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FPL SPACEBOARD DEVELOPMENT

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ABSTRACT

The future direction of structural products from fibers will be toward more efficient fiber utilization through efficient design. The Forest Products Laboratory has developed two processing methods to produce three-dimensional structural sheets and panels made from fibers. The structural board that results from combining two sheets or two panels is called FPL Spaceboard.

The thickness of the sheet or panel generally determines which processing method to use. For sheets up to 20 mm thick, a fourdrinier wire with silicone-rubber pads is used to form, press, and dry the sheets. For panels above 20 mm thick, a batch-forming mold is used with special retractable porous mandrels. This paper describes both methods.

The method for thinner materials has been used to make, combine, end test FPL Spaceboard. The FPL Spaceboard shows significant gains in strength over C-flute fiberboard. The method for thicker materials has been used to make a number of panels on a small mold. The strength and elastic modulus values for the face material are consistent with high-density hardboard values. Further strength evaluations will be conducted when 0.61- by 1.22-m panels are formed in a new mold being constructed.

The two methods show a number of advantages for producing structural products but are not without disadvantages and development challenges, which need to be addressed before FPL Spaceboard can become a reality. If the processes can be developed, there exists opportunities to use the new forming methods to produce structural boards for existing markets or for new products.

INTRODUCTION

What is FPL Spaceboard? It is a pulp-molded three-dimensional fiber or composite sandwich like structure, which is usually made of two identical sheets, each having a flat surface on one side and a structural rib pattern on the other. The two sheets are bonded rib-to-rib to form a structural board (Fig. 1). The spaceboard concept could be used for a variety of structural boards, from E-flute to wall sections. The principle of spaceboard is to distribute fibers in a three-dimensional sheet for the most efficient use of the fiber material.

The Forest Products Laboratory (FPL) has developed two processing methods (1 , 2) to form, dewater and consolidate, and dry three-dimensional spaceboard sheets. This paper describes the two processing methods; the strength and stiffness values of spaceboard; and the advantages, disadvantages, and development challenges of the product and process.

BACKGROUND

The spaceboard concept emerged from research aimed at improving the support of linerboard in corrugated fiberboard and the efficient distribution of fibers in structural boards. Experiments at FPL showed that the edgewise compression strength of corrugated fiberboard with press-dried linerboard and conventional corrugated medium was lower than anticipated. It was suspected that the corrugated medium was not providing sufficient support to the linerboard. In experiments by Vance Setterholm and Dennis Gunderson of FPL, a combined board made from two linerboards fully supported by a low-density foam core yielded higher edgewise compression strength than the combined board with the same linerboard separated by conventional corrugated medium. It was evident that improving the support of the linerboard could be used to improve the strength of the combined board,

Setterholm experimented forming sheets with an integral rib (medium) and face (linerboard) on various three-dimensional molds. The ribs crossed the face in two directions to increase the support of the facing. Combining the sheets and testing in edgewise compression, Setterholm (3) showed that the pulp-molded structural board, called spaceboard, yielded significantly improved strength compared to conventional C-flute fiberboard. The forming process was then further refined (4) so that spaceboard webs could be made with conventional forming equipment for making paper (Fig. 2).

Setterholm expanded his research to include pulp-molded structural panels approximately 20 times the size of the thinner spaceboard. The thicker spaceboard was named FPL Spaceboard II (SB II) and the thinner spaceboard, FPL Spaceboard I (SB I). The SB II combined board is nearly 89 mm thick. Possible uses for SB II are for walls, floors, roof decking, and other structural panels. The reason for exploring structural panels from fibers is that the future direction of structural products will be toward more efficient fiber utilization through efficient design (5 , 6 , 7). This can be seen in the development of wooden "I" beams, where the top flange can be made from laminated veneer and the web from plywood or hardboard. The initial forming process for SB II was patterned after the refined forming process (4) of SB I. However, several problems were encountered because of the large shrinkage of the thick wet web. A new forming process for SB II (2) was developed to overcome the problems.

