3-D FIBER FORMING - A STEP TOWARD ENGINEERED SANDWICH CONSTRUCTION

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Two fiber forming methods have been developed that can form fibers into a three-dimensional (3-D) ribbed matrix. This forming process can use wood-fibers, virgin and recycled, or most any other cellulose or synthetic fiber to form a 3-D matrix. Once the matrix is formed, there is a variety of methods that can be chosen to set the matrix for the final performance properties, ranging from natural bonding to synthetic resins. This paper will discuss the forming process, some unique capabilities of this process, and present strength properties of wood-fiber and preliminary wood-fiber/fiberglass-fiber structures made using prototype molds.

INTRODUCTION

Traditional three-dimensional (3-D) sandwich panels made from wood, wood fibers and/or synthetic fibers currently achieved the I-Beam form by reforming or reshaping two dimensional (2-D) sheet materials and then bonding or constructing them into 3-D structures. Examples include corrugated fiberboard, expanded paper honeycomb panels, wood I-Beams, 2x4 stud framing, and the like. The structures assembled in these ways perform very well. However, additional improvements could be made, for some applications, if specific material could be placed in a specific location for a specific performance requirement. With traditional fabrication techniques complex 3-D patterns are limited in shape and form because of the difficulty in reforming 2-D materials into 3-D shapes. Our

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goal is to by-pass the 2-D product manufacturing and secondary processing by selectively forming fibers into a 3-D design or structure and then processing that structure in such a way as to impart maximum performance for its specific application.

The USDA Forest Products Laboratory has developed two 3-D forming processes, called FPL Spaceboard which we believe are initial steps toward producing engineered structures directly from fibers. These technologies have been licensed to Gridcore Systems International, Carlsbad, CA for use in construction/furniture applications and to Noble Franklin Limited, Carlsbad, CA, for use in marine/aerospace/transportation applications.

FORMING PROCESS

Background

The initial concept for the FPL Spaceboard process came out of research at the Forest Products Laboratory to improve utilization of under utilized wood fiber species for use in corrugated packaging. A process was developed, called Press Drying, that improved the strength of paper by restraining the fiber matrix during the drying process through fiber-to-fiber bonding. Setterholm (1) began research into alternative forming methods that would incorporate the benefits of press drying for improved support of the linerboard or face of corrugated. Out of this research two forming process concepts were developed. One method uses rubber pads attached to a forming screen to form, densify and, if desired, restrain the fiber mat during drying and/or curing. The second concept uses retractable porous mandrels to form deep thick ribs. The formed 3-D mat is subsequently removed, pressed, and dried similar to the first method.

Concept I

Forming. The first forming concept, Setterholm and Hunt (2), is similar to forming a flat web on a paper machine or flat-sheet batch former where the fibers are suspended in a carrier fluid and then are deposited on a, screen while the carrier fluid flows through. For 3-D forming we have flow of water and fibers. The fibers flow arid are deposited between and on top of the pads thus forming the 3-D mat. The desire during forming is to selectively place fibers into a 3-D matrix for a specific structure by a predetermined pad arrangement on the screen and the individual pad geometry.

Consolidating. Once the 3-D fiber mat has been formed, it is consolidated, for subsequent processing. Both the mat and the mold are placed in a press. Under compression, the pads compress vertically but expand horizontally. The fibers on top of the pads are consolidated by the normal compression while the lateral expansion of the pads consolidate the fibers between the pads. This consolidation step prepares the fiber mat for the subsequent processing steps. For example, for cellulose fibers this consolidation step removes a significant portion of the free water prior to drying, which is similar to paper or hardboard forming techniques. For some applications, it may be desirable after consolidation to remove the mat from the mold for further processing.

Curing. One process option after consolidation is to transfer the 3-D mat and mold into a hot press. This has been the primary method used in our research with cellulose fibers. The same compression and lateral expansion of the pads that occurred during consolidation also takes place, in the hot press to consolidate and restrain the mat until it dries. For cellulose, the degree of consolidation will determine the final fiber-to-fiber bonding and hence the performance of the structure.

Concept II

Forming. To form thicker more substantial structural products, a second forming concept was developed, Gunderson (3). A thick mat is formed by first distributing the fiber/water slurry over the mold. Instead of using resilient-rubber pads to direct the flow of fibers, porous mandrels are used. To ensure proper formation in the deep sections between the mandrels, special covers are used to direct the flow of fibers to the bottom of the mold. Formation starts at the bottom of the porous mandrels and continues up as the covers are pulled up. The top surface layer forms when the covers are completely removed. By changing the mandrel arrangement, mandrel geometry, and the height of the mandrels we can begin to selectively place the fibers in a structure for a specific performance requirement.

Consolidation. The mat is dewatered and consolidated by pressing the mat while at the same time retracting the mandrels. By retracting the mandrels, the fibers are consolidated between the mandrels vertically. After wet pressing, the mat is semi-ridged but still fragile and easily damaged if carelessly handled. The mandrel arrangement, geometry, and mandrel compression ratio will determine the degree of densification of the fibers between the mandrels and thus begin to impart performance properties to the mat.

