

CHAPTER 10

Packaging and Lightweight Structural Composites

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1. INTRODUCTION

Maybe the world's first package was a dry gourd used to carry water. This package was later supplemented by skin bags, earthen jars, alabaster vases, wooden casks, and crates. Now in the modern age, we have paper tubes and cartons. This listing of "natural" materials excludes the steel, plastic, aluminum, and other manmade materials so common in packaging today. Building upon the information in Chapter 6 on pulp and paper, most of this chapter centers upon the corrugated paperboard container as the predominant packaging material from agro-based fibers. The chapter also provides background on pulp molding technology that yields lightweight structural composites for packaging, construction, and industrial applications.

2. PACKAGING: A SHORT HISTORY OF THE PAPER-BASED* PACKAGING INDUSTRY

We seldom realize how recently the cracker barrel and the candy pail were usual equipment in our food stores, sharing perilously close intimacy with the kerosene can. Not until the turn of the century came the development of the packaging systems that relied only upon fibrous paperstock to store, protect, and move our precious materials and goods in neat, economical, and sanitary packages. An invention by Robert Gair in 1879 set the stage for economical mass production of folding cartons and subsequently for the corrugated fiberboard container.

The development of the corrugated container industry did not occur within a single company; rather it grew from the developments for a number of purposes. Examples are carpet linings, bottle wrappings, padding for hat sweat-bands, interior packing, quick setup cartons, etc. Many patents have been issued on both the articles and the machines for fabricating them from paperboard in England, France, and the United States.

Corrugated materials, as distinguished from boxes, were first patented in 1856 in England by Edward C. Healey and Edward E. Allen in the form of fluted material. As a packing material, it was first patented in the U.S. in 1871 by Albert L. Jones for use in protecting vials and bottles. First, corrugated materials were largely used as cushioning and wrappers for bottled goods such as patent medicines and beverages. They then were used with a paper overwrap for light parcel post and express

* Excerpts from: Wilbur F. Howell, *A History of the Corrugated Shipping Container Industry in the United States*. Published by Samuel M. Langston Co., Camden, NJ, 1940.

boxes around 1895. The first corrugated box was used to ship lamp chimneys; then fruit jars and cereals were given the official exceptions to the freight packaging specifications in 1905. Meanwhile, solid fiber boxes were first used for cereals in 1904 with the development of equipment for pasting, scoring, and slotting fiberboard. The Official Classification Committee issued their first formal rule providing general specifications for both corrugated and solid fiber boxes. Rule 2-B was from the Official Classification, along with Rule 14 and Rule 4-C from the Western and Southern Classifications, respectively. These three specifications were merged in 1920 to become Rule 41 (Dolan, 1991), which is still in use today.

A large influence in the growth of fiber-based packaging was the Pridham Decision which ended shippers' discrimination against fiber containers. In 1914, the U.S. Interstate Commerce Commission ruled that all containers should enjoy the same rates for shipment regardless of material type. Besides the boxes for canned goods, dry goods, drugs, and countless other items, other heavy packaged items have made the transition from wood packaging to corrugated fiber. Perhaps the most dramatic development was termed V-boxes in World War II, where under wet and humid conditions, fiber boxes out-performed other types of containers. Continued development has led to use corrugated fiberboard nearly exclusively in commerce offruit, vegetables, frozen meats, and other perishables.

3. CORRUGATED FIBERBOARD SHIPPING CONTAINERS PROCESSING AND DESIGN

Corrugated board is a composite structure made up of at least one corrugated paperboard layer and at least one flat layer. The corrugated layer is formed by running the paperboard through rolls that create a sinusoidal-like wave geometry across the width of the paperboard sheet. These layers are bonded at the tips of the corrugations to the liner. The corrugated or "fluted" layer is called the "medium," due to central location in the structure, and the flat layers are called "liners." According to the way it is constructed, the corrugated board may be a single liner and a medium (single-faced board) which is commonly used for pads, partitions and cushioning wrap for odd-shaped items.

Board made with a liner on each side of a medium is called "single-wall." This design makes up 90% of all corrugated fiberboard packaging. A board with three liners bonded amidst two mediums is called a "double-wall" board and, yes, there is a "triple-wall" board made of four liners and three mediums. These constructions are used to fabricate shipping containers and associated packaging in the form of cushioning pads, partitions, inserts, comer posts, tubes and nearly any imaginable item, e.g., low-cost furniture. The double- and triple-wall constructions are predominantly for packaging large, cumbersome items such as appliances.

