PVC formulations are used where the heat-seal is applied to a PVC cup or portion pack. Ionomers (e.g., DuPont's Surlyn) are used where high melt strength is needed. Ionomers tolerate contaminants and create adequate heat-seals across contaminants such as bacon fat or fine powders. They also have superior adhesion to metal surfaces. Acrylic polymers (e.g., DuPont's Nucrel) are sometimes used alone or blended with other materials to increase adhesion to metals.

Hot melts formulated to seal at temperatures as low as 60°C (140°F) can be used when LDPE's higher seal temperature (120°C/250°F) is not acceptable. Hot melts are easier to pattern-print and have easier seal initiation at lower temperatures and pressures. EVA is a common base resin used to make hot-melt heat-seal coatings.

Time/temperature/pressure data should be developed for all heat-sealing systems. (See Figure 15.9) Excessive combinations of time, temperature and pressure tend to force melt from the seal area and create a weaker seal.

Table 15.4
The most common heat-sealing materials in the general order of performance and cost.

Material	Comments
Ionomer	highest cost, highest performance, seals through contaminants
Acid copolymers	good foil bond, good chemical resistance
Metallocene PE	low initiation temperature, fast, strong seal
LLDPE	good hot tack, tough, wide seal temperature range
PE/EVA blend	low seal temperature, very soft film, good hot tack
Medium-density PE	stiffer and better barrier than LDPE
Cast PP	higher use temperature than LDPE
LDPE	most economical, lowest performance, adequate for many uses

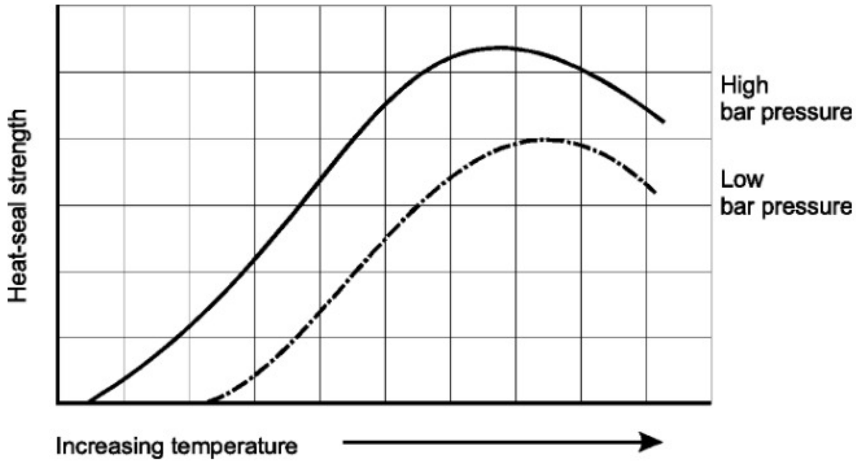

Figure 15.9
The optimum conditions for creating a strong heat-seal should be determined. Considerations include seal-bar pressure and seal-bar temperature.

Hot tack is an important sealing material characteristic, particularly on VFFS machines, where heavy product might be resting on a seal immediately after formation. A good hot-tack seal resists peeling apart, even though it is still hot.

Cold seals are based on elastomeric materials that have a great tendency to adhere to themselves but not to other materials. Cold-seal adhesives are pattern-applied by the converter to the appropriate matching sealing surfaces on the web. In the package filling operation, machinery simply brings the two surfaces together and applies a slight pressure. Since time and temperature needs have been eliminated, sealing speed is very fast. Cold seals are useful in applications such as chocolate wrappers, where the product is sensitive to elevated temperatures.

Laminate materials must be compatible with the product, and a laminate's internal plies must be adequately protected against aggressive product constituents. Aluminum foils are attacked by some chemicals, particularly caustics. Layers between the aluminum foil and the product must stop the penetration of any such ingredient to the foil interface. Aggressive flavor and perfume components can plasticize adhesive bonding layers as well as detrimentally affect other structural properties.

BARRIER PROPERTIES

Almost every food or pharmaceutical application requires some form of barrier property. "Barrier" is a nonspecific word that describes a material's ability to prevent gases from permeating through the volume of the material. As can be seen in Table 15.5, the barrier qualities of a given material vary, depending on the gas being permeated. It is not enough to say, "We need a high-barrier material." The gas to which a barrier is required must be specified.

Table 15.5
General oxygen- and moisture-barrier properties.

Material	Water-Vapor Barrier	Oxygen Barrier
LDPE	fair	poor
HDPE	excellent	poor
EVOH	poor	excellent
PVDC	excellent	excellent
PA (nylon)	poor	good
PS	poor	poor
PET	fair	good
OPP	good	poor

Oxygen and water vapor are the most common barrier concerns, being the gases most responsible for product degradation. Another class of permeants against which barrier properties are vital is the volatile or essential oils associated with aroma and flavor. These usually are present in minute concentrations, and their presence is often critical to product quality.

Flavor and aroma constituents can be delicate or very aggressive, and retaining them is a packager's challenge. Fresh coffee aroma is a complex essential oil that can evaporate quickly or oxidize readily to leave a bland, flat-tasting beverage. Coffee packaging laminates must hold essential oils in and keep moisture and oxygen out. Additionally, the vacuum pack will pull the web tight against an abrasive granular material. This places a premium on toughness and abrasion resistance.

Of the flexible packaging materials, only intact aluminum foil is potentially a 100% barrier to all gases. In the thinner gauges used for most packaging (as low as 7 μm/0.000285 in.), foils suffer from pinholing—minute holes through the foil. Furthermore, foil is not durable to repeated flexing and can develop flex cracks during machining and shipping.

Barrier properties usually are reported as the rate at which a permeant passes through a given thickness and area over 24 hours at atmospheric pressure. However, there are many ways of expressing this data, and care must be taken to ensure that identical methods and units are being compared. One standard, ASTM D1434, Method for Determining Gas Permeability Characteristics of Plastic Film and Sheeting, provides an appendix with conversion factors for the various gas-transmission units in use.

Oxygen permeability traditionally has been expressed in mixed in./pound and metric units:

$$\frac{\text{mL (STP mil)}}{100\ \text{in}^2 \times \text{d} \times \text{atm}}$$

In metric, this would be expressed as

$$\frac{\text{mL (STP mil)}}{\text{m}^2 \times \text{d} \times \text{atm}}$$

Where

STP = standard temperature and pressure

d = day

atm = atmospheric pressure

Oxygen permeability usually is measured using instrumentation developed by MOCON (ASTM D3985). The method uses a cell that is divided into two chambers by the film being evaluated. (See Figure 15.10) Nitrogen flows through one cell while oxygen flows through the other. Any oxygen that permeates through the film being evaluated is caught up in the nitrogen flow and taken to a coulometric sensor that quantifies the amount of oxygen permeated.

The permeability of plastic films can increase dramatically as temperatures and relative humidities rise. The temperature in a transport truck on a hot summer day can triple or quadruple permeability. Moisture absorption by plastics such as nylon or ethylene-vinyl alcohol (EVOH) also increases permeation substantially.

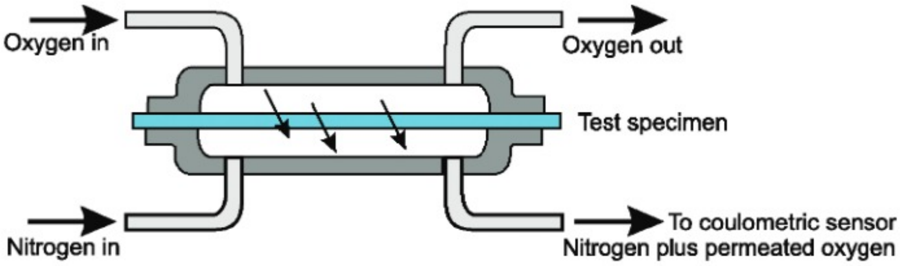

Figure 15.10
A dynamic permeation cell for measuring oxygen permeation.

WVTR is expressed as grams of water permeated rather than milliliters. The reference test method, ASTM E96, is a gravimetric determination and describes a desiccant and water method of determining WVTR. ASTM D1294 describes an instrumental method for determining the water-vapor permeability of plastic film.

Water-vapor and oxygen permeation do not correlate, other permeabilities do. In general, a good oxygen barrier will be a good carbon dioxide barrier and a good barrier to many (but not all) organic vapors.

Metallizing plastic films significantly increases barrier to all gases. Polyvinylidene chloride (PVDC, Saran) and polychlorotrifluoroethylene (Aclar) are also good all-around barrier materials.

EVOH is used as a high oxygen barrier. However, EVOH absorbs water and must be sandwiched between materials that protect it from moisture. One common construction places the EVOH between layers of PP. Since EVOH and PP do not bond, PP films must be bonded to the EVOH with an adhesive or “tie” layer.

Barrier properties, as a general rule, are inversely proportional to film thickness on a fairly linear basis. Doubling the thickness of a given barrier layer will halve the permeation rate of the gas in question. The required barrier property can be achieved with any material if it is thick enough. However, the oxygen barrier provided by 25 µm (0.001 in.) PVDC would need about 25 mm (1 in.) of PE to equal it—1,000 times thicker. Even though the cost of PVDC is two or three times that of PE, it is a thousand times more effective as a barrier. For both practical and economic reasons, the choice is PP coated with PVDC.

In designing a barrier, the options must be evaluated and the best construction selected. Usually, the final analysis concerns the amount of barrier per dollar, tempered with machinability and other use properties.

Not all packages require a high barrier. In fact, some packages must have low barrier qualities. Red meats, for example, retain bright red coloration only when there is ready access to oxygen. Fruits and vegetables need to respire, ridding themselves of water and carbon dioxide while taking in oxygen. If packed in a high moisture-barrier package, products with high water activity would establish high humidities and set up conditions for the propagation of undesirable microorganisms. Packaging films for these products must have permeability tailored to meet their respiratory requirements.

A light barrier may be needed by products that can be harmed by light, usually the UV component. Fluorescent lighting in retail dairy cabinets degrades butter, and a paper/foil combination frequently is used, as it provides both 100% dead fold and a light barrier.

AESTHETICS AND OTHER PROPERTIES

A final concern in selecting a laminate is achieving the desired shelf or decorative appearance. The laminate must take into account whether the presentation should be in a sparkling clear package or an opaque package. Usually, where the product is attractive and not adversely affected by light, a clear package is specified. The sales appeal of stewed clams, on the other hand, is not likely to be enhanced by a clear package.

OPP's combination of excellent base properties at an economical cost makes it one of the most popular materials for wraps and laminates having sparkling clarity. Coatings and treatments readily improve such properties as machinability, oxygen barrier and flavor barrier. Where additional strength or temperature tolerance is needed, OPP can be replaced by PET, though at a somewhat higher cost. Both OPP and PET are dimensionally stable films and can be printed well with good register. Maintaining tight register on extensible films such as PE is much more difficult.

In some instances, shelf appeal rests in providing a brilliant metallic appearance for all or parts of the package. Metallizing and using aluminum foil are the only ways of creating large brilliant metallic surfaces. (Local metallic decorations can be made by hot-stamp printing). OPP and PET are the most frequently metallized films.

Aesthetics often means providing a suitable printing surface. Clear plastic laminates typically are reverse-printed to lock in the printing inks and provide a smooth, high-gloss surface finish. An underlayer of white film provides the bright white background for high-quality graphics. A metallized underlayer provides a brilliant metallic background.

Laminate webs usually are printed by gravure or flexography, depending on the run size and the graphic quality desired. Clear surface coats or over-lacquers can be applied at the last printing station. Surface coatings for plastics frequently are treated with antistatic compounds to eliminate problems of dust attraction.

Other functional properties beyond the above categories may need to be provided. For example, an adhesive or "tie' layer might be needed to bond two plies of a laminate together. Sometimes primers and surface sealers are necessary to enhance adhesion. Nitrocellulose lacquers or shellacs are commonly used on aluminum.

An aluminum layer often is specified for ice cream wrapper laminates intended for sale at outdoor events, for its ability to reflect radiant heat. Both foiled and metallized substrates are used for packages where dissipation of static electricity is important.

Often, a single material serves several functional purposes. For example, PE is both a good heat-seal medium and a good moisture barrier. Metallizing improves gas barrier and provides a decorative surface.

LAMINATING PROCESSES

"Converting" is the term that describes the production of multilayer materials used in packaging. It is usually a web-fed, rather than a sheet-fed, process. Regardless of the machine, certain stations are common to all converting systems.

A coating/laminating machine has an unwind stand for each raw web-fed material that will be used in the process and a rewind stand to gather up the finished product. The unwind stands have tension-controlling devices so that materials are fed into the operating stations at a constant tension. A rewind-stand tension-controlling device ensures that the finished product is pulled out of the machine and laid up on the roll at a constant tension. Depending on the machine, there may be additional tension-control zones.

Tracking devices keep the material aligned with operational stations in the machine direction. Special rolls, such as bowed rolls and herringbone rolls, keep the material spread out flat while it is being processed.

Most converting machines that will combine or print plastic materials have a corona discharge station the plastic film passes through to increase surface polarity (dyne level) and improve bond strengths with adhesives, coatings and inks.

Coating/laminating machines have one or more coating stations where additional liquid material is applied to the base substrates. These may range from simple glue applicators to large extrusion dies attached to plasticating extruders. Depending on the coating process, the machine may have drying ovens before or after the material-combining nip.

The laminating process starts with a base web to which further layers are added until the desired construction is achieved. Additional layers can be applied as fluid coatings, by bonding additional webs, by extruding and coextruding, or any combination of these processes. Base webs may be plain or already printed, metallized or otherwise treated.

Coating Stations

Coating stations apply fluid materials such as varnishes, waxes, PVDC emulsions and adhesives. There are hundreds of ways of applying a coating to a web. The essential differences in the methods relate to how the coating is physically applied, and the way the coating is metered. These factors in turn are related to the substrate type, its texture and the coating's nature and purpose. Each method has its features and limitations. Gravure and extrusion coating predominate in flexible packaging.

Gravure coating applies and meters the coating from the cells of the gravure roll. (See Figure 15.11) Gravure rolls apply a precise coating thickness, regardless of variations in substrate thickness. Gravure does not work well with rough surfaces where the small gravure cells may lose contact with the substrate surface. The coating must be of fairly low viscosity.

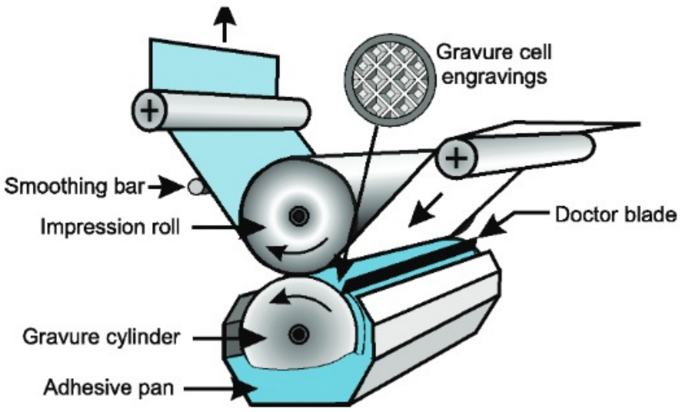

Figure 15.11
Gravure coating applies a predetermined amount of wet coating from engraved cells, shown enlarged at top.

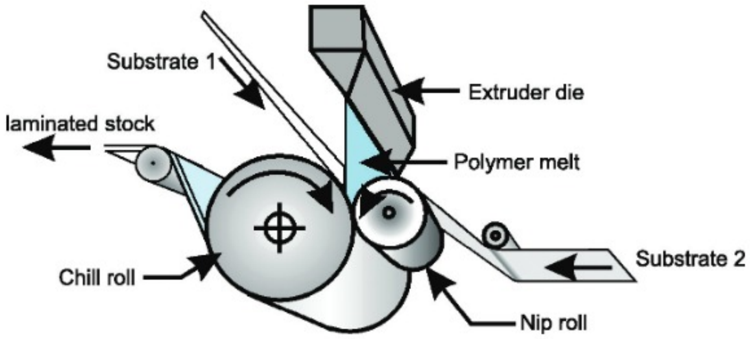

Figure 15.12 Extrusion laminating uses an extruded melt to bond two materials.