Curing. The mat can be dried basically in two ways. One method is to keep the consolidated mat on the porous mandrels and place the entire package into a hot press. Heat and pressure can be applied to the mat until all the moisture is removed or resin cured. The second method is similar to the curing process described in Concept I above, by transferring the mat from the retracted mandrels to a second mold with large resilient pads.

UNIQUE CAPABILITIES

These two processes have the potential for engineering economical structures which are designed for specific applications which are not possible with existing technology. The structures that can be made are a function of mold geometry similar to the plastic and metals industry. Some of the benefits of the two forming methods are as follows.

- Engineered placement of the fibers in a 3-D structure.
- Improved fiber bonding through uniform densification and restraint during drying.
- Recycled fiber can be used with minimal removal of contaminants to form strong 3-D structures (4).
- Structural panels can be made to the finished dimension.
- Structural panels can be made with an integral flat panel, see Figure, 1.
- An integral wide flange at the base of the formed rib is obtained which is useful in subsequent bonding operations, see Figure 1.
- Complex rib geometries can be made, see Figure 2.

STRENGTH PROPERTIES

Results: Concept 1

Selected results from two studies are shown in Table 1. Subpanels were made having a hexagonal rib pattern and an integral flat sheet. Physical and mechanical strengths were measured on both the single subpanels and also on combined full panels, see Figure 1. One study looked at using alternative agricultural fibers for structural panels, Scott et al (5). This study compared the strength properties of panels made from Kenaf to those made from various combinations of recycled fibers and Kenaf. The second study looked at the potential of using demolition wood fibers and industrial waste fiberglass fibers for structural panels.

Results: Concept II

A study was conducted where 40 test panels were fabricated, 20 by a wet-forming process and 20 by a dry-forming process, Scott and Laufenberg (6). The panels measured 63.5 by 127.0 cm by 7.6 cm thick. Subpanels were made having a 10.2 cm square rib pattern and an integral flat sheet. Tests were conducted to investigate the performance properties of the panels. Panel construction was similar to that of Figure 1. The fibers in the wet-formed boards were 75% kraft red oak and 25% kraft loblolly pine. No adhesive was used in the wet-formed panels. The fibers in the dry-formed panels was an aspen MDF fiber with 10% phenol-formaldehyde adhesive added. Both panels were pressed at 760 kPa. Selected results are listed in Table 2.

TABLE 1- Comparison of Selected Physical and Mechanical Properties[1] of Panels made from Recycled, Agricultural, Corrugated, Demolition, and Industrial Waste Fiberglass Fibers.

Fiber Type / Test Description	100% OCC[2] No Resin	100% Kenaf[3] No Resin	100% OCC 2.5% PF[6]	50% OCC 50% Demo[4] 2.5% PF	50% OCC 50% FG[5] 50% PF[7]	20% OCC 80% FG 200% Epoxy[8]
<u>Thickness</u>	(mm)					
- Full Panel	17.60	17.90	16.60	13.70	18.70	18.20
- Each Face	1.85	1.96	1.17	1.63	2.80	2.66
<u>Density</u>	(g/cc)					
- Full Panel	0.240	0.250	0.203	0.250	0.330	0.540
- Face	1.160	1.120	0.990	0.860	NA	1.38
<u>Edge Crush</u>	(MPa)					
- Panel Stress	3.10	4.80	2.81	3.13	NA	40.7
- Face Stress	14.80	21.90	19.80	14.10	NA	139.7
<u>Flat Crush</u>	(kPa)					
- Core Stress	398	634	526	217	4540	6710

1. Hexagonal Rib Pattern 18mm Width.
2. Old Corrugated Containers.
3. Agricultural Fiber
4. Demolition Wood Fiber.
5. Industrial Waste Fiberglass, Chopped Strand
6. Phenol Formaldehyde in the Process Water
7. Phenol Formaldehyde, Post Treatment, Preliminary Results
8. Epoxy; Post Treatment

TABLE 2- Selected Physical and Mechanical Properties of Panels made using the Concept II forming Method.

Test Description	Wet Formed Panels	Dry Formed Panels
Thickness		
Full Panel (cm)	6.61	6.83
Each Face (mm)	2.92	6.12
Density (g/cc)		
Full Panel	0.24	0.26
Facing	1.05	0.67
Edge Crush Test (MPa)		
Full Panel Stress	4.31	3.45
Facing Stress	48.7	19.2
Flat Crush Test (kPa)		
Core Stress	500	830

CONCLUSIONS

The full potential for applications of Spaceboard and its economic benefits continues to be explored. Bringing these forming processes to commercialization requires overcoming substantial technical challenges. Adding the third dimension significantly complicates the forming process compared to 2-D processes. However, because of the potential for improved design and performance, Spaceboard has a broad range of possible commercial applications. Spaceboard has good potential for use in commercial and residential construction, Douglis (7), pending code certification, as wall, floor and roof panels, and for applications in furniture requiring flat or curved panels. The Spaceboard concept offers a new and more efficient way to use virgin or recycled fiber, natural or synthetic, for structural products through control of the process variables to match the needs of the application. We believe that these forming concepts are a step toward being able engineer of 3-D structural products directly from fibers for a variety of market applications.