Designing a shipping container for maximum service requires consideration of appearance, weight, price, ease of handling, packing, and protection of contents. Each item is important when selecting the best paperboard, flute size, corrugated board construction, and container design. The objectives can be simply stated as identifying the minimum strength requirements of the container to protect its

contents from damage at the lowest possible cost. A person will not be able to fully design a container from this presentation, but they will know the broad problems of designing containers for maximum service. (Koning, 1995).

3.1 Corrugation Geometry

Corrugated medium is further defined by the height and number of corrugations per unit length. As shown in Table 10.1, these factors also dictate the amount of paperboard required to produce a unit length of corrugated medium (“take-up factor”). The “A” flute produces a thicker-walled board with higher top-to-bottom compression strength, and the “B” flute yields a board with better flat crush. Generally, the “A” and “C” are used where top-to-bottom stacking strength and cushioning are required. “B” is used for cushioning when stacking strength is less critical. “E” flute has high flat crush, but poor cushioning capability.

Table 10.1 Corrugated Board Flute Specifications and Relative Properties

Flute	Average flute height (mm)	Average number of flutes/meter	Medium take-up factor	Relative Estimates	
				Top-to-bottom compression	Flat crush
A	4.70	110	1.54	100%	100%
B	2.46	154	1.33	75%	150%
C	3.61	129	1.45	85%	125%
E	1.14	295	1.26	60%	350%

Wright, P. G. et al., *Corrugated Fibreboard Boxes*, APM Packaging, Melbourne, VIC, Australia, 289 p., 1988.

3.2 Corrugating Medium

In corrugated board, the thickness of the board gives the high stiffness by separating the flat liners. However, the thickness of the medium itself also contributes to the corrugated board stiffness. The container is usually made with the flutes running vertically to increase stiffness and stacking strength. Flat crush resistance is also a primary concern of the medium’s performance. Paperboard for use as a medium may be from 0.20-0.40 mm in thickness. A processing consideration for a medium is that it be capable of being corrugated without cracking and the surface adheres to the adhesive system in use.

3.3 Linerboards

Forming the inner and outer facings of the corrugated “sandwich,” the liners are most influential on the structural properties of the corrugated board. The liners will be chosen for their thickness, compression strength, or surface finish (if printing or laminating is needed). Typical thicknesses of liners are 0.25-0.65 mm.

3.4 Corrugated Container Manufacture

There are three components brought together in the first step of the continuous process known as corrugating: medium, adhesive, and liner. The medium is hot-conditioned prior to being run through the corrugated roll (matched corrugated surfaces mating or “fingerless”). The corrugating roll and an adhesive roll are in contact to apply some controlled amount of adhesive. A liner is brought in contact with the adhesive-topped flute of the medium. When the “single-faced” board is bonded, it continues onto a short residence-time conveyor prior to being fed into another adhesive roll and the “double-back” liner applied. Applying the correct pressures, temperatures, adhesives and paperboards to this process is a matter of art combined with science and will not be discussed with here.

3.5 Adhesives

Starch-based adhesives are by far the most common in use by the corrugating and folding box board industries. Cornstarch is most commonly used; however, potato and tapioca are also used. Different formulations are used for each step in the corrugating process and for effecting joints or closures. Application rates are quite variable depending upon the concentration of solids, the flute profile, and the water resistance expectations for the combined board.

Silicate adhesives, once quite common, have fallen out of use due to concerns of product weight, abrasion, wear, alkalinity, and silicosis. However, it is a low cost adhesive that is seemingly unaffected by seasonal fluctuations. In addition it is tolerant of long storage times, high moisture boards, and produces a near-permanent bond. Application rates are typically 3-6 times higher than starch adhesives.

Water-resistant adhesives are typically made using starch adhesives as the base. Some quantity of dry or liquid resin such as urea-formaldehyde and a catalyst (e.g., aluminum sulfate) added to the starch base provide a water-resistant bond. Polyvinyl alcohol is also used in the folding box industry and infrequently in the corrugating industry; however, it is a cold-set adhesive. Melamines have also found some measure of use in the container industry.