Extrusion coating applies polymer melt to a substrate. In a typical application, PE pellets are forced through an extruder barrel, where they are heated and softened to a syrup-like consistency. The viscous PE is fed through a die with a long, narrow slot, forming a thin curtain, which falls onto the substrate. At this point, it can be cooled to form a surface layer (extrusion coating) on the substrate or a third material can be pressed against the still-molten PE (extrusion laminating) and bonded to the base substrate. (See Figure 15.12)

Wax lamination is an economical method of joining a paper or tissue support to aluminum foil. It is not a structurally and environmentally stable bond and so has few other applications. The base material goes from the unwind roll to the heated-wax coating station. The second material is pinched against the hot wax at the combining nip and immediately chilled. After chilling, the finished laminate is rewound.

Wet bonding requires that at least one substrate be porous enough to allow adhesive solvent or water to escape. (See Figure 15.13) Almost invariably, this substrate is paper. Adhesive is applied to one substrate, the two substrates are nipped together and sent through an oven to set the adhesive.

In dry bonding, adhesive is applied to the substrate and then dried of solvents. (See Figure 15.14) The resinous adhesive is either tacky or can be activated and set by heat. The second substrate is joined by a heated nip against the first to create the bond.

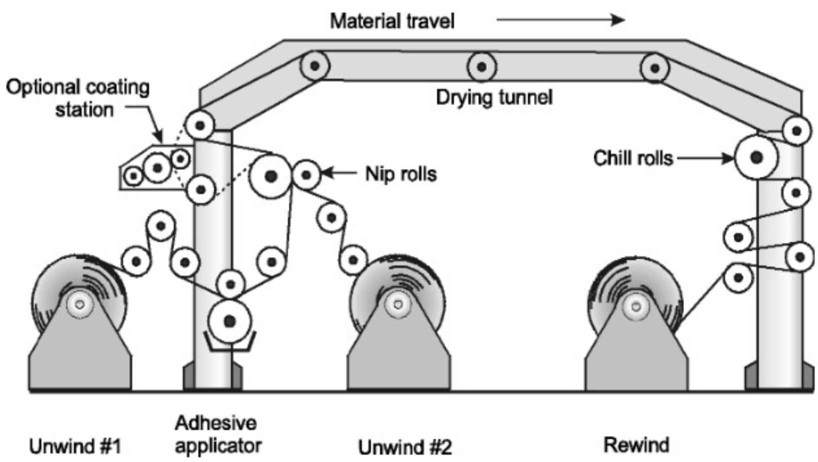

Figure 15.13 A representative wet-bond laminator.

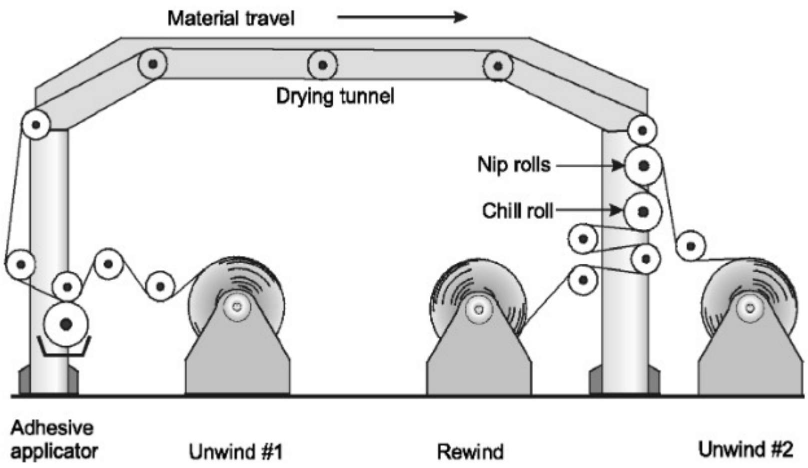

Figure 15.14
A representative dry-bond laminator. Relatively impermeable substrates cannot be nipped together until all adhesive solvents have been removed.

With both wet and dry bonding, particular care must be taken to ensure that all traces of solvent are driven out. Since laminators prefer to run their machines at top production speeds, there is always the danger that the envelope will be pushed too far and some volatiles will remain in the laminate. These can give off-flavors to packaged food products. Trapped solvents eventually can cause bubbling or blistering of the laminate. Quality laminators constantly check their production for volatiles using gas chromatography techniques.

Solventless Laminating

Many adhesives used in wet- and dry-bond laminating are solvent-based and require driers to remove the solvents. Releasing solvents into the atmosphere is no longer a tolerated practice.

Solventless laminating machines use bonding agents that have no volatile ingredients. (See Figure 15.15) They may be fluid prepolymers where hardening or curing is initiated by the addition of a catalyst or by a chemical reaction of two prepolymer components. Curing also may be initiated or accelerated by heat or UV light. Using a hot-melt adhesive is another way of eliminating solvent release.

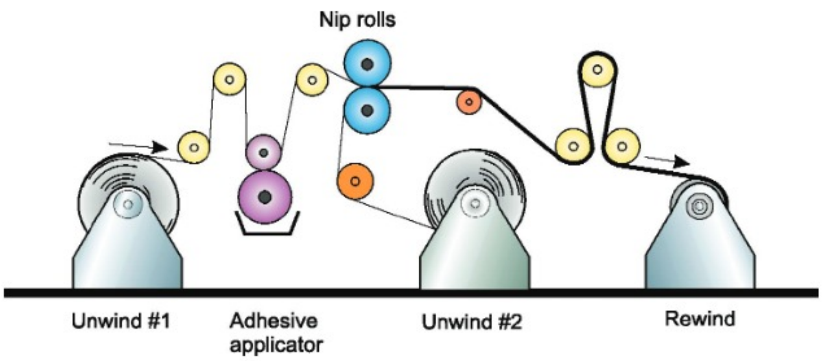

Figure 15.15
A solventless laminator is a fraction of the size of wet- or dry-bond systems.

Table 15.6
Construction of a nine-layer laminate.

Material	Function
1. PP	reverse printed surface film
2. Tie	adhesion
3. LLDPE	bulk
4. Tie	adhesion
5. PA*	barrier & formability
6. EVOH	oxygen barrier
7. PA*	barrier & formability
8. Tie	adhesion
9. EVA	sealant

Solventless laminators require significantly less floor space than conventional laminators with drying ovens.

Coextrusion

Coextrusion dies combine the outputs of two or more extruders so that the curtain of material exiting the extruder actually is several materials fused together. As with solventless laminating, there is no release of objectionable solvents. The principles of coextrusion have been described in Chapter 11, Shaping Plastics.

Technological advances in die-making have allowed for coextrusions of 11 and more layers. Table 15.6 illustrates a nine-layer, high-barrier coextrusion. Splitting the PA into two layers increases flex-crack resistance. Locating the EVOH layer between the two PA layers improves thermoformability.

SPECIFYING LAMINATES

Material plies are properly listed from the outside of the package to the inside. In metric, a laminate's weight is given in grams per square meter (grammage) and in micrometers of thickness. Microns, used to describe micrometers, is not a recognized SI unit.

(Micrometer is properly abbreviated µm. The "µ" symbol is awkward to insert and so um is commonly substituted. In the vernacular, some have taken to calling the micrometer an "oom.")

Using in./pound units, caliper may be quoted in thousandths of an in., in mils or in gauge. 1/1000 in. = 1 mil = 100 gauge. (Note that in the paperboard industry 1/1000 in. is a "point," therefore, 1 point = 1 mil.)

0.0005 in. = 50 gauge = 1/2 mil = 12.7 μm
0.001 in. = 100 gauge = 1 mil = 25.4 μm

A laminate's orientation on a roll must be specified exactly so it will unwind in the desired direction and the eye-spot register marks are located correctly for the machine that will run it. (See Figure 15.16) Printed laminates in particular can be confusing. A converter needs this information before starting the job.

Laminates have few ordering conventions. Web materials are described in pounds per 1,000 square feet (basis weight), pounds per roll, linear feet, square inches per pound (yield), number of repeats or impressions and by a variety of other methods particular to the purchaser's needs.

There is no simple formula for designing a laminate, and there are almost as many constructions as there are product types. Similar effects can be achieved in many ways, and the bottom line is the price paid to deliver a certain amount of a particular property. Foremost, understand which properties are needed and how much of each property is needed.

While many laminating machines exist in the basic configurations illustrated in this text, most producers have multipurpose lines that might, for example, combine both wet- and dry-laminating capabilities in one line. An even more complete line would include some extrusion laminating capability or even coextrusion.

Coating and laminating machines are built to accomplish specific operations. While there is some flexibility, no machine can be configured to do all possible laminating procedures. In some instances, the web material will need to pass through the machine or several machines two, three or even more times to build the specified construction. Process waste can be as high as 15% or 20%. Fewer machine passes generally mean less process waste.

Different suppliers might put together similar laminates in completely different ways, depending on their available machinery. Talk to several suppliers to obtain opinions about how a particular combination or result can be achieved and at what price.

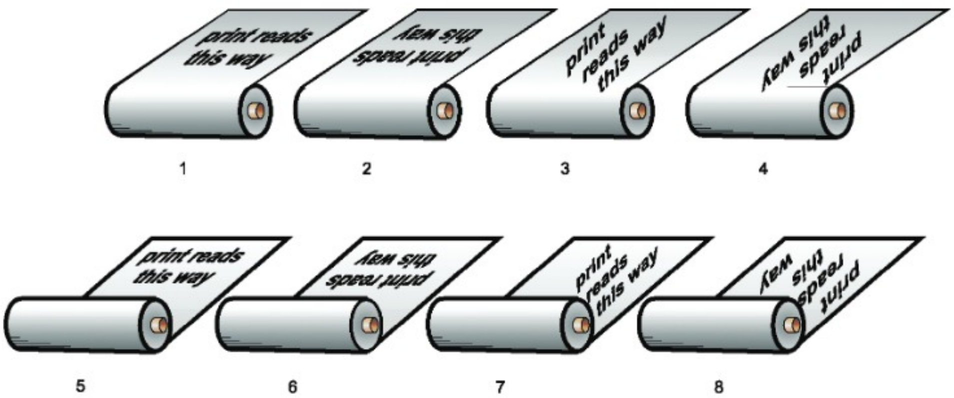

Figure 15.16
Standard roll unwind direction.

EXAMPLES OF LAMINATES

Figure 15.17 shows examples of nine typical laminates containing aluminum foil as one of the components. The purpose of the foil component in all the examples is to provide barrier to atmospheric gases and aroma constituents.

The identification "LDPE" in this figure includes LLDPE and various copolymers and blends based primarily on LDPE. In some instances, the seal material is proprietary or varies with application or converter. These are identified as "sealing medium." LDPE and other heat-seal layers (for example, ethylene-acrylic acid and ionomer) can be extruded onto a substrate or a previously manufactured film can be bonded on. Adhesive-bonded LDPE is somewhat stiffer than extrusion-applied LDPE. Bonded-on films also are used to build up thickness and provide better caliper control in thicker cross-sections. A thick heat-sealing layer is desirable in such products as instant soup pouches where the thick PE serves also to stop the dry hard noodles from cutting into the pouch stock. A vinyl heat-sealing film is used for lidding stock that will be applied to PVC single-serve containers.

Retort pouch laminates must withstand thermal process stresses. Therefore, PET is the laminate's main structural component. PET has low elongation, high tensile strength and a high softening point. Aluminum foil provides the 100% barrier required for a shelf-stable package. The adhesive and a PP-based heat-seal layer can withstand retort temperatures and pressures.

Laminates for aseptic juice packages usually consist of seven material layers. Paper provides body, while aluminum foil provides a barrier. The ionomer provides a superior bond to the aluminum metal.

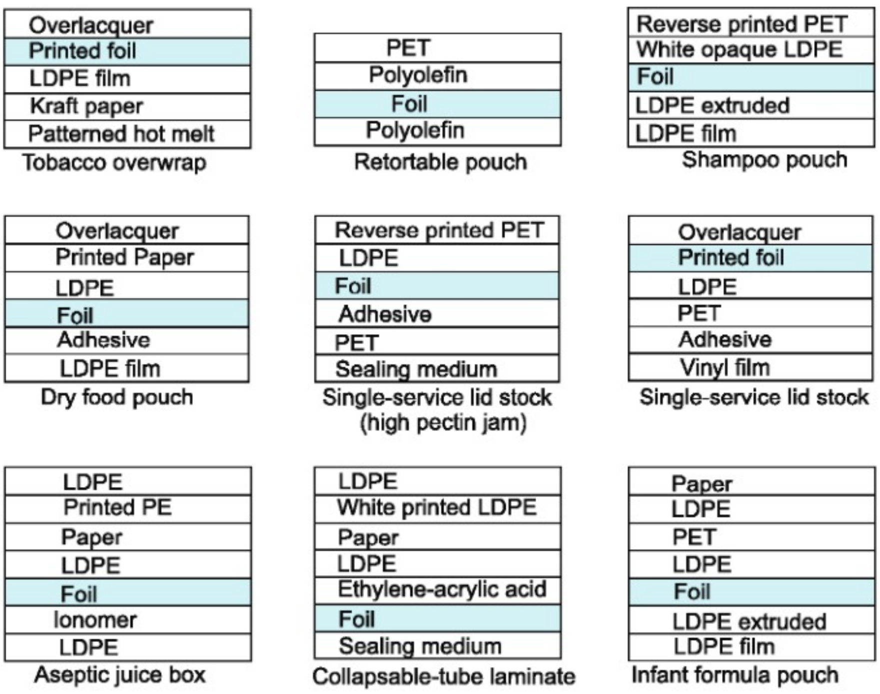

Figure 15.17
Examples of laminate constructions containing aluminum foil.

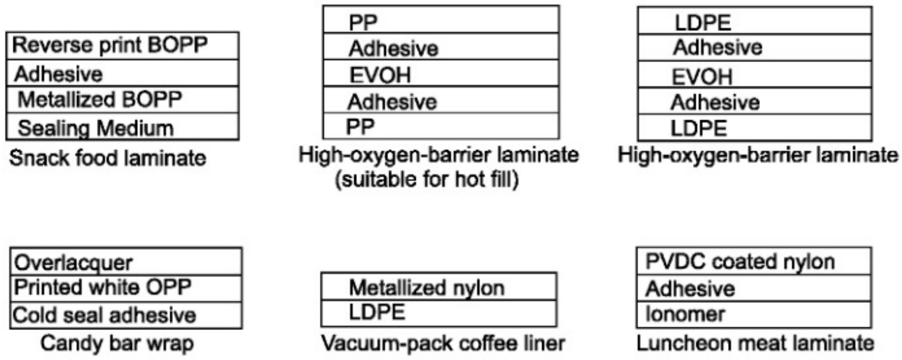

Figure 15.18 Examples of laminate constructions without aluminum foil.

The heat-seal on the tobacco overwrap is a hot-melt adhesive applied in a pattern. This allows for heat-sealing the overwrap and eliminates the need for a wet gluepot at the point of manufacture.

Pectin, a very aggressive component of some jams, will permeate LDPE and attack aluminum foil. The lidding stock for this product has a layer of PET on either side of the aluminum.

Figure 15.18 shows examples of six laminates that do not contain aluminum foil. The snack food laminate is typical of potato chip packaging. Barrier to moisture and oxygen is substantially increased by the metallized biaxially oriented PP component. Laminates are used where good oxygen barrier and clarity are desired. Although the figure shows outside LDPE and PP layers, these also could be nylon or PET, depending on what other laminate performance characteristics are needed.

Heat-sealing cannot be used near chocolate confections. A typical construction applies a pattern of cold-seal adhesive on the inside of the wrap. Two coated surfaces simply need to be brought together to form a seal. White opaque PP provides an excellent base for high-quality graphics.