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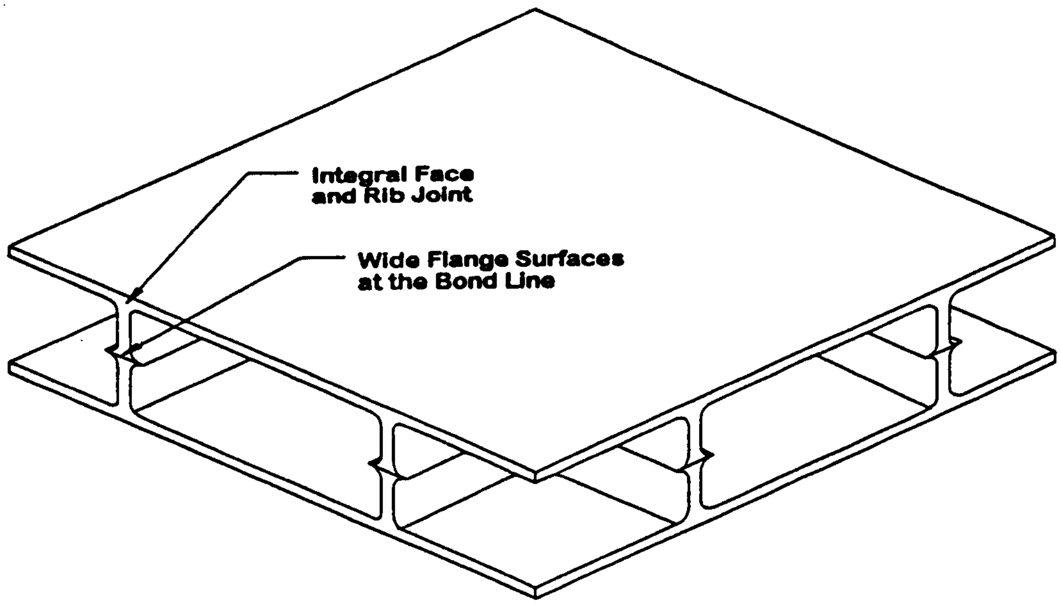

Figure 1. Two subpanels bonded at the wide flanges of the ribs to make one full panel. Each subpanel is made with rib and integral face.

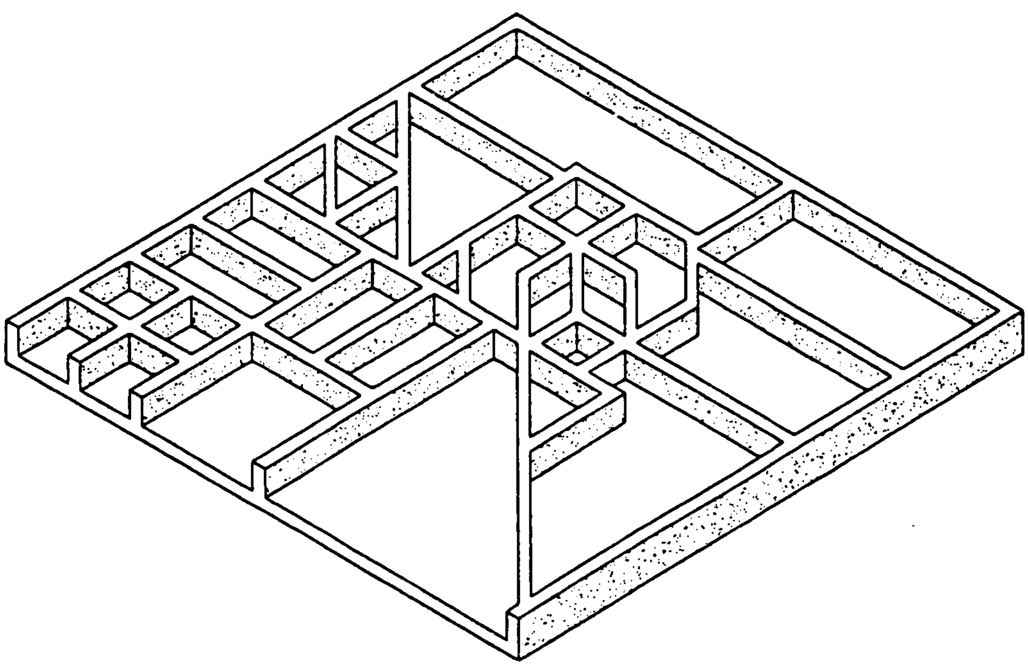

Figure 2. Complex rib geometries possible with FPL Spaceboard.