3.6 Creasing, Slotting, and Die-Cutting of Box Blanks

Many steps are involved to produce a container from the corrugated paperboard sheet. The progression of steps may be quite different in each installation. Individual machines can perform each of the operations for special containers. In most modern operations, the steps are all done at the die-cutting station, which is either a flatbed or rotary operation. Creases, or scores, are deformations pressed into the corrugated board to cause it to fold in a straight line where desired. Slots are cut into the flat sheet to create individual panels for folding and to create clearance for one panel relative to another. Die-cutting can be used to simply create the perimeter of the box blank, but it is more typically used to create slots, creases, and the perimeter cutting of corrugated boards.

3.7 Common Box Styles

Due to the simplicity of cutting flat sheets of corrugated board, the box designer has unlimited flexibility in choosing a pattern for fitting a specific packaging need. The criteria continue to be cost and performance first. To avoid large waste, the design that has proven to be most popular is the regular slotted container (RSC). RSCs require a corrugated board width equal to the container height and width and a small allowance for creases. Since RSCs have no flap overlap, the closures are critical to box performance. For heavy or perishable items that require heavier sidewalls, the full telescope container has full depth sides on the top and on the bottom to provide full overlap of the singlewall sides.

4. SPECIFICATIONS, TESTING, AND MATERIAL PERFORMANCE

In the early stages of the corrugated fiberboard container industry development, the controlling specifications were those of the railroads, known as “Rule 41” in the United States. These still form the cornerstone of the standard grades and classifications. However, most users of containers have developed their own requirements to assure performance of the container for their specific perception of packaging needs. In this environment, the role of testing plays an important role in the marketplace to assure quality, uniformity, and standard practice within the industry.

4.1 Container Specifications

The Uniform Freight Classification of the railroads contains a set of basic standards with which all containers must comply to be accepted for shipment by rail carriers (Rule 41). Their purpose is to form a basis for deciding whether damage to products in shipping containers has been due to excessively severe handling by railroads or to inadequate design and materials of the shipping container. Each boxmaker prints a certificate on his containers showing that they comply with the rule. If the carriers find damaged products in boxes that do not comply with the rule, the boxmaker is liable for the damage. The required test criteria are either:

- a. Minimum basis weight of the unfluted paperboard (liners) used in the package construction (expressed as weight per unit area) and minimum burst test strength.
- b. Minimum edge crush strength of the corrugated board.

Other Rule 41 criteria in boxes are limitations on the sum of the box dimensions, the maximum weight of the box and its contents, and a minimum basis weight and thickness of the medium. The environmental conditions under which the testing is performed are also specified along with sampling rates and acceptance/rejection criteria.

Trucking companies use a set of rules known as the National Motor Freight Classification (Item 222, 1991) which is nearly identical to the specifications in Rule 41 of the Uniform Freight Classification. Air and sea cargo lines do not have detailed

specifications, unless the item to be shipped is listed as a hazardous material and is subject to international control or treaty that the carrier's country has signed. The U. S. Government also specifies containers according to the requirements of Rule 41, but uses special grades in the federal specification for military or overseas use that may require waterproof adhesives, treated paperboards, or other testing requirements to assure performance in hostile environments.

Individual users' specifications typically rely upon Rule 41 to assure a basic standard for their containers. They can then add specifications tailored for their needs such as enhanced flat crush, compression strength, coefficient of friction, vibrational response, etc. (Ostrem and Godshall, 1979). An obvious result of added specifications is added cost for assuring performance under a quality control system. The specifier will balance that added cost against the savings from reduced product damage and increased satisfaction of the receiver.

4.2 Testing Procedures and Conditioning

There are many organizations around the world that are involved in writing standard testing procedures and specifications for paperboard packaging and containers. The two most active in the U. S. are the Technical Association of the Pulp and Paper Industry (TAPPI) and the American Society for Testing and Materials (ASTM). Industry groups such as the Fibre Box Association (FBA) are active in developing and publishing guides to support these standards. Close liaison between these groups provides the container industry with a good network of standards and supporting implementation information.

4.3 Test Conditions

Nearly all TAPPI and ASTM test specifications require the same conditions for testing room environments: 20°C and 50% relative humidity (RH). Prior to placing samples in this controlled atmosphere, they are preconditioned in a warm 45°C and dry (25–30% RH) atmosphere. This use of preconditioning allows the fiber-based paper materials to reach an equilibrium moisture content in the 50% RH test environment from the dry conditions of the preconditioning chamber. Paper absorbs and retains moisture differently depending upon its history of moisture exposure. By preconditioning the paperboard, corrugated board, or containers a more reproducible test result is obtained.