PROCESSING METHODS

Spaceboard I

Forming the SB I web 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 SB I has silicone-rubber pads, which direct the flow of water and fibers. The fourdrinier

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wire screen with the silicone-rubber pads is called the spaceboard screen. The fibers flow around the pads forming a three-dimensional web (Fig. 2a).

The silicone-rubber pads on the spaceboard screen are important for consolidating the three-dimensional web. Once the web has been formed, both the spaceboard web end screen are placed in a wet press. The resilient pads compress under the pressure but expend laterally, end this expansion densifies the fibers that form between the pads. Thus, by applying a normal force to the SB I web end screen, the web is densified in all directions (Fig. 2b).

The spaceboard screen is also used to dry the SB I web. After the web has been formed and consolidated, the web and screen are pressed in a hot press. The same compression and lateral expansion of the pads takes place in the hot press to hold the web until it dries. The final sheet thickness is dependent on the normal force, silicone properties, and spacing between the pads. The pads are made of silicone rubber because silicone is resilient and does not readily break down in the presence of heat end moisture.

Spaceboard II

Forming the thicker SB II is more complex than forming SB I. The thick mat is formed by first distributing the fiber/water slurry over the mold. Instead of using silicone-rubber pads to direct the flow of fibers, SB II uses porous mandrels (Fig. 3a). To ensure proper formation in the deep sections between the mandrels, special covers are used to direct the flow of fibers. Formation starts at the bottom of the porous mandrels end continues up as the covers are pulled up (Fig. 3b). The top surface layer forms when the covers are completely removed (Fig. 3c).

To dewater end consolidate the SB II mat also differs from the SB I method. After the mat has been formed, a flat press pushes on the face of the mat (Fig. 4). The mandrels are movable and retract under the pressure, thus dewatering and consolidating the mat. The mat is semirigid after pressing but still fragile end easily damaged if carelessly handled.

The mat can be dried in two ways. One way is to keep the consolidated mat on the porous mandrels end place the entire package into a hot press. Heat and pressure can be applied to the mat until all the moisture is removed. The mandrels continue to retract as the mat dries, thus densifying the ribs vertically. In the second way, the consolidated mat is transfered to a second mold with large silicone pads instead of mandrels. The mold and mat are then placed in the hot press. The silicone pads compress under pressure and expand to densify the ribs horizontally. In either way, consolidation pressure is applied through the drying process to maintain fiber-to-fiber bonding in the mat.

RESULTS

Spaceboard I

We conducted a study (4) with the following objectives: to describe a new forming method (1), to compare the strength of SB I formed by the new method to SB I formed by the previous method (3), and to evaluate the properties of SB I compared to C-flute fiberboard. We made a series of boards of varying board weight, from 300 to 425 g/m^2, and pressing pressure, from 20 to *550* kPa. The wet and dry pressing pressures were the same. The webs were dried in a flat press with the top and bottom platens at 190 and 135°C, respectively. The fiber furnish was birch, 60% yield unbleached kraft, refined to 570 CSF.

The SB I sheets were made on a 230- by 230-mm mold. The sheets were bonded together rib-to-rib to form a combined board. Specimens were cut from the board for tests of edgewise compression strength, bending stiffness, burst strength, and flat-crush strength. At 600 g/m^2, SB I had a similar weight distribution as a 205-126-205 g/m^2 C-flute fiberboard. When SB I weight was increased, most of the additional fibers were distributed on the surface end not in the ribs.

The edgewise compression (ECT) results are shown in Fig. 5. The ECT strength of spaceboard increased with increased static pressure end basis weight. At equal static pressure of 70 kPa, the new forming method gave equivalent strength as the previous forming method reported by Setterholm (3). When compared to average C-flute fiberboard values, SB I strength was significantly higher than that of C-flute fiberboard in its strongest direction, cross-machine direction (CD), or parallel to the flutes. The ECT strength of SB I pressed at 70 to 550 kpa was 50% to 113% greater then that of C-flute fiberboard at 600 g/m^2 end 78% to 169% greater then that of C-flute fiberboard at 800 g/m^2. The dashed line represents the estimated ECT strength of C-flute fiberboard in the machine direction (MD) or perpendicular to the flutes. Also shown is the machine and cross-machine direction ECT strengths for C-flute fiberboard tested at the FPL, designated C-flute F1131.

