static pressure of 70 kPa, the new forming method resulted in slightly higher ECT strength at 600 g/m^2 and slightly lower ECT strength at 800 g/m^2 than that formed by the previous method (*1*). When compared to average C-flute fiberboard values. spaceboard strength was higher than that of C-flute in its strongest direction, the crass direction (CD), parallel to the flutes. The ECT strength of spaceboard pressed at 70–550kPa (10–80psi) was 50–113% greater than that of C-flute at 600 g/m^2 and was 78–169% greater at 800 g/m^2.

The dashed line in Fig. 3 represents estimated C-flute ECT strength in the machine direction (MD), perpendicular to the flutes. Also shown are MD and CD data points for C-flute F1131. The estimated ECT line was calculated by multiplying the ECT strengths by the ratio of MD to CD ECT strength for C-flute F1131 Each data point shown for the new method represents the average value for two specimens per spaceboard.

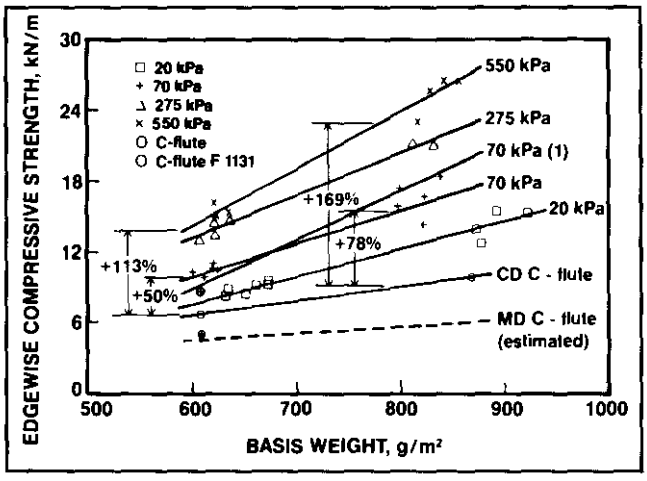
Bending stiffness values for spaceboard and C-flute are shown in Fig. 4. Since bending stiffness is a function of thickness, it is best to compare specimens of equal thickness. For this study, spaceboard pressed at 550 kPa was similar in thickness to C-flute **(Table 1).** The average combined board thickness was 4.1 mm (0.163 in.) at 626 g/m^2 and 4.3 mm (0.169 in.) at 838 g/m^2. Extrapolating bending stiffness values to 600 and 800 g/m^2, the values for spaceboard were 69% and 94% greater. respectively. than the geometric mean stiffness for C-flute F1131.

C-flute F1131, which was tested on the same bending apparatus as the spaceboard specimens, has a geometric mean value less than the average C-flute values reported by the Institute of Paper Chemistry (*3*). Bending stiffness values for spaceboard specimens pressed at 20, 70, and 275 kPa (3, 10, and 40 psi) are shown in Fig. 4, along with thevaluesfor C-flute F1131. However, unlike the specimen pressed at 550 kPa, the combined board thicknesses for these specimens were greater than that of C-flute, so these specimens are not comparable to C-flute. Each spaceboard stiffness data point represents the average value of two specimens per board.