Luncheon and cheese package laminates often use nylon as one of the layers. Nylon has good oxygen barrier properties (needed for high-fat luncheon meats and cheeses) and thermoforms easily into a product-conforming shape. The ionomer heat-seal layer is capable of sealing through any fatty contamination that might be over the seal area.

REVIEW QUESTIONS

1. What is the objective of combining various materials into a laminated packaging material?
2. Describe the coextrusion process and explain its advantages, compared with alternate systems.
3. Describe the laminate structure of a juice box container and explain the purpose of each layer.
4. You want a transparent package with a high-oxygen barrier. What two polymeric materials are candidates for adding barrier properties to the laminate structure? If the package did not need transparency, what other options might you consider?
5. Describe the difference between dry-bond laminating and wet-bond laminating.
6. How might you recognize whether a pouch was made on a VFFS machine or a HFFS machine?
7. A 25-micrometer-thick plastic film has a moisture permeability that is 840 mg/100 square in/24 hours. What is the likely permeability if we go to a 12.5-micrometer film of the same material?
8. When designing a laminate, what material
   a. Tolerates the highest use temperature?
   b. Is an economical way of adding stiffness or bulk?
   c. Is a good oxygen barrier and can be thermoformed?
   d. Heat-seals through grease and bonds well to aluminum?
9. In what order are the components of a laminate specified?
10. How thick is a 150-gauge film in thousandths of an in.? How many mils is that?
11. Why is it always necessary to specify the permeant(s) when discussing barrier properties?
12. Raising the temperature or increasing the pressure of heat-sealing jaws in some instances can decrease bond strength. Why?
13. What three material characteristics might be important for good machinability on a VFFS machine?
14. What is the advantage of a HFFS machine over a VFFS machine?
15. Why might a heat-seal's poor hot-tack performance slow down a filling operation?
16. What provision is needed when designing an EVOH-based barrier laminate for an organic soup product?
17. Which is easier to make, a fin seal or a lap seal? Why?

18. From an appearance and marketing point of view, what might be the advantages of a pouch made on an HFFS machine?
19. List six unique foil properties available to packagers and give an example of a package that uses each property.
20. Foils are almost always coated. What are some reasons that foil might be coated?
21. Below what gauge does pinholing become a major concern? What is the concern?
22. Why should all barrier measurements be conducted on the finished package, preferably after a real or simulated shipping test?
23. How is a reflective gold surface developed on a plastic film using metallizing technology?
24. What advantage is gained by metallizing paper?
25. Why must paper be dried before being metallized?
26. Which are the most commonly metallized plastic films?
27. What advantage is gained by metallizing films?
28. What is a susceptor film?

CORRUGATED FIBERBOARD

16

Chapter text and cited Figures and Tables

CONTENTS

CORRUGATED FIBERBOARD 16

INTRODUCTION

In the late 19th and early 20th century United States, goods were transported mostly by rail. Equalizing freight rates between wood crates, the transport packaging of the time, and corrugated boxes in 1914 (Rule 41) set the stage for tremendous growth which brought the corrugated industry to where it is now. Packaging market analysts estimate that corrugated packaging transports at least 95% of America's consumer goods.

Going forward, the industry is addressing environmental and sustainability issues that challenge all segments of the packaging industry today. To learn more about the corrugated industry's activities and efforts to meet these challenges, go to corrugated.org and click on the Responsibility tab.

PAPERMAKING

Fiber Sources

Whether the boxes you use are brown or white, made from newly harvested fiber, 100% recycled fiber—or something in between—the fibers that make up the box were once in a growing plant. In the papermaking process, the fibers are separated but still retain their cellulosic structure and other attributes of the original plant. [*Encyclopedia Britannica*, Papermaking, Fibre Sources, https://www.britannica.com/technology/papermaking/Fibre-sources.]

Elsewhere in the world, fibers from tree types not grown commercially in the United States, and other woody cellulose are used for making containerboard—the papers from which corrugated fiberboard boxes are made. And in some global locations, fiber supply is limited, leading to an increased reliance on recycled fibers from a variety of sources. This can have an impact on the properties of the material produced, depending on the fiber sources and recycling processes used.

In North America, containerboard fiber comes almost exclusively from forests. Here, trees for paper and wood products are grown mainly by nonindustrial private landowners on family tree farms or tree plantations, using silviculture and reforestation practices. [National Academy of Engineering 1998. *The Ecology of Industry: Sectors and Linkages*. Washington, DC: The National Academies Press. https://doi.org/10.17226/5793.]

Fiber from trees is best suited to the needs of containerboard. All fibers have inherently different physical properties that contribute to their ability to bond, conform into the plane of a sheet and form a robust network—all of which establishes the strength of the paper, as well as other characteristics.

Different kinds of trees have different kinds of fibers. Softwood trees are those with needles, and are primarily grown in the Southeast and in the northwest United States. Their fibers are relatively long and conformable. They can make a very uniform and smooth-looking surface on a sheet of paper. For packaging, they typically form the primary component of linerboard, the visible surface layers of the corrugated board.

Hardwood trees, those with leaves, are primarily grown in the Northeast and in the north central United States. Hardwood fibers are shorter and bulkier and do not easily make a very smooth surface. But paper made from hardwood can be more easily shaped. Hardwood is typically used for medium, the fluted paper in the middle of the corrugated board.

In wood, the fibers are held together with lignin and need to be separated for papermaking. The separation process is known as pulping. The pulping process can be chemical, where the lignin in the wood is dissolved to free the fibers. Or it can be mechanical, where the fibers are pulled out of the matrix and the lignin bonds are broken, typically with heat and moisture. Then the fibers are refined, meaning they are further softened and their surfaces are mechanically roughened to enhance their ability to bond to each other and form a sheet. The goal is to maintain the fibers' length and chemical nature, as those contribute to valuable sheet properties.

Fibers for containerboard can also come from old corrugated containers (OCC) or other sources of corrugated fiberboard material. These fibers are typically pulped using hot water and agitation; that process separates the fibers so, again they can be made into containerboard sheets. Because the OCC contains a mix of hardwood and softwood fibers (and perhaps other fibers as well), the resulting paper has a mix of materials. The proportion of recycled material in corrugated fiberboard end products has been steadily increasing. The average box is 50% recycled OCC. (See Figure 16.1)

Figure 16.1 Versions of the Corrugated Recycles symbol.

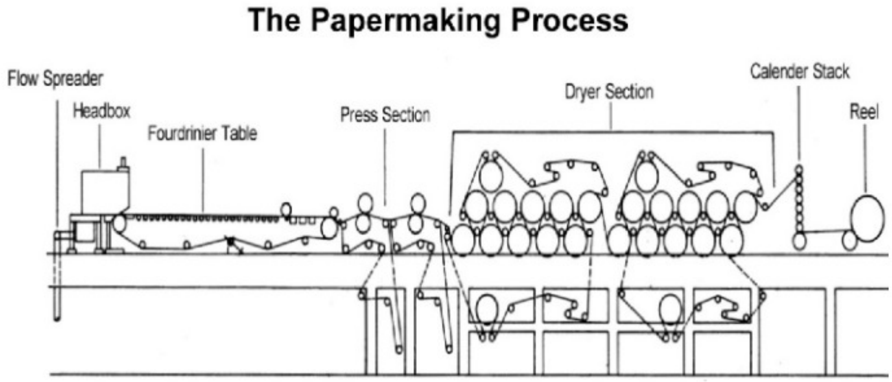

Figure 16.2 Depiction of a paper machine in the paper-making process.

The Papermaking Process

Regardless of whether the fibers come from softwood trees, hardwood trees or recycled sources, the process of turning them into paper is similar. The refined and cleaned fibers are made into a dilute slurry, about 99% water and 1% fiber. This slurry flows from the headbox at one end of a paper machine, out onto a large moving screen, the wire. The wire allows the water to drain away, forming a fiber mat which gets pressed to remove more water, then dried against hot metal drums to remove even more water that produces a sheet which is 90% to 93% fiber and 7–10% water.

Because this process has a flow direction, the fibers align parallel to the flow, called the "machine direction" of the sheet. This alignment leads to differences between the machine direction and "cross direction" in the properties of the paper. (See Figure 16.2)

In the sheet, the fibers are close enough together to be entangled and form some chemical bonds to give the sheet strength and durability. The process is continuous, forming a long paper web that is wound onto cores, forming large rolls at the end of the paper machine. These jumbo rolls are then unwound, slit to size and rewound onto smaller cores forming rolls suitable for shipping and use on a corrugator.

Whether the feedstock is chipped wood that is cooked into pulp and cleaned or bales of old corrugated containers that are rewetted and agitated into pulp and cleaned, the pulp is in stored tanks until sent to the headbox of the paper machine.

Paper Grades

Containerboard is a general term for the two basic types of paper used in making combined board. Linerboard is used as the outer facings. And medium gets fluted and attached to the linerboard.

Sheets of linerboard are also laminated together to make a type of fiberboard called solid fiber. Solid fiber is more moisture-resistant than corrugated fiberboard. And corrugated fiberboard provides more cushioning and compression strength than solid fiber.

Two types of linerboard are produced in North America: basis weight grades and performance grades. Medium is classed by basis weights.

The linerboard grades are based on either nominal weight or progressively on one or more performance metrics. Traditional burst strength-basis weight grades are sold and traded by basis weight and used to make burst-strength-specified corrugated board. Performance grades are not tied to fixed basis weights.

Performance grades of linerboard were developed with higher levels of cross-directional compressive strength per pound of fiber, after almost 100 years of focus on basis weight only. Changes on the paper machine were required to reach these higher strength targets. Some of these machine adjustments have been applied to production of basis weight grades as well, blurring the distinctions between the types of containerboard grades.

Containerboard is produced by several companies in different regions of North America, and it is also traded globally. Paper properties depend on the raw material fiber types, pulping and recycling equipment and on paper machine operation. Therefore, all the containerboard within a grade does not have similar strength, nor does it necessarily combine in the same way on a corrugator. And the strengths of basis weight and performance grades can overlap across the paper supply range. The similarity among grade structures is the ongoing shift to ever lighter and stronger papers.

Differences beyond converting between metric and customary units should be expected when matching specifications for materials marketed in North America and specifications applied in other parts of the world. For example, the European market has separate grades for Kraft and recycled liners (Testliners) and for semi-chemical and recycled mediums. These differentiations result in more grades and subgrades, and multiple weights available for each grade (occasionally in nuances as close together as 10 grams per square meter (g/m^2).

When given European or Asian paper specifications for combined board, it is not pragmatic to try—and often not possible to find—any equivalent board produced in North America. It is better to determine the specifications for the packaging based on structural and protection requirements. The results will be more verifiable and productive. (See section, Box Requirements and Box Design, below)

CORRUGATED FIBERBOARD

Combined Board Structures

The load capacity of corrugated boxes depends on the compression strengths of each of the papers, and just as importantly, how they are combined. The strongest papers are just three sheets with no structure, if they don't have adequate bonding.

Liner and medium can be combined for a variety of structures. For example, one liner glued to one medium produces singleface board. However, the medium deforms easily when absorbing shocks while protecting a wrapped product. The addition of a second liner creates singlewall board, the most common corrugated combined board structure.

As an engineered structure, singlewall acts like an I-beam, with most of the mass of the structure in the liners, away from the centerline of the board. This leads to a high bending stiffness, relative to the mass of material present.

The fluted medium also provides cushioning in the direction perpendicular to the liners and load-carrying capacity along the plane of the board (parallel to the liners). These properties are known, respectively, as flat crush and edge crush test (ECT). (See section, Testing, below) Corrugated packaging combines structural rigidity with cushioning qualities to protect both fragile and heavy contents from damage.

Because of its structure, singlewall corrugated board also has high compression resistance, relative to its weight. When formed into boxes, the ratio of the carrying capacity to the box weight is almost always in the hundreds and can exceed 500:1. Doublewall boxes are made by adding another layer of medium and liner to the singlewall structure, and triplewall adds yet another, each increasing the stiffness and load-carrying capacity of the whole.

Some manufacturers combine smaller flute structures into doublewall and triplewall board. These use more layers of paper than singlewall but may enable the use of lighter papers to meet box strength in some applications, and improved visual quality in others. These structures are not always cost-effective but they are innovations to address the complexity of box requirements in the marketplace.

Flute Structures

Containerboard flute structures draw their strength the same way as ancient architectural structures, arches. Forces against the convex curve of the arches resolve the pressures in the direction the paper is strongest.

Changing flute profiles, the specifics of the flute's structure, changes combined board properties by increasing or decreasing the flute height and number of flutes per foot. This defines the take-up factor (TUF), which is the ratio of medium used per unit of liner. Shortening the flute height brings the liners closer together and increases the number of flutes per linear unit of board, so less medium is used.

Combined board with flute profiles that have more flutes and use less medium, a lower TUF, have greater resistance to crushing. However, less thickness or caliper—the measurement of the perpendicular distance between the bottom of one flute and the top of the next one—equates to less bending rigidity and lower ECT. Strength can be added by substituting heavier medium. However, heavier medium can make the flute tips less flexible, which would adversely affect the surface finish and, consequently, print quality, especially when using large flute profiles. Knowing the packaging needs allows for judicious use of the many options possible with corrugated fiberboard.

Flute structures have letters assigned to them which box users and manufacturers recognize and use to normalize the characteristics of combined corrugated board influenced by flute structure. (See Table 16.1) Each structure uses different amounts of paper and provides different levels of compression strength, cushioning, stiffness, print quality, caliper and other properties.

A range of flute profiles is available, swapping flutes per foot for thickness in an almost uninterrupted succession of structures. The majority of singlewall board made in the United States is C-flute. B-flute doublewall combinations with C-flute or E-flute are also used for transport packaging, and together they provide optimal relationships between cost, compression strength, printability and cushioning for the typical distribution process.

Table 16.1
Flute configurations. (Source: Fibre Box Association.)

Flute	Flutes per Foot * = most common	Flutes per meter	Flute Height in.	Flute Height mm	Take-up Factor (TUF)
A	32–*33–38	107–*110–127	.158–.221	4.67	1.49–*1.54–1.60
B	44–*47–52	147–*157–173	.079–.110	2.46	1.24–*1.33–1.44
C	36–*38–41	120–*123–137	.130–.158	3.63	1.36–*1.43–1.52
E	74–98	247–327	.044-.055	1.19	1.18–1.30
F	124–128		.028–.035		1.19–1.24
G	146–169		.020–.027		1.17–1.19
K	25–30		.234–.275		1.50–1.56
N	152–170		.018–.020		1.19–1.23

COMBINED BOARD MANUFACTURING

The basic operation of a full-line box plant is, they combine rolls of paper to produce combined board in a continuous web that is then formed into various types of boxes. To accomplish this, three basic raw materials are needed: paper, steam and adhesive.

Paper Selection

In the Papermaking section, the idea that paper can vary even at the same weight was introduced. Each variety, based on mill, machine, furnish, etc., has specific properties that allow the box manufacturer to optimize the packaging to meet customer needs. The paper weights available to box plants range from less than 17 pounds per thousand square feet (#/MSF) to more than 96#/MSF. Box plants order containerboard, which matches the needs of most of their customers, in roll widths to fit the sizes of their machinery.

Treatments can be applied to containerboard at the paper mills or specialty locations, to each of these grades, expanding the palette of options. Box plants can also have capabilities to apply coatings and other processes that alter and improve the box's attributes.

Box users should work closely with box manufacturers to determine the performance levels and characteristics necessary to meet their purposes. The goal of the box user should be to define the end-use requirements for the packaging needed. Placing inflexible requirements on a packaging supplier's raw materials may do little more for a box design and performance than increase its cost.

Steam

Steam is the driving force needed for everything from making the adhesive to conditioning the layers of paper and heating the pressure vessels that help bond the liners to the fluted medium. While seemingly straightforward, steam generation is actually a complex process that is not generally well understood by those who don't work with it directly. In a box plant with a corrugator, boiler fuel can represent a significant cost in box manufacturing, even though the condensed steam is reprocessed. Also, typical steam pressures of 150 psig present considerable handling and safety concerns.