Bending stiffness values for SB I and C-flute fiberboard are shown in Fig. 6. For this study, SB I pressed at 550 kPa was similar in thickness to C-flute fiberboard (Table 1). Bending stiffness values at 600 end 800 g/m^2 were 69% and 94% greater, respectively, than the C-flute fiberboard geometric mean of the machine end cross-machine directions, $(MD \times CD)^{1/2}$. The C-flute F1131 has a geometric mean value less than C-flute fiberboard values reported in the literature.

Burst strength values are shown in Fig. 7. At 600 g/m^2, the burst strength of specimens pressed with 20 kPa was 43% less then that of C-flute fiberboard, end with 550 kpa, the burst strength was 31% less. As SB I weight increased, burst strengths for specimens pressed at 70, 275, end 550 kPa increased at a faster rate then the strength of

C-flute fiberboard, so that at 800 g/m^2, the burst strength of SB I pressed with 550 kPa was slightly less than the strength of C-flute fiberboard.

In Fig. *8,* flat-crush strength as a function of deformation is plotted for SB I and C-flute F1131. The amount of fiber in the core for SB I and corrugated medium was equivalent, 180 g/m^2 (medium x 1.42 takeup factor). Flat-crush curves for SB I 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 C-flute F1131 shows that the corrugated medium reached a maximum load end then collapsed.

Spaceboard II

The development of SB II lags behind that of SB I. To date, we have fabricated 20 test panels of reasonably consistent quality. They measure 280 by 280 by 50 mm thick. This size is too small for meaningful bending tests. Our initial tests examined the material properties in face and web. Density of the face was 900 to 1,000 kg/m^3 (specific gravity 0.9-1.0), while that of the web section was as low as 200 kg/m^3. Tensile strength and elastic modulus values for the face material were nominally 37.9 MPa end 7.6 GPa, respectively. These values are consistent with handbook values for high-density hardboard (8). Compression strength values for the face were somewhat greater than handbook values for reasons not yet apparent. In both tension and compression tests, the face material failed in the region over the rib. We believe this reflects lower density in the face at the rib--a condition we intend to correct in further process development. It is not clear at this point to what degree we should attempt to increase rib density. This will be determined from strength and bending stiffness tests conducted on 0.61-m by 1.21-m by 50-mm panels soon to be formed in a new mold apparatus.

DISCUSSION

Spaceboard I Advantages, Disadvantages, and Development Challenges

Spaceboard I has several evident advantages. First, the concept of three-dimensional fiberboard, when compared to corrugated board, would eliminate the need for a corrugator. The purpose of corrugated medium is to separate the two linerboards to form a structural board. In SB I, the formed ribs provide the means to separate the facings. Second, since the facing and ribs form one integral board, there is only one glueline at the neutral axis of the combined board rather than two with corrugated fiberboard. Third, SB I has higher strength and stiffness per unit basis weight, which is caused by several factors such as cross support of the facing, integral rib and facing, more efficient placement of the fibers, and three-dimensional densification capabilities of the silicone-rubber pads. Fourth, the cross-support pattern also provides more uniform properties in the machine and cross-machine directions, whereas corrugated fiberboard has more unidirectional properties. Finally, the three-dimensional-shaped mold opens up new design possibilities for finished boards for specific applications.

While SB I has advantages, it is not without some disadvantages. First, the ribs cannot be formed with long fibers. The reason is that longer fibers bridge the gap between the pads rather than form down between the pads. However, the ribs can be formed with hardwood or recycled newsprint fiber, Second, the pattern on the facing may detract from appearance or from printing. The pattern is both a visual and physical variation. The visual pattern is due to differences in the face density. The physical variation is due to pressure differences across the face during drying and fiber shrinkage forces. The pattern differences decrease as pressing pressure increases during drying.