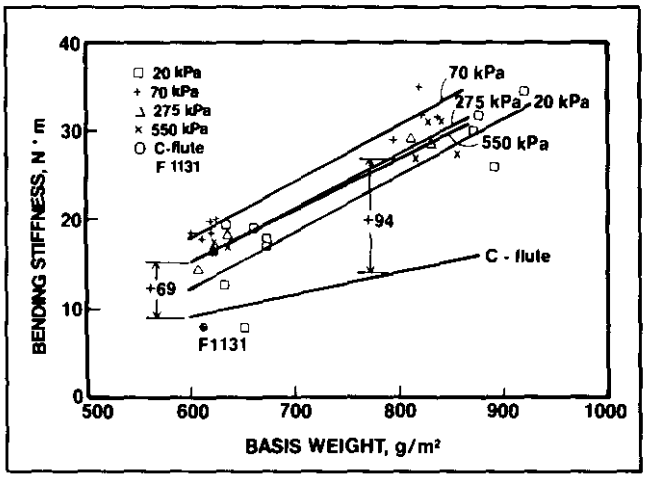
Burst strength values are shown in Fig. 5. Spaceboard burst values for basis weights around 600 g/m^2 are grouped together. but they do show a general trend to increase with increasing static pressure. At 600 g/m^2. the burst strength of spaceboard pressed with 20 kPa was 43% less than that of C-flute. while spaceboard pressed with 550 kPa was 31% less. As spaceboard basis weight increased, burst strengths for specimens pressed at 70, 275, and 550 kPa increased at a faster rate than the strength of C-flute: at 800 g/m^2. the burst strength of spaceboard pressed with 550 kPa was slightly less than the strength of C-flute. Each spaceboard data point represents one specimen per board.

In **Fig. 6.** flat-crush strength as a function of deformation is plotted for spaceboard and C-flute F1131. Spaceboard has a rib weight of 180 g/m^2, ±17%. Rib weight was determined by weighing a bonded sample, grinding the ribs off. and reweighing the remaining sheet. The calculated weight for the glue was subtracted from the

3. Edgewise compressive strength of spaceboard. C-flute fiberboard, and C-flute F1131.



4. Bending stiffness of spaceboard. C-flute F1131, and C-flute fiberboard.

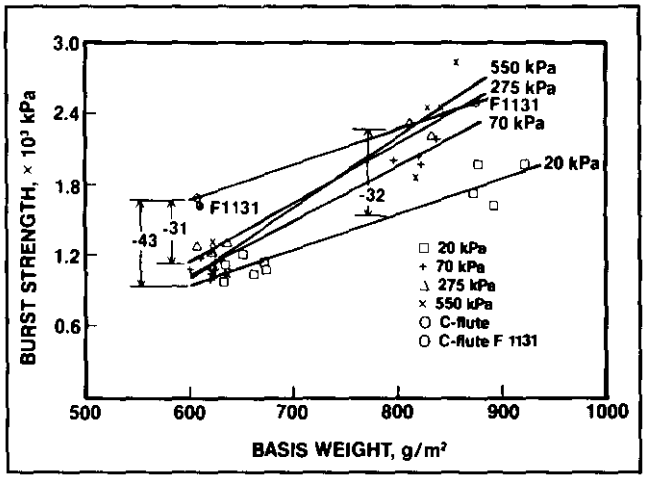


I. Thickness of FPL spaceboard and C-flute fiberboard

	Thickness, mm (in.)	
	600–700 g/m²	800–900 g/m²
Spaceboard*		
20 kPa	5.4 (0.213)	5.7 (0.224)
70 kPa	5.3 (0.208)	5.5 (0.216)
275 kPa	4.4 (0.174)	4.6 (0.181)
550 kPa	4.1 (0.163)	4.3 (0.169)
C-flute	4.2 (0.165)	4.4 (0.174)

*Wet-press and dry-press pressures.

5. Burst strength of spaceboard. C-flute F1131, and C-flute fiberboard.



rib weight. The corrugated medium of F1131 has a weight of 180 g/m² (medium × 1.42 takeup factor). Flat-crush curves for spaceboard do not show complete collapse of the ribs. Partial failure occurred where the slope decreases, but then core resistance increased with further deformation. The curve for F1131 shows that C-flute reaches a maximum load and then collapses. Each curve is the average of five or more flat-crush specimens.