4.4 Paperboard Tests

Basis Weight: Weight of the paperboard per unit area (e.g., grams per square meter).

Burst Test: A strength measure of the liner, medium, or corrugated board to resist a membrane pressure applied over a small area of the fiber sheet.

Caliper: Caliper is the thickness of the liner, medium, or corrugated board, expressed in millimeters or inches and measured with a micrometer.

Cushioning: A test for cushioning can be conducted over a wide array of loads and speeds but the usual report consists of deceleration plots for impacts of different speeds and of different weights.

Edge Crush Test: A rectangular area of corrugated board is cut precisely for edge loading to determine the edge-loaded strength of the section in the direction of the flutes.

Flat Crush of Corrugated Board: A circular specimen of a standard area is subjected to a compression from liner to liner to determine the fluted medium's ability to resist collapse.

Flat Crush of Corrugated Medium: The test uses a strip of medium that is corrugated in the lab and subsequently placed in compression to obtain a prediction of flat crush of the corrugated board.

Four-Point Flexure Test: This test uses a strip of corrugated board cut either along or across the flutes and measures the change in specimen radius between the two central loading points (the outer two being the supports) to calculate the flexural stiffness of the board.

Friction Coefficient: This test measures the "angle of slide" or the horizontal force needed to move a controlled weight over the surface of the paperboard.

Liner Crush: A long strip of liner is held rigidly upright and subjected to a compression force to measure the liner's ability to carry compression loads.

Porosity: This is a test for measuring the resistance to airflow through paperboard and has an influence on the corrugating and handling speeds.

Puncture: As a test for performance of corrugated board, the puncture test measures the ability of a board to resist a tetrahedral solid's puncture through the face of the corrugated board.

Short Span Compression: A narrow strip of paperboard is subjected to compression loads over a very short (>1 mm) gage length.

Tear: This is a measure of the force required to continue a tear in paperboard once an artificial "cut" has been made in the edge of the fiber sheet.

Tension: Regarded as a simple indicator of the structural performance of a paperboard, this indicates the force required to pull a narrow strip to failure.

Water Absorbitivity: This is a measure of the quantity of water absorbed by a paperboard in a specified time under standard conditions and relates to the rate at which a water-based adhesive may be sorbed during the corrugating process.

There is a wide array of other tests that are routinely used for specifying performance of paperboards for specific applications. The advent of the container as a marketing tool has required tests that allow evaluation of a paperboard as a printing substrate in addition to its ability to carry loads. We will not attempt to summarize these tests here.

4.5 Corrugated Fiberboard Container Tests

After fabrication, sealing, and usually: filling, container compression strength is measured on a flat platen compression tester. Measurements of compression strength and the container's load-deflection behavior may be completed for top-to-bottom, end-to-end, and side-to-side strength. Load is applied at a constant rate until the

container fails catastrophically. Each of these loading directions may play a role in a container's shipping environment. Top-to-bottom is the most obvious condition when the container is in a stack or part of a palletized system of containers with pallets loaded on top. End-to-end and side-to-side compression may also be loading conditions when containers are palletized or stacked and require the use of clamping trucks or other clamping pressures to secure the load during handling or while in transit.

4.6 Other Container Handling Tests

4.6.1 Effects of Environmental Conditions

When conditions prevailing in storage or in transit may be much more severe than the standard conditions of testing (e.g., fresh or frozen food packaging), the compression testing may be carried out under these more severe conditions. Typically, when a container design is tested under these conditions, designers will be able to extrapolate the results to apply to containers of the same general design. However, when the design changes and a different mode of container failure may be controlling, these tests no longer have relevance.

4.6.2 Stack Life Testing

When goods are to be stored for extended periods under uncontrolled environmental conditions, tests may be needed for determining the time that a container can carry a load in compression. The loss of strength with time is accompanied by creep (deflection) of the container, resulting in stack tilting, which aggravates the situation and hastens the stack's failure. The tests may utilize machines to apply a constant load to determine the rate at which the container shortens (creep rate).

4.6.3 Vibration

These tests are intended to simulate the effects of vibration on the contents when the contents may be susceptible to damage (e.g., electronic devices or fresh produce). The interaction of the container, internal packing, and the product yields a unique set of circumstances in terms of natural frequencies. Thus, the latest test techniques call for application of a vibration spectrum from actual measurements of handling, road, or rail vibration conditions. When tested with expected vibrational spectra, the designer can assess factors of safety by stipulating the number of "transit lifetimes" that a package and its contents should endure.