If the SB I concept is to become a reality, several development challenges need to be addressed. First, a viable commercial method for attaching silicone-rubber pads to a wire screen needs to be developed. Second, once the web is formed and wet pressed, drying the web will be a challenge. Adding the third dimension to a web adds new variables to existing flat-web drying processes. Third, since strength properties are a function of drying pressure, new dryer configurations may need to be developed, such as continuous press dryers. Fourth, handling the structure will be different. The three-dimensional structure is complete at the end of the drying process and cannot be rolled up. The sheet must be cut off and stacked. Finally, bonding the two sheets at the ribs may require unique alignment machines.

Spaceboard II Advantages, Disadvantages, and Development Challenges

The SB II material, reconstituted from pulped fiber, is highly uniform; it has no grain, checks, or knots. Its compressive strength and stiffness can be as great as that of solid clear wood--without the strength-reducing defects inherent in wood. The structural design is efficient. It can be optimized for the demands of a specific application, and the fiber can be placed where it is most needed. A complex efficient design can be constructed. Highly efficient designs in solid wood, on the other hand, often involve extensive labor, precision millwork, and considerable waste of material. The design of SB II is also attractive because the material is formed in a ready-to-use configuration. We envision that panels for structural applications would be formed in the final shape with all design features built in-- interface end fastening means included. Construction would entail assembly of engineered components rather than onsite fabrication from a variety of basic components. Spaceboard II is also attractive from a material point of view. Solid wood that is unusable for other construction and material purposes would be a valuable resource for SB II fabrication. Solid wood scraps end wastes, woodlot residues and rejects, and underutilized species are all candidate materials for SB II.

The SB II concept is not without tradeoffs, however. As now envisioned, SB II will not be a general use, commodity panel product but will be designed and fabricated for specific construction configurations. Our intent is to trade off application flexibility for efficiency in material use end assembly. For applications involving long-term stability in changing temperature and humidity, the performance of solid wood and, of course, metal construction is hard to equal. The dimensional stability of untreated SB II will be similar to that of dense fiberboard--unsuitable in some applications but entirely acceptable in others.

The development of SB II involves many challenges. The greatest technical challenge at present is to form, dewater, and dry the board in a way that yields consistent density throughout the cross section <u>and</u> to accomplish this at a production rate that renders the board economically attractive. The performance of forming methods developed thus far is very promising; economic feasibility is yet to be determined.

Spaceboard II material and products will be unique. Acceptance in the construction, furniture, or packaging markets will require not only that SB II perform well but that it overcome the many natural barriers to change inherent in the marketing, application, and licensing or code requirements for any new material. Key performance issues to be addressed in the development process are as follows: dimensional stability in changing humidity environment; loss of strength, stiffness, and surface finish in humidity environments; creep under load; and fire resistance. These performance concerns (common to all fiber-based composite panel products) are amenable to change through use of chemical additives and fiber modification. The research and development of effective, safe, end economical processes is a challenging opportunity for chemical and polymer scientists.

CONCLUSIONS

In this paper we have shown two processing methods for forming three-dimensional structures from fibers We believe that these methods could provide a means to design efficient structural products made from fibers. For SB I and SB II to become a reality, several engineering challenges need to be addressed to determine if the methods are technically feasible and economically viable. If the processes can be developed, there are numerous opportunities to use the new methods to form structural boards either for existing markets or for new products. It is interesting to note that, parallel to these developments, significant advances are being made in fiber modification and fiber composites. These advances will further enhance the performance of three-dimensional structural fiber products.

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Table 1. Thickness of FPL Spaceboard and C-flute fiberboard.

Board type	Board thickness, mm	
	600-700 g/m^2	800-900 g/m^2
Spaceboard[a]		
20 kPa	5.4	5.7
70 kPa	5.3	5.5
275 kPa	4.4	4.6
550 kPa	4.1	4.3
C-flute fiberboard	4.2	4.4

[a]Wet-press and dry-press pressures.