Discussion

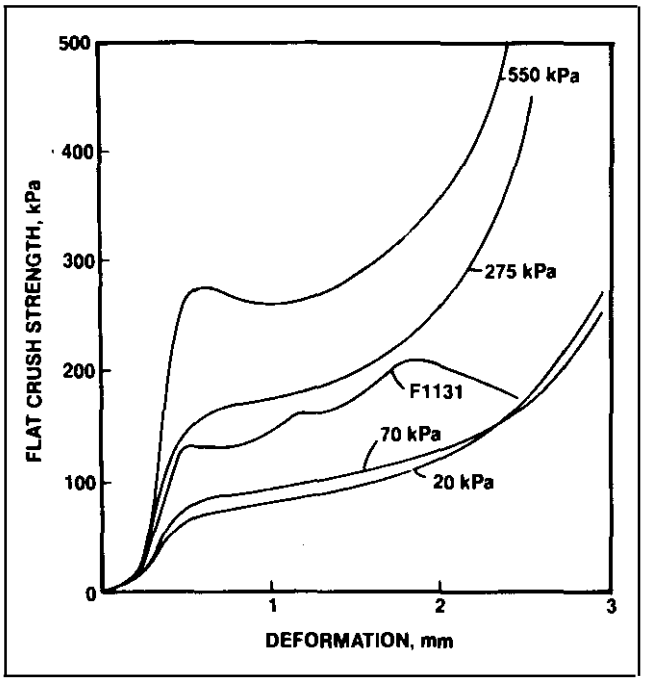
The new method for forming spaceboard has several advantages over the previous method. By forming the three-dimensional web on a specially fabricated wire screen, for instance, we can use existing fourdrinier or cylinder-forming technology. When we use flowthrough forming, the pulp slurry is more dilute, resulting in better fiber distribution over the entire web. The wire screen on thebottomallows the water to exit vertically, whereas with the solid molds used in the previous method. the water must exit laterally.

Because the fibers are more dispersed and the water can travel vertically, the entire spaceboard web can be formed at once and in less time. Another advantage of placing the pads on the wire screen is that the pads act independently of the wire screen base. In the previous method, the rubber base would spread the overall matrix pattern of pads when the mold was pressed. We used a metal retainer on the outside of the mold to prevent the spread of the mold and spaceboard web. No retainer is needed with the new spaceboard screen.

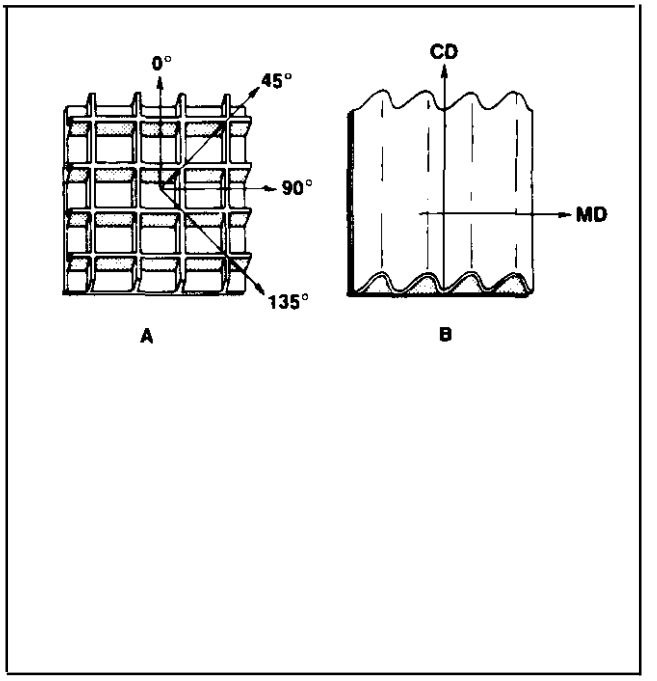
Taking into account the differences in the two forming methods, both produce spaceboards of equivalent strength (Fig. 3). Assuming that the three-dimensional fiber distribution is the same for both methods, the procedure and effect of pressing and drying on silicone-rubber pads is also the same. Both press and dry the web, densifying and holding it by pad deformation.