Corrugating Adhesive

The linerboard and medium that make corrugated board are combined using a starch adhesive. This adhesive is typically composed of food-grade corn starch, water and additives that control the adhesive's moisture-resistance and fluid properties.

It is applied to the surface of the flute tips of the medium, and the flute tips are brought into contact with the surface of the liner. A typical process involves using partially cooked starch as a carrier to transport raw starch to the tips of the fluted medium, where it is heated and allowed to cook or gelatinize, bonding the paper layers together.

Temperature control is critical for this process to occur correctly. Chemical bonds must be formed between the starch adhesive and the fibers in both the liner and the medium, with very limited physical entanglement or penetration by the glue solids.

Strong bonds are formed when the starch binds to the surface fibers and the surface fibers are strongly attached to their paper networks. Insufficient cooking of the starch, excessive heat during the bonding process, inadequate amounts of adhesive and poorly bound fibers on the paper surface are some problems that may lead to poor bonding of the sheet.

The typical starch adhesive has very limited moisture resistance, which can cause the bonds to fail under conditions of high humidity or exposure to water vapor or water. Regular adhesive is used in situations where the board is not expected to be exposed to moisture or high humidity for extended periods of time, which describes the field conditions of most products and includes typical packing and warehousing environments. Resins are added to the adhesive formulation, as needed, to provide a level of water resistance.

Several different standards for water-resistant adhesives are used, depending on how much resistance to high humidity, etc. is required by customer applications and expected transport and warehousing needs. Some adhesive manufacturers produce moisture-resistant adhesives (MRA) that include very low levels of resin and can be used in applications with limited moisture challenges. Water-resistant adhesive (WRA) is advised for applications where exposure to high humidity—especially under load—is expected. Examples include field packing of produce or refrigeration of perishables. More significant demands can require even higher levels of resin added to the adhesive mix, and some manufacturers produce what they call waterproof adhesive (WPA), though it should be noted that no corrugating adhesive is truly waterproof.

The Corrugator

The three basic raw materials needed to produce combined corrugated board as discussed above, paper, steam and adhesive, are put together on a corrugator. Corrugators integrate a series of operations through which the linerboard and medium are combined to form the rigid end product, sheets. Corrugators can produce combined board at more than 1,000 feet per minute, combining paper webs up to 110 inches across to make millions of square feet a day.

This is the process. At the "wet end" of the corrugator, rolls of linerboard and medium are mounted on "unwind stands" and pulled into the machine. The papers are pulled into the corrugating operation by the continuous movement of the web farther along in the system.

At the singlefacer, the medium is treated with heat and steam to make it pliable and more able to be formed into the flute structures. The medium passes through a pair of gear-like cylinders, corrugating rolls or "rolls," that shape the medium into the fluted profile required. Glue is applied to the flute tips and the tips are pressed firmly against the first liner, the singleface liner, which may also have been treated with heat and/or steam. This creates a bond between the liner and medium as the heat, pressure and moisture cause the adhesive to rapidly gel. (See Figure 16.3)

The resulting singleface web then travels through the corrugator to the doubleback station where adhesive is applied to the exposed flute tips on the other side of the medium. Then those tips are brought into contact with a second liner, the doubleback liner. (See Figure 16.4)

This liner may or may not be of the same type as the liner at the singleface, depending on the requirements of the final container. Significant pressure would cause the flutes to crush at this point, so the bond is formed more gradually, primarily through heating, as the board passes over heated plates in a hot plate section.

The resulting rigid board exiting the hot plate section can now be "scored," so that later, it will fold on these creases to create the three-dimensional box. The board must not be rolled at this point. It is slit to width and cut to length, producing flat sheets that match the customer's requirements for a box.

These sheets are then stacked and conveyed from the corrugator, allowing time for the adhesive to dry and cure properly before subsequent operations. The corrugating process adds moisture to the papers through the steam conditioning and the starch adhesive and the removal of moisture through the heating and curing processes. These moisture shifts must be balanced to avoid warp in the combined board sheets.

Other attributes can be built into the combined board during the corrugating operation. One or more of the papers can be impregnated with wax or other treatments to impart different and unique properties. The board also can be coated on the singleface side which usually becomes the inside of the box, by using a variety of possible treatments on the surface.

Polymeric tapes can be incorporated, typically between the singleface web and the doubleback liner, to reinforce critical box areas like handholds or provide easy-opening features (tear strips) on the final box. Because of the operation of the cor-

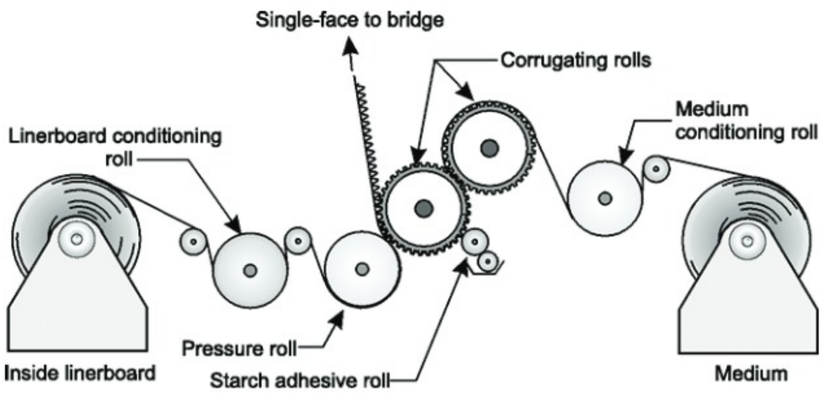

Figure 16.3
The singlefacer station of a corrugating machine is where the flutes are formed and bonded to the inside liner.

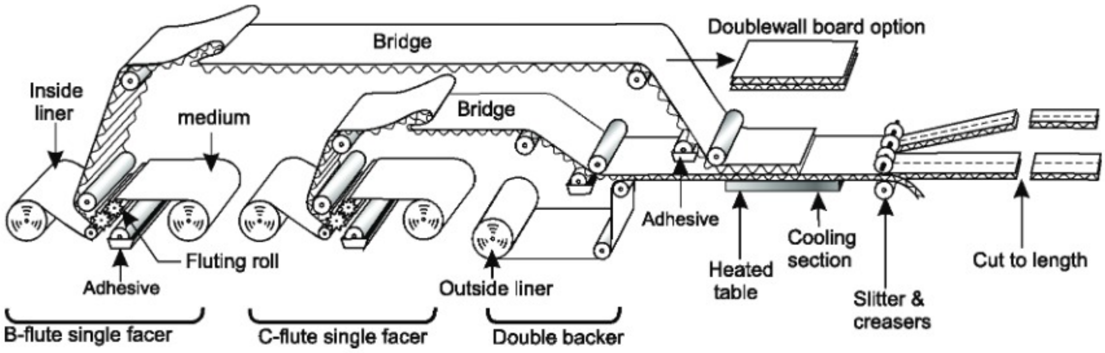

Figure 16.4
A corrugating machine. Doublewall boards are produced by combining the output of two singlefacers.

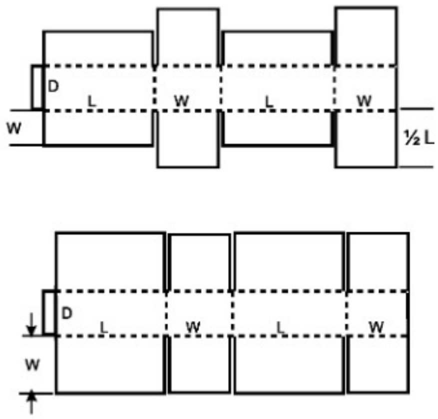

Figure 16.5
Examples of box blanks: Center special (top) and full overlap slotted box (bottom) are part of the regular slotted container (RSC) series.

rugator, these tapes would be fed in continuously and would run in the machine direction of the combined board.

Critical quality measurements are performed during the corrugating and finishing processes to ensure consistent package performance. These are discussed in the Testing section.

FINISHING/CONVERTING COMBINED BOARD TO BOXES

Finishing/Converting Equipment

Box Blanks

The combined board sheet produced by the corrugator isn't a box yet. It has to be made into a box blank first. A box blank is a flat sheet of combined board that has been cut, slotted and scored. (See Figure 16.5)

The combined board can be made into a box blank in different ways using different equipment: with a printer-slotter, a flexo folder-gluer or a die-cutter. Each of these machines uses a different process and produces a slightly different type of box blank. Examples of boxes produced by the equipment described below can be found in the “Box Styles” information material at information material at http://www.iopp.org.

Printer-Slotters

The printer-slotter is the least sophisticated machine for making box blanks from combined board. Unlike the die-cutter, it scores and slots in straight lines only. Printer-slotters are made in various sizes to accommodate various sizes of sheets.

The printer-slotter prints text and graphics using water-based inks, which are easier to work with, dry more quickly and are environmentally preferable to oil-based inks. It then makes the necessary cuts, slots and scores, and stacks the completed box blanks.

Flexo Folder-Gluers

Like the printer-slotter, flexo folder-gluers can print and cut combined board into box blanks. The flexo folder-gluer’s special attribute is its ability to apply glue to the blanks, fold them into flat, finished box blanks and bundle and stack them. Flexo folder-gluers also print using water-based inks. It works much faster than the printer-slotter, so it is often used when large quantities of boxes need to be produced quickly.

Figure 16.6 is a schematic of a flexo folder-gluer. It can include a die-cutting section, or not. A printer-slotter would consist of only the first half of the schematic, less the die-cutter section but with a sheet delivery section. A rotary die-cutter would look like a printer-slotter with a die-cutting section and a sheet delivery section.

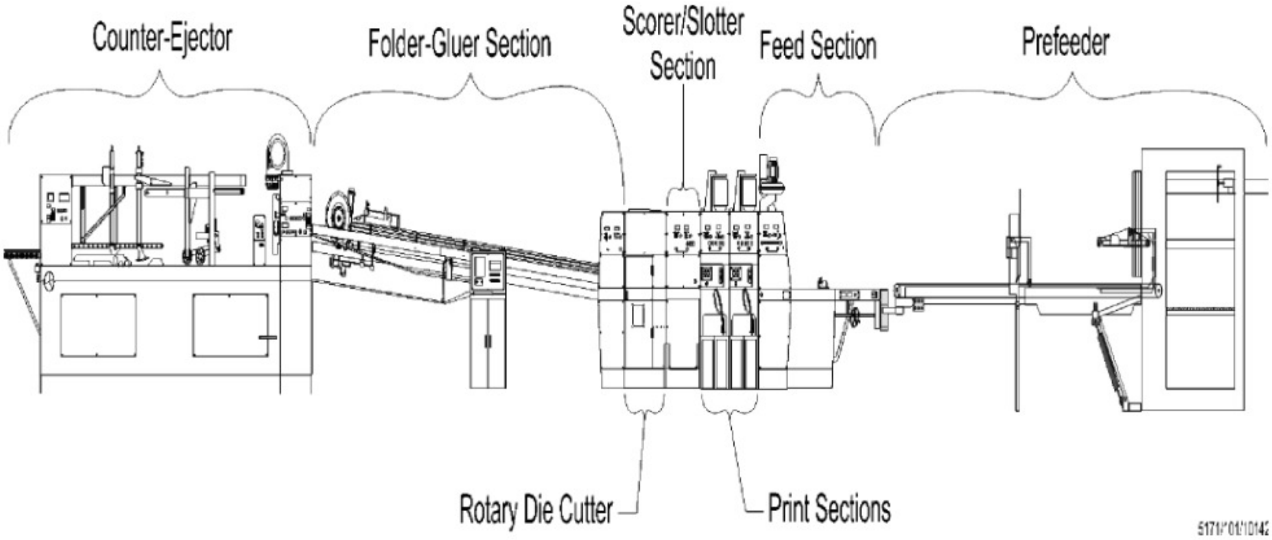

Figure 16.6
A schematic of a flexo folder-gluer. (Source: Fibre Box Association.)

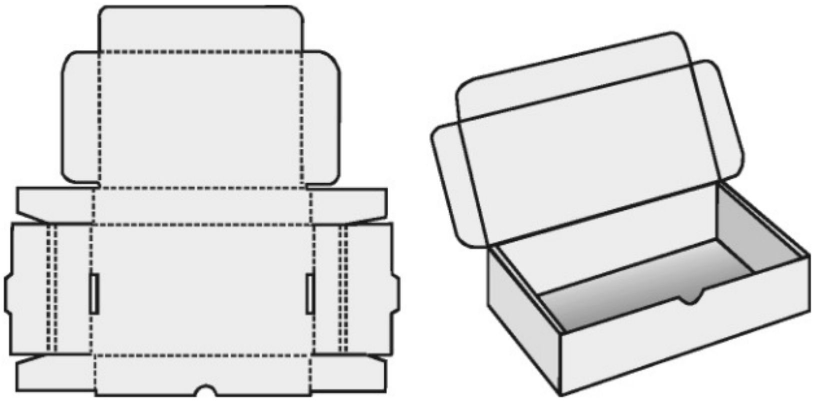

Figure 16.7
Typical die-cut box: Bliss style.

Die-Cutters

A die-cutter uses a die to cut and score the combined board into shapes. A cutting die consists of custom-made steel tooling mounted on a wood frame. Rotary die-cutters use a circular motion to apply the die to the sheet while platen (flatbed) die-cutters use a vertical motion to make the cuts.

Die-cutters are used to make die-cut boxes and combined board pieces with unique designs which require angular, circular or other unusual cuts, slots and scores. Die-cutters also can make perforated lines, ventilation holes or access holes in boxes. However, cutting dies can be expensive, and if only straight cuts and scores are needed, the printer-slotter is usually the more economical option. Printing also can be done on a die-cutter, or printing can be done on another machine before the combined board is fed into the die-cutter.

Die-cutters (and printer-slotters) also may be used to produce complete, but unjoined box blanks and Bliss-style parts that are shipped "in-the-flat" to customers for assembly at the end-user's plant. (See Figure 16.7)

Specialty Processes

Some box users require unique boxes to protect, cushion or organize their products. A box manufacturer might use foam sheets, plastic film or extra corrugated board to accomplish this. Examples of specialty products include laminated corrugated pads, corrugated board glued to foam sheets, corrugated board glued to plastic film, preglued trays and box bottoms, die-cut shapes and corrugated partitions.

Graphics

The corrugated industry has long had lithographically printed labels applied to one or more panels of a corrugated box. Print quality is high, but the process is slow and relatively expensive.

Flexographic inks and electronic controls enabled equipment to print rolls of linerboard (preprint linerboard) with close registration of multiple colors and controls on the corrugator cutoff knives that accurately cut the corrugated web to the marked length.

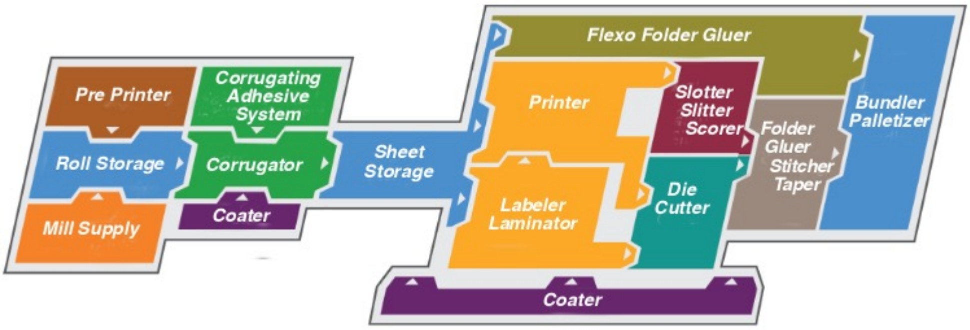

Figure 16.8
General box plant production flow.

Improvements in registration controls and the ink metering and transfer systems on flexographic folder-gluers, along with improvements in ink quality, have facilitated multicolor flexographic printing presses that direct print on corrugated board and compete with preprinted liners.

Computer-controlled, laser-direct digital printing produces boxes with high-quality graphics, without printing plates. Box manufacturers and their customers now have several options for high-quality graphics for displays and point-of-purchase items.