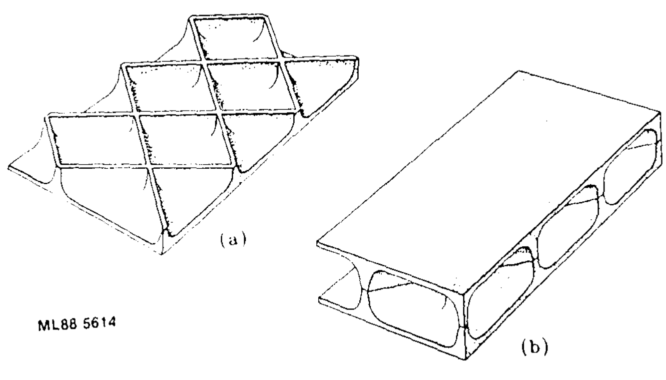
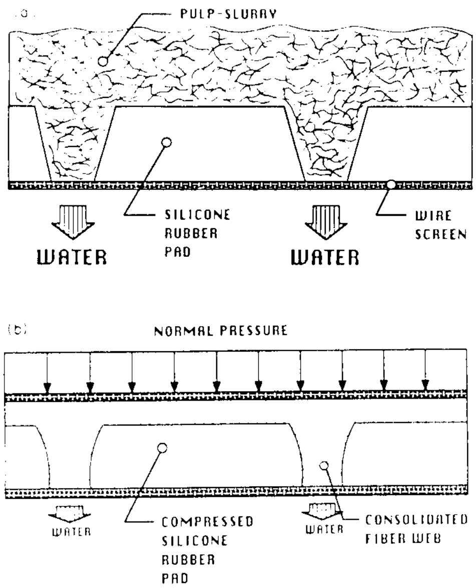
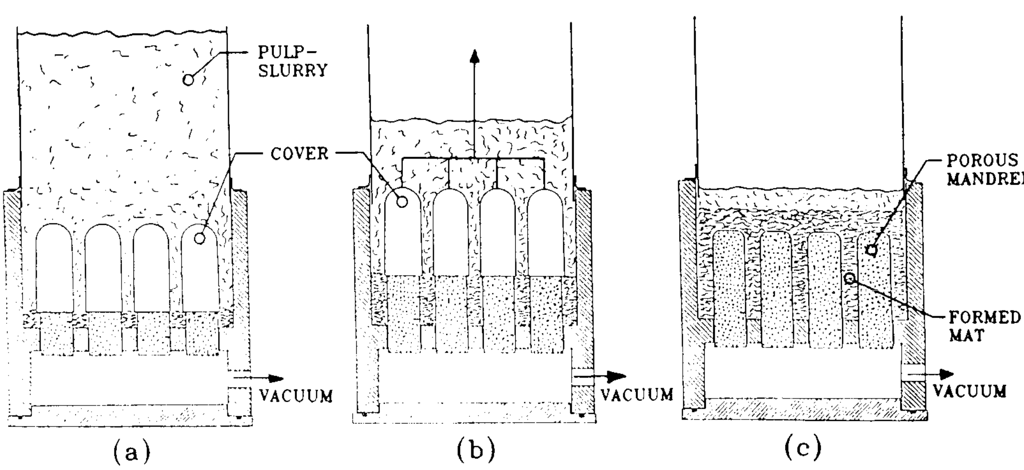


Figure 1. Construction of FPL Spaceboard. (a) One sheet of the spaceboard "sandwich" shown with the ribs facing up. (b) Two sheets bonded together at the ribs form the structural board. (ML88 5614)