4.6.4 Inclined Impact

Designed to simulate a massive low speed impact, this test uses a wheeled test platform to which the containers are mounted. The platform is released down an inclined ramp to meet with a solid bulkhead. Due to the variability of the test

platforms, bulkheads, and other factors, this test is primarily used to compare one packaging situation to another on the same inclined impact device.

4.6.5 Revolving Drum Test

As the name implies, a six-sided drum with baffles mounted inside is rotated, which allows the container inside the drum to roll or tumble in an uncontrolled manner. This test provides some insight on the integrity of the package joints and closures, and the ability of the package to resist shifting and penetration of the contents through the sidewalls.

5. CUSHIONING MATERIALS FROM AGRO-BASED RESOURCES

A small but identifiable quantity of fibrous material is used in packaging of delicate items to create an extremely soft cushioning material. Prime examples of products that may require this level of softness are vacuum tubes, delicate electronics, crystal glassware, and fine china. Traditional materials used for this purpose are excelsior (wood wool), coir (coconut husk fiber), and shredded wastepaper. For the bulk of packaged items, the corrugated board provides adequate levels of cushioning, especially in the A and C flute configurations. Singlewall is also still in use for cushioning items which can be wrapped in a tubular fashion.

6. PARTITIONS IN PACKAGING

When packaging multiple individual items, the use of partitions may be desired to prevent item-to-item scuffing, rubbing, and impact. Partitions may be made from a wide array of sheet materials but solid fiberboard is the most common. The partitions usually impart no stacking strength and, thus, have little structural requirements other than cushioning or integrity to keep items apart. Corrugated and singlewall are also used when added cushioning is desired.

7. MOLDED PULP PACKAGING

A growing segment of the packaging industry relies upon the use of molded fiber products in packaging. Examples include: spacers to isolate products from container sidewalls; trays for perishable or fragile items such as eggs, apples, and frozen meats; and damage protection for self-packaged large items such as furniture and appliances. The processes for molding are described in the section on Structural Molded Pulp Products.

8. STRUCTURAL MOLDED PULP PRODUCTS

The development of new process technologies to produce products from cellulose pulps has been an active area of research at the USDA Forest Service, Forest Products Laboratory (FPL). A decade ago, Setterholm (1985) introduced the unique method of forming a three-dimensional, wafflelike structure from molded wood pulp. He called the board “Space-board” because of the presence of open cells or “space” between the ribs of the “board” (Figure 10.1). At the time, Setterholm envisioned producing a Spaceboard panel that would have strength characteristics similar to that of corrugated boxboard but could be produced in a one-step forming process. Additionally, the process could accommodate under-utilized fiber sources such as mixed hardwoods and recycled papers. These two goals set the stage for several breakthroughs in molded pulp processing technology at FPL. Subsequent process improvements by other FPL researchers were developed to optimize the formation and densification of Spaceboard. With these improvements, it became possible to produce Spaceboard in a variety of sizes, ranging from thin boxboard (Hunt and Gunderson, 1988) to thick sheathing panels called Spaceboard II (Scott and Laufenberg, 1994).