Planning

An important part of making boxes is scheduling a box factory's many orders for efficient production and meeting customer delivery requirements. The necessary considerations are, separating orders by board combination and flute profiles and balancing orders for machinery downstream from the corrugator so machines aren't scheduled beyond capacity while other machines sit idle. (See Figure 16.8)

Box plants used to maintain large inventories of containerboard to make sure paper was on hand to take care of the occasional rush delivery, but increased warehousing costs, competition and customer demands have forced the corrugated industry to evolve. Now, orders often have short lead times, get converted within a few hours of corrugating and are shipped directly to the customer, while the plant focuses on increased productivity and reducing waste.

REGULATIONS AND STANDARDS

Below are descriptions of the most frequently referenced and used regulations and standards that impact the corrugated industry. In addition, customers may have special marking or other requirements for their corrugated suppliers.

Carrier Rules

Many different types of carriers transport items packaged in corrugated shipping containers. This includes small and single-parcel delivery services (FedEx, UPS, USPS, etc.), as well as numerous over-the-road or "freight" trucking services and railroads. In North America, they all impose packaging rules in exchange for accepting damage liability for the "articles" they transport.

If box customers want packages to be shipped and insured by the carrier, they must follow their rules. Any item deemed improperly packaged or not properly marked in conformance with the applicable carrier rule(s) can subject the shipper to penalties such as higher freight rates, nonpayment of damage claims or refusal of acceptance by the carrier, AKA "frustrated in transportation."

Carrier rules address only the issues associated with their mode of transportation. The requirements for packing, storage and further distribution of the contents often exceed carrier's corrugated packaging material minimums. To ensure the boxed goods arrive at their ultimate destination—the consumer—in acceptable condition, box suppliers and customers should agree to specifications addressing all the environments the package is intended to protect against.

Truck and Rail Rules

The rules for shipping products in corrugated boxes by truck or rail are specified in two publications: the *National Motor Freight Classification (NMFC)* for trucks—specifically LTL/carrier members of the National Motor Freight Traffic Association (NMFTA)—and the *Uniform Freight Classification (UFC)* by rail. These publications list detailed packaging rules (tariffs) based on the "articles" being transported.

If the listing for the article (what will be inside the box) doesn't give any packaging information, for carrier liability purposes, the article can be shipped without any packaging. If the tariff says "in packages," the articles must be packaged but no further specifics regarding packaging are required by the Carrier Rules.

The rule may state "in boxes" and/or other package type, which means there are rules in the tariffs for those package types. Boxes are containers that fully enclose the articles inside on all sides, ends, top and bottom. Item 222 in the *NMFC* is for corrugated and solid fiberboard boxes, and Rule 41 is the *UFC* fiberboard box rule. They are very similar, and in practice, they're fundamentally the same.

Item 222 and Rule 41 set minimums that the box manufacturer must meet. But box manufacturers usually exceed the minimums to cover box requirements beyond the trip on the highway or rails—stacked only as high as the inside of a trailer/boxcar. (See section, Estimating Required Compression Strength, Chapter 18, Shock, Vibration and Compression)

The material specifications in the carrier rules are tied to maximum gross weight and size (length + width + depth) of the box and its contents. Boxes can be made to conform to either Table A (burst and basis weight) or Table B (ECT).

Box Manufacturer's/Maker's Certificates

To be covered under the general liability provisions of the rules, an Item 222/Rule 41 box must carry a circular box manufacturer's/maker's certificate (BMC) on an outside panel. (See Figure 16.9) Without the BMC, carriers are not obligated to honor damage claims or established freight rates. Boxes can be made to either the burst (Table A) or ECT (Table B) provisions of these rules.

BMCs must match the specifications and definitions in Item 222-1 and the maximum weights and dimensions and minimum fiberboard requirements in Tables A or B (of Item 222 or Rule 41) per the box and contents—exactly. No substitutions can be made or the box will be deemed not properly marked in conformance with the rule (Item 222/Rule 41) and may suffer the consequences.

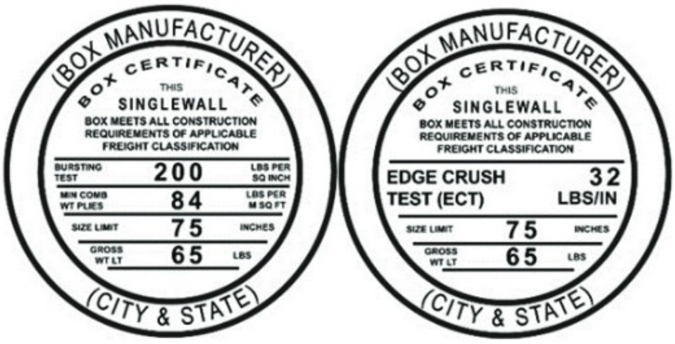

Figure 16.9 Box manufacturer's/maker's certificates for boxes conforming to Item 222/Rule 41 (*NMFC* and *UFC*), using burst test and edge crush test values.

Numbered Packages: Some items require a specific packaging system. In the *NMFC*, the description for the article will say, "in Package Number ###," and the box specifications are in Specifications for Numbered Packages, but the authorization and certification details for boxes are in Item 299.

The *UFC* calls the specification packaging, "Authorized Packages," and the corrugated packaging specifications are included in Rule 41, but the system is much the same. Numbered Package rules for boxes require a rectangular BMC that shows the package number and the burst strength (test) or ECT values of the corrugated fiberboard. (See Figure 16.10)

Most corrugated manufacturers use basis weight containerboard grades to meet the burst strength requirements of customers and the carrier rules. The burst test is an indicator of durability in the shipping environment, making it an appropriate metric for boxes that are exposed to rough handling or for heavyweight bulk.

However, more board combinations are available for meeting ECT needs, addressing top to bottom compression strength requirements of warehousing products in boxes. Using ECT to fulfill the carrier rules, box manufacturers have more latitude to design and supply boxes that more closely target the user's performance requirements.

Non-U.S. Packaging Rules

Item 222 and Rule 41 are recognized throughout North America. They also apply to boxes made elsewhere and shipped knocked down (KD), or flat, into Canada or the United States for filling and distribution by NMFTA member carriers. A BMC on a box provides the carriers with certification of the structural integrity according to their box requirements, as a condition for providing shippers with damage insurance and preferred tariff rates.

Other countries and organizations have certification markings that show compliance with testing or material specifications. Individual European countries have their own regulations, and the European Federation of Corrugated Board Manufacturers (FEFCO) has certifications, which apply in all member countries but may differ from those of the countries. In practice, selection is done at the discretion of the box customer.

The *NMFC* and *UFC* are the only requirements worldwide that include limited damage claim liability for items damaged in transportation. When any other box certification marking is used, it is either because of the nature of the item that is being shipped or it is done by customer request.

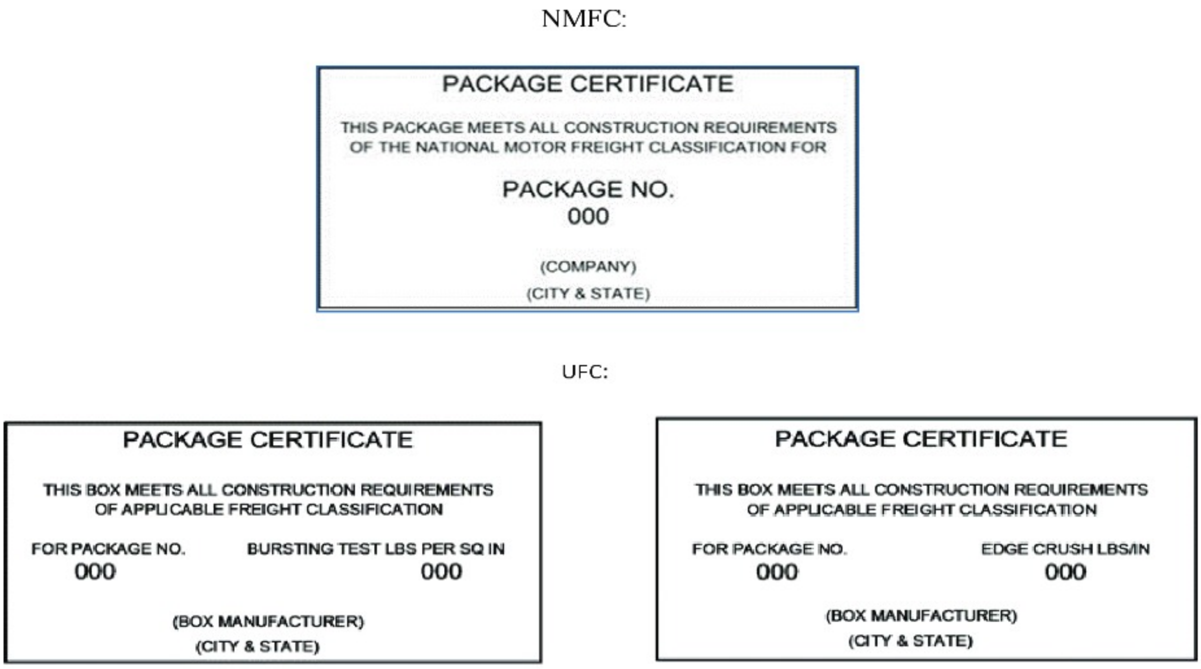

Figure 16.10
Package certificates for Numbered Packages: *NMFC* (1) and *UFC* (2).

U.S. Government Rules and Regulations

Military Specifications

The federal government and the military have standards that apply whenever they purchase corrugated packages or items shipped in corrugated packages. The Office of Management and Budget has directed executive agencies to use commercially available products and services whenever possible. A number of military standards affecting corrugated packaging have since been converted to ASTM International standards such as ASTM D5118, ASTM D5168 and ASTM D4727.

These standards list options for boxes and sheet stock by: Type (corrugated, solid fiber); Class (domestic, weather-resistant, water- and water vapor-resistant, fire-retardant); Variety (singlewall, doublewall, triplewall); and Grade (125 psi burst, V3c, WWVR, etc.). ECT corrugated fiberboard may be used when it is available for the specified class when authorized and appropriate for the intended application. More information is at: ASTM.org/Standard/index.

Federal Regulations

Federal regulations are in the *Code of Federal Regulations (CFR)*, divided into titles of the agency under whose jurisdiction the issue falls. The *CFR* is updated each time a change is made to a regulation. The easiest access to the most current regulations in each of the titles in the *CFR* is eCFR.gov/search. Or, if you know the title and section you're looking for, search ecfr.gov/index.

DOT Regulations (49 *CFR*): The Department of Transportation (DOT) regulates the packaging and transport of hazardous materials. Standards for various types (nonbulk, bulk, composite, etc.) of fiberboard boxes are in 49 *CFR* §§178.516, 178.522, 178.702-708 and 178.930. Training in awareness and job functions (and more) of the Hazardous Materials Regulations is mandated by the DOT in sections 172.702 and 172.704.

For testing recommendations, see ASTM D10.22 Hazardous Materials Subcommittee, D4919-17 Standard Guide for Testing of Hazardous Materials (Dangerous Goods) Packagings.

USDA Regulations (9 *CFR*): The U.S. Department of Agriculture (USDA) regulates meat and poultry packaging. Though box plants wouldn't fall directly under the regulations, they may be obligated under 9 *CFR* Part 417 Hazard Analysis and Critical Control Point (HACCP) Systems (§417.2–417.8) to develop and act upon a HACCP plan relevant to their operations. They also require certification by the packaging manufacturer that the materials used in the packaging meet the Food and Drug Administration's indirect food additive regulations, specify required markings in Part 112 Packaging and Labeling.

FDA Regulations (21 *CFR*): Corrugated fiberboard is not usually used for direct food contact. Most often there is a barrier, such as another package or a coating between the containerboard and food. In that case, the Food and Drug Administration (FDA) regulates paper and paperboard foods packaging as indirect food additives. See 21 *CFR* Part 174 Indirect Food Additives: General and §186.1 Substances added indirectly to human food affirmed as generally recognized as safe (GRAS) or §570.14 Indirect food additives resulting from packaging materials for animal feed and pet food.

If the corrugated box is directly contacting food, see §74.6 Threshold of regulation for substances used in food-contact articles, all of Subchapter B (including Parts 109, 117, 120, 121, 175-177, 182, 184, Subpart D 189.220–189.301) and others as needed. Sections 170.30 Eligibility for classification as GRAS or §570.30 with the same name (for animal food) may be applicable.

The FDA also regulates the nutritional labeling of consumer packages. And both the FDA and the Federal Trade Commission (FTC) require metric as well as standard measurement units to be displayed on many consumer product packages.

FTC Regulations (16 *CFR*): The FTC defines voluntary eco-label statements such as "recycled," "biodegradable," "recyclable," etc. Under these rules, corrugated fiberboard that has not been coated or treated with unrecyclable materials can be labeled "recyclable." Most of the U.S. population has access to collection systems that return OCC and used corrugated products to paper mills. ASTM International has a compostability standard. ASTM D8410 can facilitate corrugated manufacturers to label their products as compostable per 16 *CFR* §260.7 Compostable Claims.

BOX REQUIREMENTS AND BOX DESIGN

Many features must be considered when designing a box. The most common are box style, flute profile, board combination, manufacturer's joint type, special corrugating adhesive, coatings; white top, full bleach or kraft colored (the natural color of wood-based paper); graphics; unitization; warehousing loads and conditions; and shipping and delivery modes and rules.

The designer must consider what product protection and customer needs must be designed into the container and prioritize them. To make these decisions, the designer must have details like what the product is and what the customer expects from the container, how it will be shipped and what special needs the product requires, including regulatory demands. Providing or collecting the correct information before deciding on the materials, box style and dimensions accelerates and supports protecting the contents efficiently and effectively.

Structural Needs

To determine what the product needs from the box, consider whether the product can and should provide any structural support of its own. Or is the box going to need to support all external loads? Is it a solid, liquid or powder? Are there primary containers? Are they able to support loads from above or only to contain the product? Understanding the product's state and the forces and impacts it may exert on the container will help the designer select the proper structure.

To learn more about the structural needs of boxes, see the Estimating Required Compression Strength section in Chapter 18, Shock, Vibration and Compression and Fibre Box Association publications, *How to Get the Best Box* and *Understanding Box Performance*.

Protecting the Contents

Box designers must know a product's protection demands. Is the product fragile or easily marred? Fragile items require inner packaging that will help to absorb the shock of a drop or will isolate the product away from the corners of the container, allowing the corners to absorb shocks without transferring them to the product. If the product can be damaged by rubbing against the packaging, a coating could be used on the inner liner to reduce friction.

Should there be vent holes to ensure proper cooling of the product or access holes to allow the container to be picked up and carried? The designer needs answers to such questions to properly design the container. To assist in judging survivability in varieties and combinations of distribution environments, the International Safe Transit Association (ISTA) and ASTM International have developed package testing protocols incorporating drop, vibration, impact and compression. They are not specific to the packaging materials used.

Printing

Boxes can be single-use transport packaging to protect the product. They can advertise the product inside. And they can do both. A box that is used to ship from the manufacturer to the retailer, where product will be removed from the container and placed on shelves or displayed on pallets, is going to look a lot different from a box that is supposed to inform and influence the consumer to choose this product instead of another.

Knowing the coverage and complexity of the print on a box or display will help the designer select the type of outer facings to use to accommodate the print. A lot of the printing done in a box plant today is flexographic, a process in which a printing plate is coated with ink and then rolled across the outer surface of the container. The printing process is high-speed. Each color used in the print is laid down at a separate station, the more colors, the more stations in the printing process.

Complex prints can be beyond the capabilities of some box plants. In these cases, a designer may suggest using a preprinted liner, a liner that is printed prior to the corrugating process. Preprinted linerboard, preprint liner or preprint (mentioned earlier in this chapter under Graphics in the Finishing/Converting section) will add to the cost of the packaging or display since the printing of the liners isn't often done at the same facility where the box is produced, also adding transportation costs. But while preprint is an increased cost, it offers a much higher quality of graphics and will not contribute to a loss in compression in the process.