All the strength and stiffness properties of spaceboard increased as static pressure increased from 20 to 550 kPa. This improvement was expected since increased pressure increases the pad deformation, which increases the fiber-

6. Flat-crush curves for spaceboard and C-flute F1131



7. Principal loading directions for spaceboard and C-flute fiberboard. A: Symmetry of spaceboard at 0° and 90° and at 45° and 135°. B: Machine and cross-machine directions of C-flute.



to-fiber bonds. The silicone-rubber pads also provide more uniform pressure because the rubber conforms to the fiber formation.

Burst strength of spaceboard was lower than that of C-flute except for spaceboards of high basis weight pressed at 550 kPa. We believe that burst strength can be improved through changing process variables or the fiber furnish. For example, in unreported trials. we found that by increasing the static pressure to 1100 kPa (160 psi) at 800 g/m^2, the burst strength increased to 13% above C-flute values.

Changes in basis weight did not affect flat-crush strength because the amount of material formed between the pads remained the same as the basis weight increased. The mode of failure was different in spaceboard and C-flute: the ribs on spaceboard crush vertically. Therefore, the material in the ribs compresses, especially at the rib intersections, increasing the resistance to further crushing. In contrast, the corrugated medium ("ribs") of C-flute progressively buckle until complete collapse occurs.

Conclusions

The new forming method for FPL spaceboard opens the way for producing three-dimensional fiber structures using flowthrough technology. Three-dimensional forming, consolidating, and drying on a spaceboard screen result in a product with improved strength and stiffness, compared to C-flute.

Our data represent only one mold size, one forming procedure, one fiber furnish, one pressing and drying procedure, and one arrangement for combining the components. Studies are needed in each of these areas to understand and optimize the strength and stiffness properties of spaceboard. In addition, as we refine the spacehoard process, we need to fabricate a large sheet to determine actual container properties.

Experimental procedures

Formation of test spaceboard

We chose a pad geometry of a partial pyramid that was 6.22 mm square (0.245 in.) at the bottom, 5.72 mm square (0.225 in.) at the top, and 2.54 mm (0.100 in.) tall. The spacing between each pad was 1.4 mm (0.055 in.). The fiber furnish was birch. 60% yield, unbleached kraft, refined to 570 mL CSF (Canadian Standard Freeness). The consistency of the pulp slurry was 0.2%. The spaceboard screen size was 23 × 23 cm (9 × 9 in.). We pulled a vacuum of 10–13.5 kPa (3–4 in. Hg) below the screen to form the web. The forming time was 10–12 s with this spaceboard screen, fiber furnish, consistency, and vacuum.

After the web was formed, the web and the spaceboard screen were transferred to a static press for dewatering and consolidation. The static press was also used for hot pressing, so the dewatering package was insulated on top and bottom to prevent drying.. The dewatering package consisted of the following items: a 1.6-cm-thick (0.625 in.) wooden caul, blotters. nylon fabric. fiber web, spaceboard screen, blotters, metal caul, and a second 1.6-cm-thick wooden caul. The nylon fabric was used to prevent bonding between the fiber web and the blotters. The wet webs were pressed for 15 s at one of four pressure levels: 20.70.275, or 550 kPa (3, 10, 40, and 80 psi). The exiting moisture content of the web (wet basis, g water/g total) decreased with increasing pressure, from 84% at 20 kPa to 68% at 550 kPa.

The drying package consisted of a flat-warp, phosphor bronze screen, at a mesh of 34 × 36 wire/cm (88 × 92 wire/in.). This screen was placed on top of the spaceboard web, and a bronze screen with a mesh of 6 × 7 wire/cm (15 ×

18 wire/in.) was placed below the spaceboard screen. This package was placed back into the hot press and was pressed at the same pressure used for the wet press. The temperature of the top platen was 190°C (375°F). The bottom platen temperature was 132°C (270°F). Drying times decreased from 5 min for the low-pressure, high-basis-weight webs to 1 min for the high-pressure. low-basis-weight webs. For this study, we were not interested in determining the drying rates. The spaceboard sheets were oven dry when removed from the press. They were placed overnight in a Conditioning room held at 23°C (73°F) and 50% RH (relative humidity).