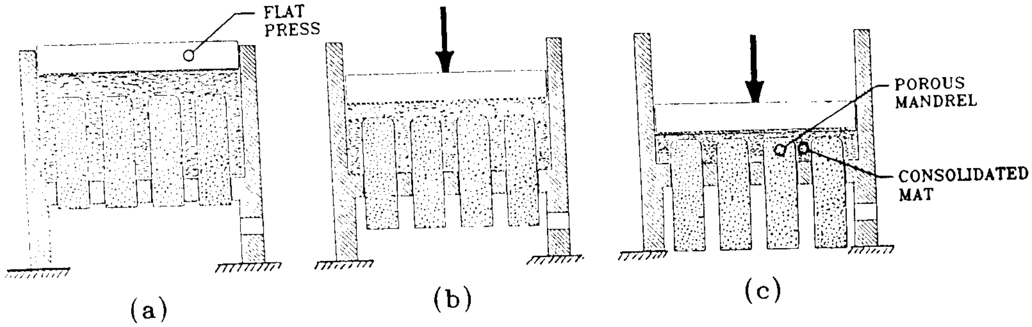
ML88 5449

Figure 2. Side view of the spaceboard screen consisting of silicone-rubber pads attached to a fourdrinier screen. (a) A fiber mat is formed around the pads as water passes through the screen. (b) Normal force applied to the spaceboard screen compresses the pads causing them to expand laterally and consolidate the fibers between the pads. (ML88 5449)



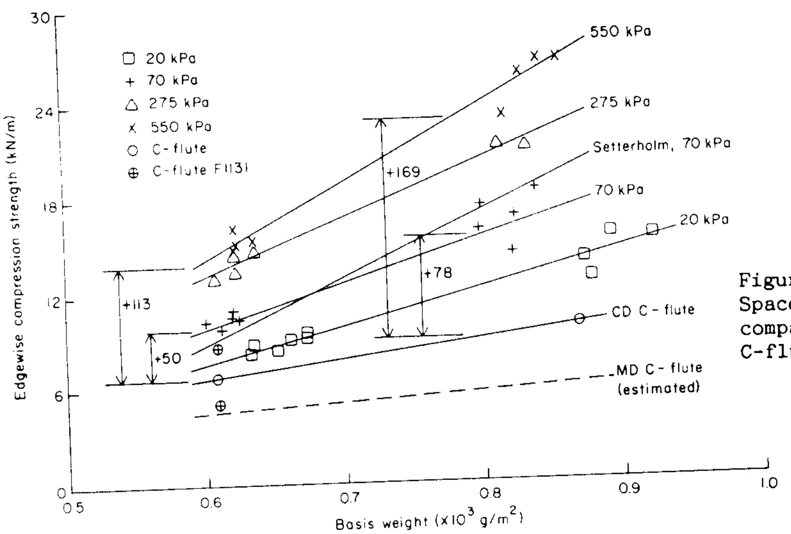
ML88 5615

3. Side view of Spaceboard II being formed. (a) Fibers are distributed over the mold and special covers are placed over porous mandrels. (b) The covers are slowly removed, forming the web from the bottom up. (c) The top surface forms when the covers are completely removed. (ML88 5615)



ML88 5616

Figure 4. Side view of Spaceboard II being dewatered and consolidated. (a) A flat press pushes on the face of the mat. (b) The mandrels retract under the pressure of the press. Water passes through the surface screen and porous mandrels. (c) Both the ribs and the face have been consolidated. (ML88 5616)



ML88 5435

Figure 5. Edgewise compression strength of Spaceboard I made with the new forming method compared with the strength of previous spaceboard and C-flute fiberboard. (ML88 5435).