Digital preprint has become more common. It offers faster speeds for developing and delivering designs, for production time, and probably its main benefit is in versioning. The ability to quickly change or adopt current opportunities or trends, and not having large minimum orders or the larger inventories they induce, are clear advantages.

Packing Equipment and Box Setup

Information about the box-handling or packing equipment and knowing how the container will be opened, set up, and filled will inform how the box design should be configured. For example, there are left-handed and right-handed boxes. Looking at a box in its KD position with the manufacturer's joint up and the top of the box away from you, if the longer panel is to the right, the container is a right-handed box. If the longer panel is to the left, it's a left-handed box. The (setup equipment) manufacturers will normally specify feeding right-handed or left-handed boxes depending on how the equipment is designed to open the boxes, ensuring that the panels are in the correct configuration for the equipment.

How the product is inserted into the box also helps define the design of the box. If the product is slid in from the side, the designer should make sure the manufacturer's joint is on the top when the equipment opens the box so the product will not catch on the joint. The speed at which the setup equipment will operate is also important to the design of a container. High-speed setup equipment may exert more force and require tighter tolerances than equipment running at slower speeds. PMMI, The Association for Packaging and Processing, and the Fibre Box Association have published technical reports that provide voluntary guidelines for RSCs, Die-cut Sheets, which, if followed, ensure that containers set up properly on most equipment.

Distribution Extremes

Boxes experience environmental extremes, such as being top-iced, flash-frozen, baked or irradiated. Specialty coatings and treatments are designed to protect the box and product from such environments. Some of these coatings can be applied prior to the corrugating process, some can be applied at the corrugator or in the finishing process. Coating manufacturers can assist in the selection of the correct coating and application processes to meet the packaging's needs. Wax and wax alternatives are coatings that can help protect the container from ice and water.

It's important to assess the conditions the packaging will likely encounter during the distribution process. Some conditions, such as temperature, humidity and stacking time are difficult to control in the distribution environment. Others like pallet patterns or overhang, deck board gaps and excessive handling, logically should be avoidable, but they're random, making it more effective to build solutions into the packaging design.

Both kinds of conditions need to be mitigated for the sake of the goods being transported. Knowing the distribution environment variables allows designers to estimate the impact on a box and apply a safety factor to the design.

Programs are available to aid in estimating the required box compression strength, which is measured as box compression (BCT). Also, safety/environmental factors have been extrapolated from academic and professional research and applied and recalculated at box plants. Misjudging or ignoring the distribution circumstances or shipping requirements will lead to field failures which not only are costly but can also create a safety hazard for people handing the containers. (See section, Estimating Required Compression Strength, Chapter 18, Shock, Vibration and Compression)

Container Styles and Codes

There are many standard corrugated box styles, too many to describe here. The box styles are identified in three ways: descriptive name, an acronym for the name and a code number. For example, an RSC is International Fiberboard Case Code #0201. Slotted boxes, telescope boxes, folders, rigid boxes, self-erecting boxes and interior forms are all part of the Case Code.

The numerical code system, known as the International Fiberboard Case Code, was developed by FEFCO in collaboration with the European Solid Board Organization to avoid confusion when communicating in different languages. This code also has been adopted by the International Corrugated Case Association and the United Nations. The complete International Fiberboard Case Code is available from FEFCO at: https://www.fefco.org/technical-information/fefco-code (multilingual PDF in English, French, German, Italian and Spanish) and http://www.okart.sk/vlnitalepenkafefco.pdf (English).

Voluntary Standard Designs (Corrugated Common Footprint and Case-Ready Modular System)

Grocery retailers and their distribution centers were challenged by the vast range of corrugated container box sizes. The differences in box dimensions led to poorly stacked pallets. And produce boxes were being designed for accommodating field conditions, not to display the products. So, the corrugated packaging industry developed a modular packaging system—the Corrugated Common Footprint container (CCF).

Voluntary standard designs are shared by the corrugated industry. The technical specifications for the CCF for produce are available at Fibrebox.org, search CCF (also see links for comparative Research Results and Informational Brochure).

The common footprint term refers to the standardization of the length and width dimensions of the produce container. The containers come in two standard sizes. The Full-Size Footprint container is 60 x 40 centimeters (cm) (23 ½ × 15 11/16 inches). In a full-size pallet configuration, five full-size containers fit easily within the dimensions of Grocery Manufacturers Association (GMA) standard 48- × 40-inch pallets.

The Half-Size Footprint container is 40 × 30 cm (15 11/16 × 11 11/16 inches.). Half-size pallet configurations allow 10 half-size containers to fit on the same pallet. And because of their standard sizes and stacking tab locations, both half-size and full-size containers can be successfully fitted together within the same tier of a palletized load and from tier to tier within the load. The containers form a secure unit when assembled and the designs optimize cube space, reducing shipping costs. (See Figure 16.11)

The Corrugated Case-Ready Modular System (CRMS) offers two parallel footprints and standards: a five-down (full-size) and a six-down-long (full-size). The two different footprints facilitate maximum shipping density. (See Figure 16.12) The technical specifications for corrugated modular systems for case-ready meat are also available at Fibrebox.org, search CRMS.

Both voluntary standards have practical enhancements in common. The modular design of the length and width dimensions of the corrugated shipping containers ensures that the containers can be stacked in the ideal pallet-load cube space without overhang, on any GMA or metric industry-standard pallet (48 × 40 inches or 1200 × 1000 millimeters). The Fibre Box Association and FEFCO worked in close cooperation to ensure compatibility of U.S. and European common footprint standards. As a result, shipping containers manufactured to either standard are compatible with each other.

Figure 16.11
Corrugated Common Footprint containers.

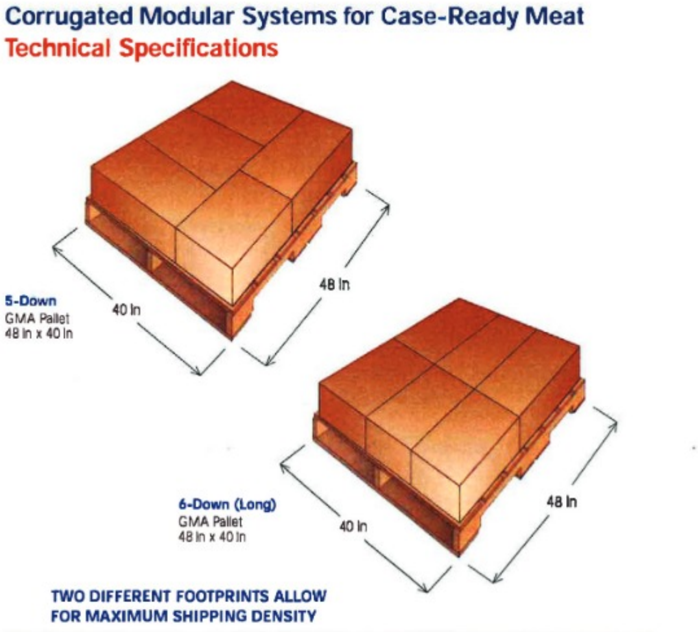

Figure 16.12 Corrugated Case-Ready Modular Systems for meat.

The height of the containers may be adjusted to allow for increased capacity, the structural design can be modified for strength, more efficient packing and to meet other specific product needs. The graphics may be as diverse as the products.

TESTING

The Need for Testing and Test Organizations

Corrugated fiberboard, or combined board, has three main components: liner, medium and corrugating adhesive (starch). Consistent quality of each component is critical to the performance of finished boxes. Since it is impractical to conduct strength tests on liner and medium at the corrugator, corrugated manufacturers must rely on containerboard mill standards to establish that liners and medium meet performance as combined board and finished boxes.

Humidity impacts the physical properties of containerboard, and consequently, test results of corrugated sheets and the boxes they are made with. Unreliable reproducibility between laboratories using recognized test methods leads to misunderstandings when comparing data produced by different labs, even under the strictest conditions. It is important to understand that tests used on the shop floor without proper preconditioning and conditioning are suitable only as indicators of processing impacts.

Several internationally recognized organizations have developed testing procedures to establish consistency of data produced by manufacturers and independent labs. (See Table 16.2) TAPPI is a leading association for the worldwide pulp, paper and converting industries and is an ANSI-certified standards developer. Search "TAPPI numerical list" for titles and status of standards.

TAPPI Test Methods are identified by a code numbering system:

- Paper and Paperboard Testing, T 400-500 Series.
- Container Testing, T 800 Series.
- Testing Practices, T 1200 Series.

ASTM International develops and publishes voluntary consensus technical standards for many materials, products, systems and services. ASTM's D10 Committee on Packaging, D4727 Standard Specification for Corrugated and Solid Fiberboard Sheet Stock and D5118 Standard Practice for Fabrication of Fiberboard Shipping Boxes cover many materials and processes discussed in this chapter and cite the relevant ASTM and TAPPI test methods.

ISTA has well-recognized package performance protocols and a Custom Test Builder. (See ISTA.org)

- For a list of FEFCO test methods, search "FEFCO testing methods" or see FEFCO.org, under Technical Information > Testing Methods and Recommendations.
- FEFCO also compares global test methods (FEFCO, EN, ISO and TAPPI) at FEFCO.org, under Technical Information > Standards & Guidelines > World Standards—Comparison Testing Methods.

Table 16.2
Most-used corrugated fiberboard test methods. (Source: *Fibre Box Handbook.*)

Property	TAPPI
Testing Practices	
Sampling	T 400
Conditioning	T 402
Containerboard	
Burst—Containerboard	T 403
Basis Weight	T 410
Caliper—Containerboard	T 411
Moisture	T 412
Elmendorf—Tear	T 414
Cobb	T 441
Moisture Transmission Rate (WVTR)	T 448
Brightness—TAPPI	T 452
Gurley Air Resistance	T 460
Tensile	T 494
Smoothness—Sheffield	T 538

Property	TAPPI
Containerboard (continued)	
Stiffness—Taber	T 566
Internal Bond—Scott Method	T 569
Smoothness—Stylus	T 575
Flat Crush—Medium—CMT	T 809
Ring Crush—RSM	T 822
SCT (STFI)	T 826
Water Absorb Med Water Drop	T 831/T 835
Water Absorb Med Float Curl	T 832
Concora Fluted Crush Med	T 843
Combined Board	
Caliper—Combined Board	T 411
Puncture—Container Board	T 803
Burst—Combined Board	T 810
*ECT—Wax Dip Method	T 811
Ply Separation—Finger Flick	T 812
Coefficient of Friction—Slide Angle	T 815
Flexural Stiffness	T 820
Pin Adhesion	T 821
Flat Crush—Combined Board	T 825
Box Blank Dimensioning	T 827
Score Quality	T 829
Ink Rub	T 830
Bending Stiffness—4 point	T 836
ECT—Clamp Method	T 839
Manufacturer Joint Adhesive Testing	T 840
Board Basis Weight Analysis—Soak Apart	T 844

*ECT—Item 222/Rule 41 recognizes only the T 811 method for referee testing.

Finished Boxes	
Drop	T 802
Box Compression - BCT	T 804
	ASTM
Incline and Horizontal Impact	D880/D4003
Vibration	D999/D4728
Determining Dimensions of Fiberboard Boxes	D2658
Containers & Systems	D4169
Specifications for Various Grades and Classes	D4727
Fabrication of Fiberboard Shipping Boxes	D5118

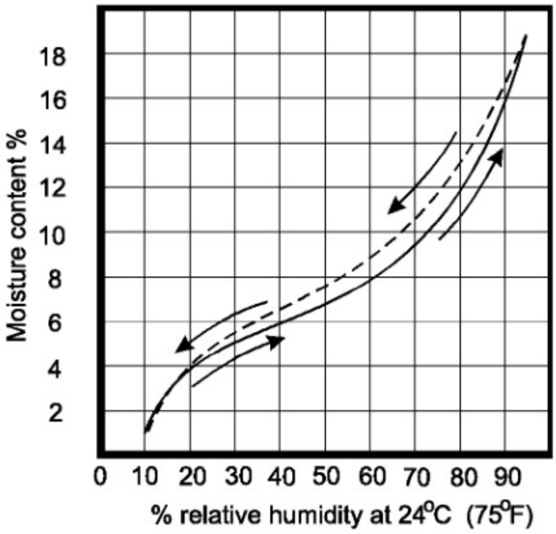

Figure 16.13
Equilibrium moisture content for paper and fiberboard.

Preconditioning/Conditioning

Preconditioning followed by conditioning at standard conditions (see TAPPI T 402) is required to ensure that the equilibrium moisture content of the sample is reached. This process is required by all standard test methods to minimize the hysteresis effect inherent in paper. Equilibrium moisture content for paper is different if the sample reaches standard conditions from the wet side than if it is reached from the dry side. Containerboard and combined board test results are more repeatable when samples are preconditioned before being brought to standard conditions. (See Figure 16.13)

Moisture Content

Paper, including containerboard, has no intrinsic moisture content level. Paper is hygroscopic. It absorbs moisture in high-humidity environments and gives up moisture in low-humidity environments. The atmosphere in which containerboard or boxes are placed determines the moisture content of these materials. While temperature has some effect, relative humidity (R.H.) is the driving factor in determining the moisture content of paper. The test results of most characteristics of containerboard and corrugated board are affected by the moisture content of the samples being tested. That is why standard testing requires preconditioning and then conditioning before testing.

Oven Dry: Test methods are written that use accurate balances and ovens to determine the moisture content of a sample of containerboard or combined board at a point in time. Speed in collecting samples and making the initial weight measurement is critical to achieving accurate results, as the fiberboard begins to move to a different moisture equilibrium point immediately after paper machine or corrugator production or the moment they are moved from one R.H. to another.

Infrared Balances: Several devices are available that weigh a specimen, remove moisture, measure the dry sample and calculate the moisture percentage of the specimen. These devices generally are accepted as accurate. The cautions regarding speed of the process, noted previously, apply when using these instruments.

"Probe" Devices: These devices are used by some box users to estimate moisture content of their boxes. They don't give accurate readings of the moisture content, but these instruments are good for measuring moisture differential at various locations.

Some box manufacturers and box plant customers have moisture content correction factors that are used to correct shop-floor-measured BCT and ECT results to standard conditions. Oven-dry and infrared measurement results work reasonably well with the tables of moisture correction factors.

Moisture content of combined board, as the board exits the corrugator, is a good indicator of process control, i.e., heat application and starch application. Low moisture content may indicate at least one component of the sheet was overheated on the corrugator. Low moisture board may result in low pin adhesion, low ECT, low box compression and box failure. Use the oven-dry or infrared balance procedures.

Performance Testing

Corrugated packages may meet minimum ECT or burst/basis weight minimums as specified in the carrier rules, but still may not be up to the rigors of a product's expected distribution system. ISTA and ASTM have performance testing protocols to evaluate performance against drop, vibration (truck-trailers on highways), impact, compression and other distribution conditions.

Tests

Basis Weight (Containerboard and Corrugated Board)

The weight per unit area of containerboard is expressed as basis weight, pounds/1,000 square feet (lb/msf) or grams per square meter (gsm). Basis weight is used in calculations of strength properties and in some box specifications, so accurate measurement of basis weight is critical.

However standard tests for basis weight use sample sizes smaller than basis weight is specified—significantly smaller for U.S. containerboard. Additionally, the test measurements are generally taken from combined board that has been soaked apart. It isn't because of inaccuracy by a lab that tested basis weights of samples, cut to even less than 1-foot square samples, are not accurate compared to those measured at the containerboard mills for 1,000 square feet.

Basis weight of combined corrugated board is not measured but may be estimated by adding the individual basis weights of the liners and medium(s) times TUF(s). The sum of the medium and linerboard components yields the combined board basis weight for lb/msf or gsm.

Figure 16.14
Compression testing for corrugated boxes.

Box Compression

BCT determines the compressive resistance of shipping containers by measuring uniform force applied by two flat surfaces to two opposing sides of a container, causing a specific type of deflection. (See Figure 16.14) BCT (values) can be measured for a box, package components (by comparing identical boxes with and without the components), a stack of boxes and unit loads.