Each conditioned sheet was weighed and paired with another sheet with the closest matching weight. Polyvinylacetate adhesive was applied to the top of the ribs on each sheet. The adhesive spread was 4% to 8% (g adhesive/g total). For this study, we were more concerned with establishing a good bond between the sheets than with the amount of adhesive applied. After the adhesive was applied, the two sheets were aligned rib to rib (Fig. 1). The combined board was pressed with 7–14 kPa (1–2 psi) between hot platens for 2 min to set the adhesive. The top and bottom platen temperature was 132°C. The finished spaceboard was placed back in the conditioning room for approximately 24 h before test specimens were cut.

Tests of board properties

Test specimens were cut from the 23 × 23-cm spaceboard we had made. Two bending specimens were first cut from the middle of the spaceboard across the diagonal. Each specimen was 3.8 cm (1.5 in.) wide by 24.0 cm (9.5 in.) long. We used a specially modified. four-point loading apparatus (*5*) to apply the load and measure the deflection of the specimen, as specified by TAPPI method T 820. The total span between the outside loading points was 20.3 cm (8.0 in.), and the inner span between loading points was 10.2 cm (4.0 in.). The crosshead speed was 0.5 cm/min (0.2 in./min). Deflection was recorded as a function of load.

The ECT specimens were prepared and tested on a flexible beam tester according to TAPPI method T 811. For both ECT and bending stiffness specimens, the ribs were aligned at 45° to the principal loading direction. Preliminary ECT had shown that a 45° alignment results in approximately 30% higher ECT strength than a 0° alignment. For bending strength. our preliminary tests had indicated no significant difference between rib orientations. The cross-rib pattern of spaceboard yields the same properties measured 90° apart (at 0° and 90°) and at 45° and 135° **(Fig. 7A).** whereas the properties for C-flute are more directional because of the orientation of the corrugated medium **(Fig. 7B).** Because of the orthogonal symmetry of spaceboard, we measured only one direction for ECT strength and bending stiffness. The effect of the rib orientation (0° compared to 45°) on in-plane properties will be reported in a later study.

One specimen, 5.4 cm (2.13 in.) in diameter, was cut from each spaceboard to test flat-crush strength. Each specimen was compressed between two parallel rigid platens. The crosshead rate was 1.0 cm/min (0.39 in./min). Load as a function of spaceboard deformation was recorded. We chose this method for determining flat-crush strength rather than TAPPI method T 808, in which failure is defined as "the maximum load sustained before complete collapse," because we preferred to view load as a function of deformation. This view allowed us to better characterize the flat-crush strength of spaceboard as compared to C-flute.

One specimen was taken from each spaceboard to test burst strength. The shape of the specimen was a right triangle with two 16.5-cm (6.5 in.) sides. The test procedure followed TAPPI method T 810.

All test specimens were conditioned at 23°C and 50% RH for approximately 24 h before testing. We used four sources of data to compare the strength properties of the new forming method. First, we used previous spaceboard ECT data from Setterholm's report (*1*). Second, we used data from a 1982 report (*2*), which lists the average C-flute fiberboard values for ECT and burst strengths only. Third, we used data from an older report (*3*) to obtain approximate bending stiffness values for C-flute. Finally, we measured the four properties for a C-flute fiberboard, designated C-flute F1131.

Literature cited

1. Setterholm, V. C., Tappi 68(10): 97(1985).
2. Institute of Paper Chemistry, Project 3511, Oct. 10, 1982.
3. Institute of Paper Chemistry, Report 85, Project 2695-3, Dec. 29, 1967.
4. Setterholm, V. C. and Hunt, J. F., U.S. pat. 4,702,870 (Oct. 27, 1987).
5. Flexural stiffness of corrugated fiberboard (mechanical method). TAPPI urn 818, TAPPI PRESS, Atlanta, 1988.

Received for review May 19, 1988.

Accepted July 27, 1988.