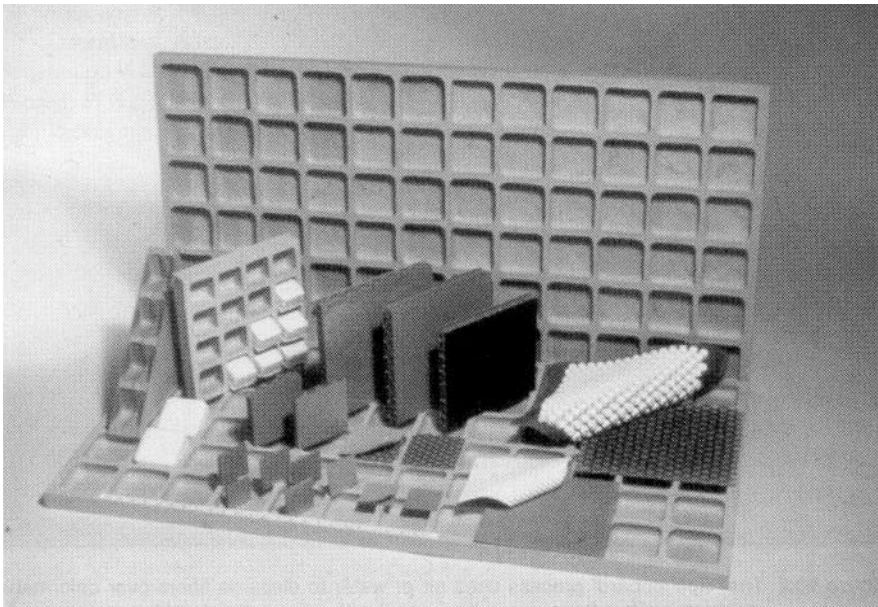


Figure 10.1 A wide variety of products can be made using the “Spaceboard” technology.

9. WET PULP MOLDING PROCESS

With water as the forming medium, two basic mechanisms determine bond strength development: fiber flexibility (conformation) and hydrogen bonding. When

the board is uniformly densified at elevated temperatures, the conformable fibers are pressed into intimate contact with each other. As the water vaporizes, strong hydrogen bonds are produced, resulting in densities of approximately 1.0 g/cc.

Wet pulp molding requires two basic steps: (1) forming a dense network of wet fiber onto a configured surface, and (2) drying the dense network (Figure 10.2). In the vast majority of molded pulp products, the forming is done onto a hard drainable surface. That surface may be a multilayer of stainless steel backing materials with the pulp contact surface of fine mesh or perforated plate to retain the pulp fiber. Deposition of the fiber onto that surface may be through a number of approaches: (1) gravity flow of the pulp suspension through the porous surface, (2) dipping of the mold into the pulp suspension while withdrawing water through the mold surface thus depositing the fiber onto the mold surface, or (3) pumping the pulp into a closed mold space and withdrawing water from the mold faces. Forming may be accomplished with pulp consistencies (dry weight/wet weight) of 0.5-5 percent. For applications that require highly uniform formations of the wet pulp mat, the consistency needs to be quite low.

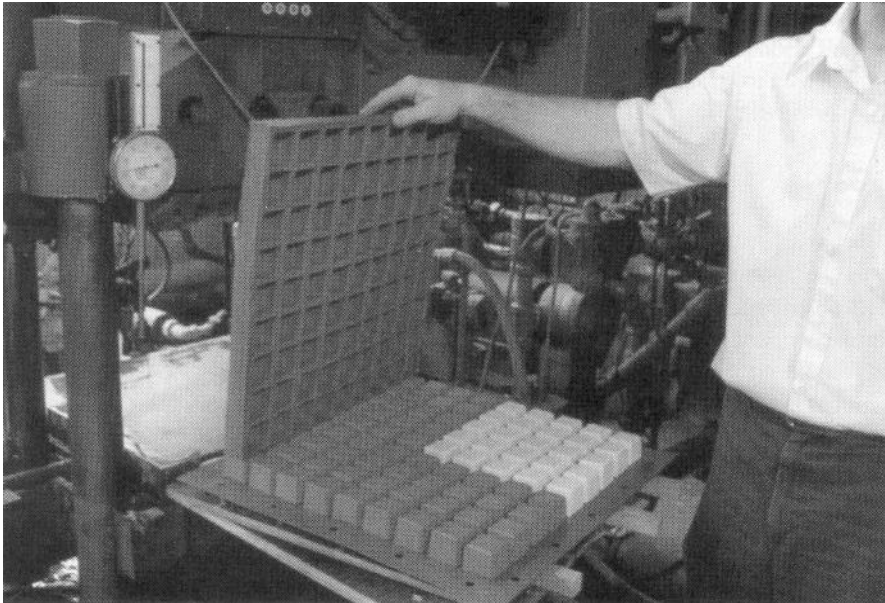


Figure 10.2 The "Spaceboard" process uses air or water to disperse fibers over deformable molds to make a honeycomb type panel with unique structural properties.

Drying of the wet pulp mat may be accomplished in a wide variety of ways. The major variable that differentiates molded pulp from structural molded pulp products is the extent of densification and pressure applied when the pulp is drying. Minimal density (and strength) of the resulting pulp product will occur if no pressure is applied. This type of molded pulp product is typically formed on the wet mold, vacuum dewatered, then deposited onto a dryer conveyor system for the extended

time required to dry the product (0.5–4h). Products of this type are used as spacers, corner blocking, cushioning materials, or trays for perishable or sensitive items.

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