Results are used to estimate the ability of a corrugated box to resist vertical compressive forces, thereby establishing stacking strength. As with other strength tests of paper-based materials, if the results are for comparative purposes and standard preconditioning and conditioning requirements are not performed, moisture contents of materials should be measured so use of moisture-correction factors can be applied.

Burst Strength of Containerboard

The bursting strength of containerboard, including linerboard with bursting strength about 50 psi (350 kPa) or greater, is measured using a disk-shaped, molded diaphragm-type instrument commonly known as a Mullen tester. (See Figure 16.15)

Burst Strength of Combined Board

Bursting strength of combined board is a measure of the containment properties of combined board. The same device is used to measure the bursting strength of containerboard, singlewall and doublewall corrugated, and solid fiberboard. Clamp depth is controlled for testing corrugated board.

Caliper

The procedure (T 411) listed in Table 16.2 is for measuring thickness and variations in containerboard and combined board. Consistent caliper, especially in the cross direction of containerboard, is essential to corrugator operations.

In combined board production, caliper measurements should be taken often to

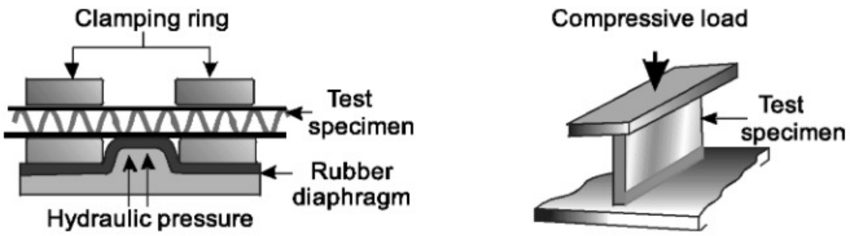

Figure 16.15
Combined board burst and edge crush tests.

identify potential crush of combined board, by comparing before and after caliper measurements for materials traveling through converting equipment. Crushing damages flutes and reduces the compression strength of boxes.

Edge Crush

Edge crush is a predictor of BCT for RSCs, the most common box style used. The ECT of corrugated combined board given by the manufacturer signifies that converted boxes will provide ECT of at least that rating. Therefore, the ECT of corrugated sheets must be strong enough to deliver the stated ECT after converting.

Many corrugated plants conduct ECT testing at the corrugator without any conditioning. Results of these tests are not reliable as they will reflect ambient R.H. and combined board moisture content. This testing is useful for process checks but not as verification of actual performance metrics.

Flat Crush

Flat crush resistance prevents crushing of the flute structure on the corrugator and other converting equipment. Flat crush can be measured on medium or combined board.

Pin Adhesion

The pin adhesion test measures the force required to separate the flute tips of corrugated medium from the linerboard facings of corrugated combined board. Low results may indicate adhesive application defects, adhesive deficiencies, liner/medium absorbency problems, excessive heat applied on the corrugator and low internal bond of the containerboard.

Score Quality/Score Bending

Score quality affects bend resistance. Bend resistance, along with other score quality characteristics of corrugated sheets and boxes, affects box performance in end-use applications, such as case erecting, filling and sealing operations on packaging lines. A score ratio test is described in the Score Quality test method. Many operations judge score bending by measuring the force required to bend a scored sample, but score quality should include calculating the score ratio.

Slide Angle

Some box customers require a minimum coefficient of friction (CoF) to minimize shifting or slipping during box filling and handling. In the corrugated industry, CoF is measured by determining … *the angle at which one test surface begins to slide* *against another inclined surface as the incline is increased at a constant and prescribed rate.* [TAPPI] Corrugator-applied treatments are available to enhance slide angle if a customer requires a slide angle above the normal range of linerboard. Test instruments are available for shop floor use.

Water Absorption

Water absorption is reported as the time for a specimen to complete the process listed in the standard. The Float Curl method is most common for use at the corrugator as it requires no special equipment. Water Drop tests are preferred lab tests and can be performed with equal repeatability, but they do not give the same results. In general, each of the tests demonstrates variability among rolls of medium.

Corrugator Adhesive Evaluation

Consistent adhesive quality is critical for manufacturing corrugated sheets. Unmodified raw corn starch (Pearl starch) and water are the primary ingredients.

Corn milling operations control moisture and caustic sensitivity of Pearl starch to ensure that corrugated operations can produce consistent, stable batches for their operation. Starch suppliers can provide technical assistance for onsite moisture and sensitivity checks, as well as each topic discussed below, and for wet-strength adhesives and soak tanks.

- **Gel Temperature:** Gel temperature, the temperature at which the liquid starch mixture becomes a highly viscous glue, impacts glue's ability to develop a strong bond between the liners and medium, thereby impacting corrugator speed and combined board strength. While there are no standard test methods to evaluate gel temperature, the well-used shop floor method uses a thermometer, a beaker and a heating apparatus.
- **Starch Viscosity:** Viscosity is probably the most common measurement for corrugating adhesive. Viscosity is a measurement of the fluid's resistance to flow. Corrugator starch viscosity is a measure of the time (seconds) for a measured volume of adhesive to pass through an opening in the bottom of a cup specific to the method used.
- **Starch Solids:** The percent of starch solids is the ratio of the weight of the dry ingredients to the weight of the total batch. Solids are usually calculated by the list of ingredients in a glue formula. Some systems calculate batch solids and display it with the formula. Solids may be measured by cooking a sample in an oven to remove all of the moisture and calculating the ratio of the dry weight and the wet weight of the sample.

Wet Strength of Corrugating Adhesives

See TAPPI—TIP 0304, Understanding Wet Strength: What are MRA, WRA, and WPA? for three levels of wet strength for corrugating adhesives:

1. Moisture Resistant (MRA) for the lightest level of performance.
2. Water Resistant (WRA) for a medium level of performance.
3. Waterproof (WPA): (WPA) for the highest level of performance.

TAPPI T 821 Pin Adhesion of Corrugated Board by Selective Separation (using samples immersed in water) and TAPPI T 812 Ply Separation of Solid and Corrugated Fiberboard Wet are applied to determine these levels.

Routine Box Plant Quality Assurance Practices

All box plants perform some routine quality assurance activities. Some of them are visual or manual observations without test methods. Testing the corrugator bond by flexing a sheet of corrugated board or making experienced cuts in the corrugated board and pulling the sheet apart are common practices. Dimensions are checked using a 10-foot tape measure. Various manual methods are used to measure warp. Print copy is matched to a production card, and print quality and color are observed or checked against color charts. Manufacturer's joint quality, fractured scores, slot quality, unit load quality and trailer loading quality are other characteristics that are evaluated visually. Many plants formalize these and other product inspections by using a checklist.

REFERENCE ORGANIZATIONS

American Forest & Paper Association (AF&PA), www.afandpa.org.

ASTM International, Committee D10 on Packaging, www.astm.org.

Association of Independent Corrugated Converters (AICC), www.aiccbox.org.

Corrugated Packaging Alliance (CPA), www.corrugated.org.

European Federation of Corrugated Board Manufacturers (FEFCO), www.fefco.org.

Fibre Box Association (FBA), www.fibrebox.org.

International Safe Transit Association (ISTA), www.ista.org.

TAPPI, www.tappi.org.

REVIEW QUESTIONS

1. What is paper made from?
2. Why are there so many paper grades?
3. What does "basis weight" mean for paper?
4. Is there any correlation among the different grades of containerboard?
5. Why are there so many different grades within the three major types of containerboard?
6. What is the flute of a corrugated combined board sheet?
7. What are the predominant flutes used in combined board?
8. What are the other flutes used for?
9. What are the purposes of flutes in corrugated boxes?
10. Why is corrugated adhesive called starch?
11. Can boxes be made "waterproof"?
12. How can boxes for fresh produce, fish and meat be kept intact when wet?
13. What is a die-cutter's purpose with combined board?
14. What is "converting equipment"?
15. What is the difference between a printer-slotter and a flexo folder-gluer?
16. What "joint" most commonly makes a flat blank into a box?
17. Are corrugated fiberboard boxes an example of sustainable packaging? Why or why not?
18. Is it possible to print a picture on a box?
19. How is preprinted liner utilized?
20. What is the box manufacturer's certificate?
21. What are some tests associated with carrier rules?
22. What is meant by preconditioning and conditioning?

DISTRIBUTION PACKAGING

17

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DISTRIBUTION PACKAGING 17

DISTRIBUTION PACKAGING: A SYSTEMS APPROACH

Designing for Distribution

Distribution packaging describes technical packaging functions that provide product protection and facilitate safe and cost-effective product distribution. We may further observe that distribution packaging not only *conserves value* but when designed properly, *adds value* to products being delivered directly to consumers.

The designer of a laptop computer might logically consider the environment in which the product will be used. However, the household environment is gentle compared to the transport conditions experienced to reach its destination. Such a product, designed only with its end use in mind, is quite likely to cost the manufacturer extra dollars in protective packaging. More costs will be incurred if the product doesn't fit efficiently into a standard distribution system.

This has never been more apparent than now. The packaging world continues to face new challenges as consumers increasingly seek convenient delivery of purchased items. This becomes especially challenging when existing packaging configurations are repurposed for new supply chains. To help ensure success, designers need to contrast supply chain hazards with product vulnerabilities. For example, orientation is not guaranteed in a single parcel delivery system (UPS, USPS, FedEx, SF Express, etc.), increasing the likelihood that a liquid product will leak during shipment if it was designed with only vertical (store shelf) orientation in mind. Anticipating these hazards early in the product-package design cycle will enable better packaging optimization across distribution channels. Furthermore, optimizing a packaged product doesn't have to be limited to the packaging. In some instances, optimizing the product could yield the greatest benefits.

The time to start considering distribution packaging is at the inception of a product's design. Unfortunately, there is a marked tendency to concentrate time and resources on product promotion and the consumer package, and then add the distribution package—as an afterthought when all other design aspects have been committed. (See Figure 17.1)

Figure 17.1
A sequential approach considers each step at the completion of the preceding step.

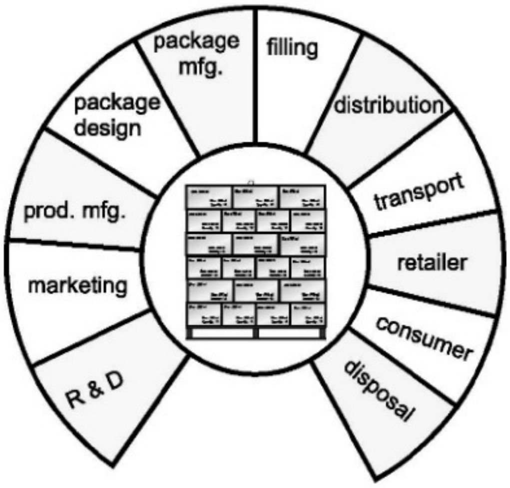

Figure 17.2
A systems approach to distribution package design considers all inputs.

Design tools, such as preshipment distribution testing, help confirm insights and offer a valuable understanding of packaged-product performance. Whether fulfilled through an e-commerce retailer or shipped directly from a product manufacturer, gaining insight into supply chain hazards and ensuring the most appropriate design tool is leveraged are critical to success. This chapter provides context around the most common testing methods used by packaging designers for e-commerce shipments.

A systems approach (see Figure 17.2) treats distribution packaging as an integrated activity. During product design, it considers all inputs and all events that the product and package will experience on its way to the final consumer.

System Considerations

Product Design

Whether a product will survive a particular journey depends partly on its susceptibility to damage from the hazards it will experience. In considering a packaging system for a product, the packaging engineer must start with the product itself.

"Fragility" describes a product's susceptibility to damage. Sound package design must consider quantified fragility factors, not general statements. The design process needs to assess potential damage from many sources including:

Compression	What is the safe working load?
Shock	What are the critical drop and "*G*" levels?
Vibration	What are the resonance frequencies and their response to random vibration?
Heat or cold	What are the critical temperatures?
Moisture	What is the critical humidity?
Time	What is the projected shelf life?
Electrostatics	What is the critical discharge voltage?

Product fragility factors must be evaluated and compared against likely distribution occurrences. Providing protective packaging for an unreasonably fragile product can be very costly. It is often more cost-effective to improve the product design. Protective package design should be considered only after one understands the product's unavoidable fragilities.

The Distribution Environment

You must thoroughly understand the nature of the distribution environment through which the product must travel:

- How will the product be handled?
- How will it be stored?
- How will it be transported?
- How high will it be stacked?
- What will the temperature and humidity range be?
- How many times will it be transferred and handled?
- What kind of pallets will be used?
- Will it be unitized or containerized?

The distribution package must be able to survive the environment. A container for local shipment need not be as sturdy as one that will be warehoused and shipped nationally or internationally. The distribution package or shipper must suit the handling methods used and provide appropriate protection for the contents.

The Primary Container as a Shipping Container

Make no unwarranted assumptions as to what the shipping container will be for different stages of the journey. A household toaster may be packed in a primary paperboard carton, and then six of these may be packed into a corrugated box. However, the sturdy corrugated box may go only as far as the local distribution warehouse. From that point, the actual distribution container may become the carton that houses each toaster.

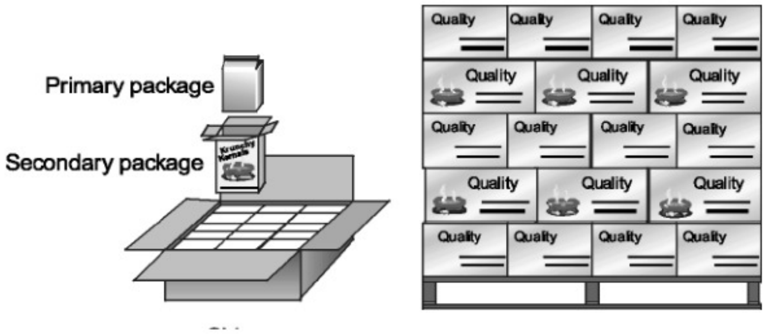

Figure 17.3
A packaging system may consist of many subsystems.

Complementary Primary and Shipping Containers

The distribution system may require several "layers" or levels of packaging. (See Figure 17.3) Optimal distribution packaging builds the correct protective and handling qualities into each packaging subunit and ensures that all the qualities are mutually complementary. This requires an understanding of which package will be used for different stages of distribution and the best compromise for such factors as load sharing and sizing.

Dimensions for Maximum Efficiency

An "arrangement" is a way of orienting several primary packages in a shipper. Each potential arrangement needs a different size shipping container, each requiring different corrugated board and divider material areas. Carrying the problem further, each shipping box size will have multiple palletizing pattern options. Some patterns will provide better cube utilization, while others may yield more stable loads. Still others may give maximum stack strength. Small adjustments to primary container dimensions can have major impacts on total shipping efficiencies and costs through better cube utilization. (See section, Unit Load Efficiency, below for details.)

The final objective is system efficiency: a shipping container that is cost-effective to produce and efficient to palletize, transport and warehouse.

Ease of Assembly and Disassembly

Every shipping container must be erected for packing and, when the container has served its purpose, must be opened or dismantled. Ease of disassembly, particularly for consumer products at the retail level and for components that will be used for further manufacture in an industrial package, can be a significant design feature.

A major problem at retail locations is knife cuts into package or product when stocking personnel cut open corrugated containers. Easy-opening features or specific indicators for opening will reduce this damage.

Sustainability

The package design process should include sustainability considerations, such as damage prevention, material selection and package design optimization. Sustainability considerations also involve decisions about whether the packaging is designed for multiple use or reuse and the expected end-of-life (EoL), which may be recycling, composting or disposal.

Damage Prevention. Damage prevention is the most critical packaging function from a sustainability perspective and is of greatest concern in the manufacturing and distribution phases of the product life cycle. If a product is damaged, it means more life cycle greenhouse gas (GHG) emissions, since that product will need to be returned or immediately sent to landfill, and its initial trip was essentially a waste.