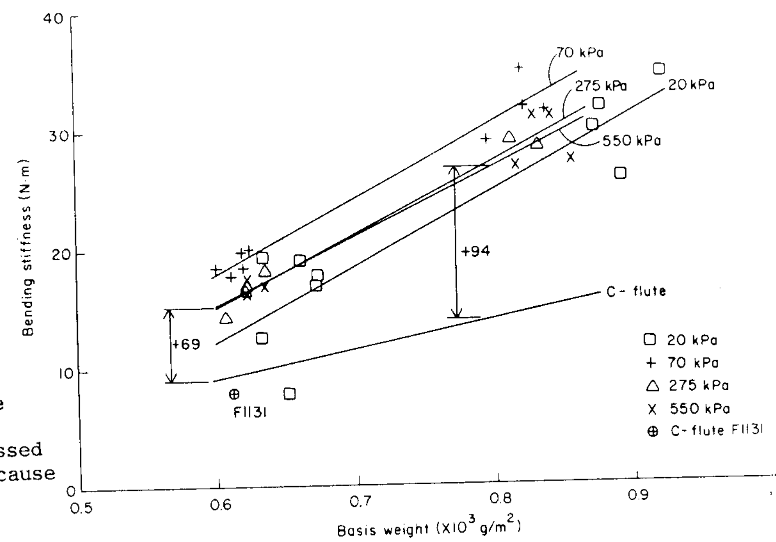
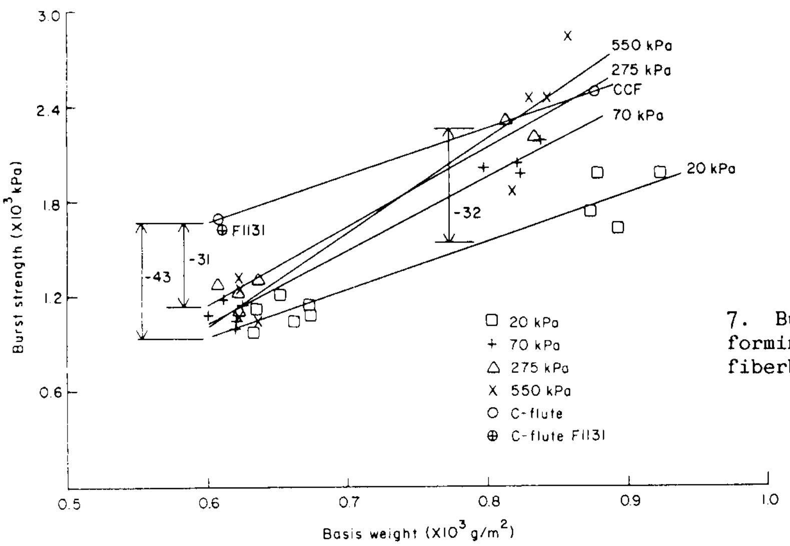


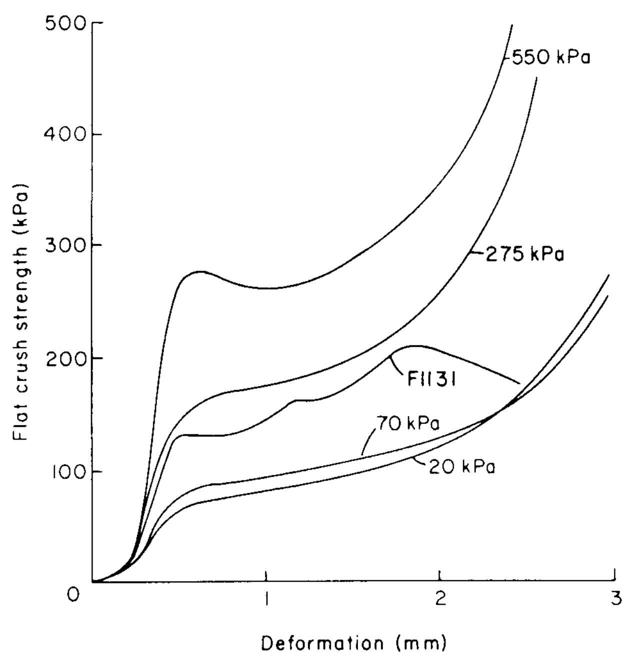
Figure 6. Bending stiffness of Spaceboard I made with the new forming method compared with the stiffness of C-flute fiberboard. Spaceboard pressed at 550 kPa was compared to C-flute fiberboard because both boards had similar thickness. (ML88 5434)

ML88 5434



ML88 5436

7. Burst strength of Spaceboard I made with the new forming method compared with that of C-flute fiberboard. (ML88 5436)



ML88 5437

8. Flat-crush strength curves for Spaceboard I made with the new forming method plotted in comparison with that of C-flute F1131. (ML88 5437)