Replacing damaged products accounts for a much higher GHG output and resource usage than does packaging. This is estimated to be 10–15 times more than the environmental impact of packaging. Damage prevention also reduces unnecessary extra shipments due to returns and replacements.

Studies by The ULS (Use Less Stuff) Report and The Industry Council for Packaging and the Environment (INCPEN) show that packaging only accounts for 7–10% of the total environmental impact of a product. By protecting the product, a small amount of packaging can significantly reduce the relatively large amount of environmental and economic waste that can result from product breakage, spoilage, mishandling and/or misuse.

Material and optimization choices to increase overall packaging sustainability should not increase the risk of product damage.

Material Selection. Material sustainability has to do with sourcing and EoL. Renewable or recyclable packaging materials should be from well-managed sources, which means the material manufacturer has environmental and socially responsible practices. The distance the material must travel also should be considered. These aspects contribute to the emissions associated with a material choice. Material sustainability also is impacted by the EoL, which is what happens once a material has been discarded from its first use as a product package. Is it recyclable? Is it curbside recyclable? Is it otherwise recoverable by composting or reuse?

These design decisions always should consider performance implications through package testing, as well as overall life cycle impacts. A more detailed discussion of packaging, the environment and sustainability may be found in Chapter 5, Environmental and Sustainability Issues.

Packaging Design Optimization. Optimization includes optimizing packaging design to be more lightweight (consume less material) as well as to occupy less space—also referred to as volumetric efficiency or Dimensional Weight.

Using less material, means fewer resources need to be extracted and that there is less weight that vehicles must carry per trip. This reduces GHG emissions and carbon footprint.

Focusing on volumetric-efficient packaging (using less space) enables more packages to be transported per trip, meaning more product is shipped versus empty space—reducing the number of trips required and therefore also reducing emissions.

Multiple Use and Reuse. Henry Ford is said to have designed a wood engine-packing crate to exacting tolerances. When the engine was removed, the crate boards were reassembled as the automobile floor.

There are many examples of packaging components having continued or useful value beyond the obvious. The use of distribution packaging as part of the sales display is perhaps the most common. Component protective packaging has been used as part of finished product packaging. Protective expanded polystyrene forms have been used as assembly jigs and fixtures. For high-volume products or products with a fixed or controllable distribution cycle, multiple-trip and bulk containers should be considered.

Design decisions contribute to a package's ultimate recoverability and also how a consumer learns about proper disposal. It is essential that consumers understand package EoL since they play a role in the reverse materials supply chain and recovery of materials for reuse.

Compliance with Legal and/or Carrier Requirements

Commodities classed as dangerous must, by law, be packed in containers that meet specified construction, performance, labeling and identification specifications. Packaging practices recommended by carriers and the trade are not all mandatory, but are based on experience and should not be bypassed without thorough analysis.

Efficient Materials Handling

Thoughtful product and package design frequently yields savings during the distribution cycle. Many export automobiles, for example, have tie-down eyes as part of their construction. For mechanical handling, keep load centers of gravity low. Provide clearance for forklift tines. Select stable pallet patterns and further increase load stability with stretch-wrapping, banding, caps, slip sheets or friction coatings.

Consider ergonomics where manual handling is expected. Simple features such as handholds can control orientation better, reduce the chance of dropping and—in the event of a drop—reduce the probable drop height. Avoid boxes heavier than 20 kilograms (kg) (44 lb.) for general consumer goods.

The Physical Distribution Environment

The physical distribution environment consists of all the handling, storage, transport and other events that a product is subjected to between the end of a production line and the final consumer. Think of the physical distribution environment as an area that is hazardous to the product. (See Table 17.1) Distribution packaging protects the product and ensures a safe, cost-effective journey.

Typical distribution systems have a surprising number of individual events, each with its own characteristic potential for damaging the product. It is said that a breakfast cereal carton will be picked up, moved, stacked, transported and otherwise handled 17 (or more) times before the final consumer selects it at a retail outlet. Consider the distribution environment for a nationally shipped 8.5-liter (L) plastic bottle of agricultural chemical manufactured in the east and used in the midwest:

- Two 8.5-liter plastic bottles packed in a corrugated box.
- Palletized manually.
- Pallet moved by forklift.
- Warehouse storage, three pallets high.

Table 17.1
Typical distribution environment hazards.

Basic Hazard	Typical Circumstances
Shock	Drops during manual handling; package thrown, rolled or tipped over; mechanical shocks (chutes, conveyors, palletizers); vehicle shocks (rail shunting, potholes, curbs).
Vibration	Roadbed patterns (rail joints, tar strips), suspension-generated vibration, out-of-balance wheels, drive-train vibrations.
Static compression	Warehouse stacking, bracing and other restraints.
Dynamic compression	Rail shunting, clamp trucks, arrests on conveyors and chutes, stacked packages during vehicle transport.
Piercing, puncturing	Equipment misuse, projections, hooks, shifting cargo, damaged pallets.
Racking, deformation	Uneven support, uneven lifting.
Elevated temperature	High ambient temperatures, direct sun exposure, proximity to boilers.
Reduced temperature	Cold climate, unheated transport vehicles.
Low pressure	Unpressurized aircraft holds, high elevations. (See Figure 17.4)
Light	Direct exposure to sunlight.
Moisture, water	High ambient humidity, rain on unprotected cargo, condensation, bilge water and seawater.
Biological hazards	Microorganisms, fungi, mold, insects, rodents.
Time	Long storage.
Contamination	Dust, dirt, rust, adjacent product leakage, other external materials.

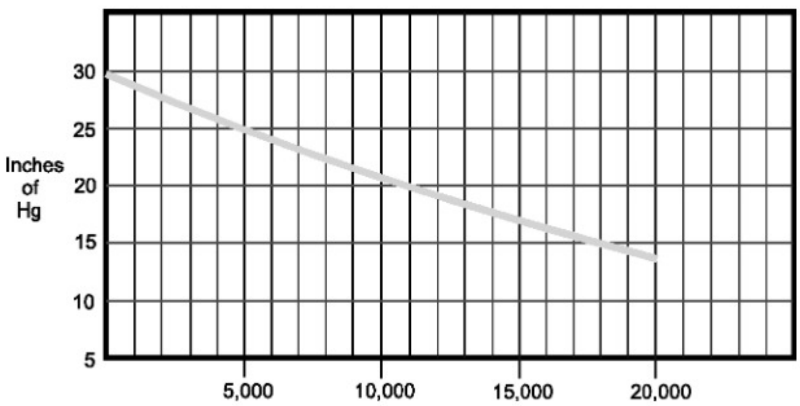

Figure 17.4
Air pressure and altitude. Most commercial aircraft maintain cabin pressure at about 8,000 feet.

- Pallet moved by forklift.
- Road transport by truck.
- Rail transit, trailer on flatcar.
- Road transport by truck.
- Pallet moved by forklift.
- Warehouse storage, three pallets high.
- Pallet moved by forklift.
- Road transport by truck.
- Pallet moved by hand truck.
- Warehouse, retail outlet, one pallet high.
- Manual handling of individual corrugated boxes, load into truck.
- Manual handling of corrugated boxes, unload from truck.
- Consumption.

By far the greatest damage is caused by the "physical" events: damage during warehousing, transport and handling and damage caused by compression, shock and vibration.

To protect against the dangers listed in Table 17.1, their nature and magnitude must be thoroughly understood. It is not possible to exactly identify the hazards encountered for any particular journey; however, statistical descriptions of what typically happens are available.

For example, there is no way to predict exactly what will happen on a transcontinental train trip, but it can be determined that the typical railcar shunt speed (the speed at which one railcar runs into another during coupling) is about 9.3 kilometers per hour (5.6 miles per hour). (See Figure 18.3 in Chapter 18, Shock, Vibration and Compression, for a detailed distribution of speeds.)

It also can be determined that if a boxcar is shunted three times during its journey, there is a 33% chance that at least one of the shunts will exceed 9.7 km/hr (6 mph). The wise packaging engineer will ensure that the container and the product are capable of withstanding these shocks and that the boxcar is loaded in a way that will minimize movement.

TRACKING DISTRIBUTION LOSSES

The Insurance Company of North America estimates that 75% of international cargo losses are preventable, much of them through better packaging systems. In less developed countries, food loss between producer and consumer can be as high as 45%; unfortunately, in some instances this represents the difference between self-sufficiency and starvation.

It is vital to good distribution packaging development that the cause and nature of any loss be examined and understood. It is not enough to say, "The boxes fell

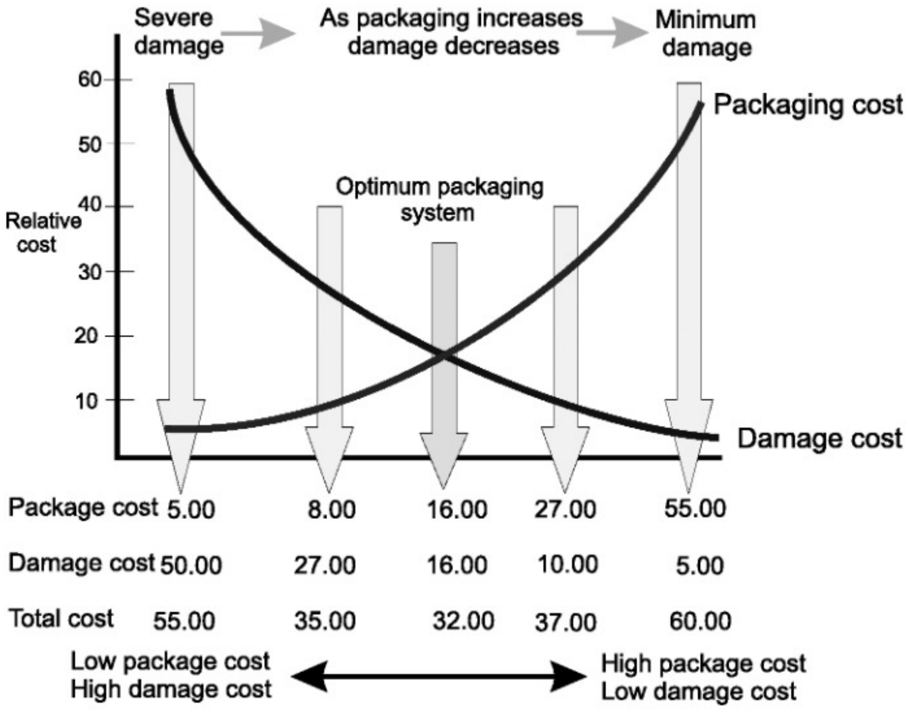

Figure 17.5
The optimum packaging system balances costs from excessive damage with the costs of over-packaging.

over." The exact events leading up to the loss must be analyzed and the loss quantified. Only careful attention to detail forms a logical basis for new packaging systems or reducing losses with existing systems. Detailed loss data can also reveal over- or under-packaging.

Consider the impact of a loss on net profit. After all the materials, salaries and overhead had been paid, product loss is subtracted from net profit. How much more product is going to have to be sold to make up this loss? If net profit is 5%, a $500 claim means that an additional $10,000 in sales will have to be generated to bring the profit line back up. North American Van Lines estimated that hidden damage reaction costs are typically five times higher than the cost of cargo repair or replacement.

Since money is invested in distribution packaging to avoid loss, it is logical that product lost from inadequate packaging should be accounted as a packaging cost. Generally, increasing packaging will reduce damage. (See Figure 17.5) However, there is an optimum balance between packaging costs and damage losses. To find the minimum system costs, total distribution costs—including packaging cost and damage cost—must be established.

The relationship reflected in total cost helps to determine the optimum investment in distribution packaging. Keeping packaging costs down can be a false economy if the result is a higher damage rate.

The total cost can be the same for over- or underpackaging. In one instance the principal expense is package costs; and the other is the cost of product loss. Increasing packaging will reduce damage rates until at some point the additional packaging costs are greater than the damage being prevented. Additional packaging would be overpackaging. Some overpackaging can be justified if it provides additional value such as goodwill or an impression of quality.

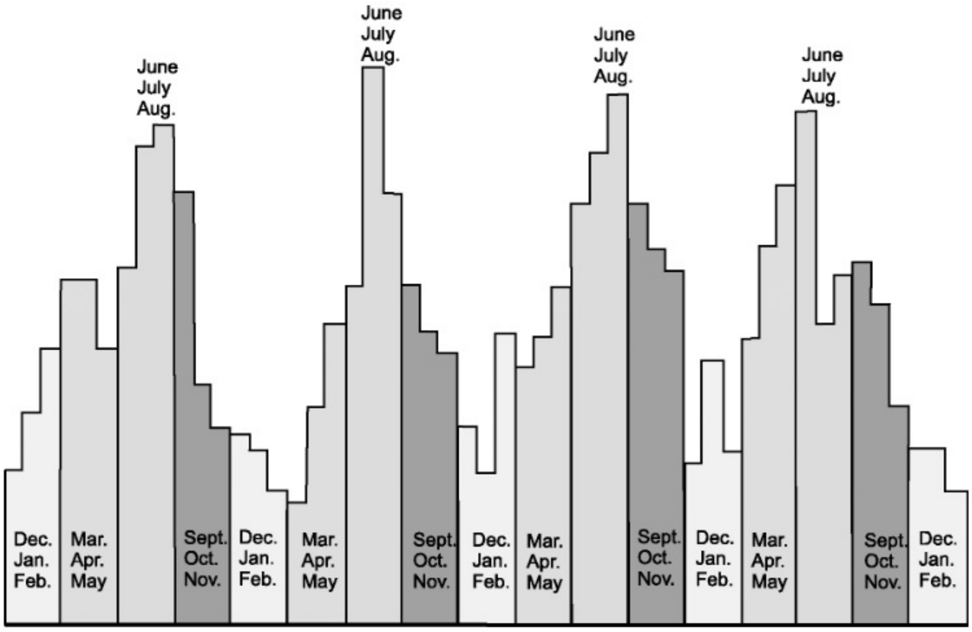

Figure 17.6
Seasonal trends of product shipping damage on all major products.
(Source: International Safe Transit Association)

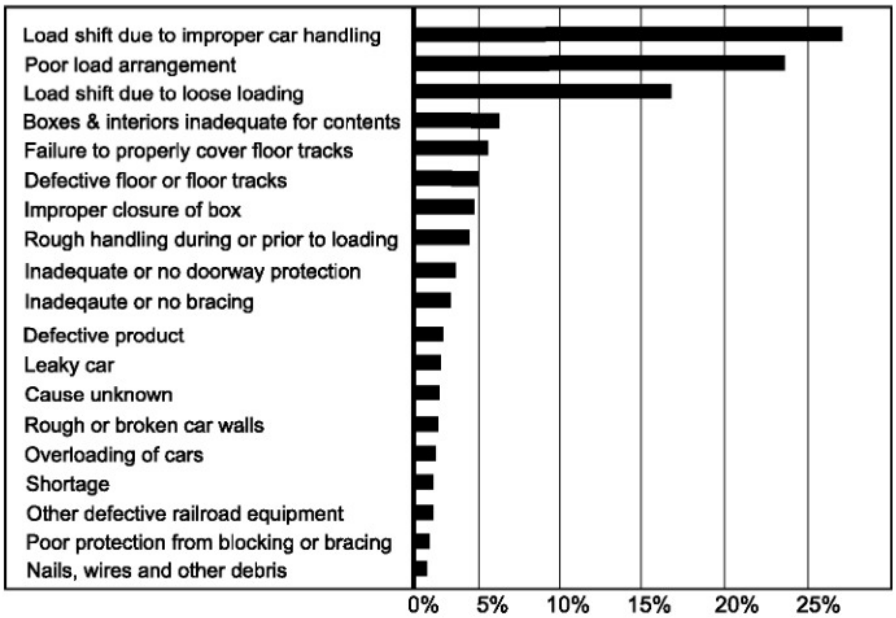

Figure 17.7
Causes of rail shipping damage.
(Source: Fibre Box Association)

An International Safe Transit Association study determined that product losses were higher in summer than in winter. (See Figure 17.6) The difference is attributed mostly to higher humidity.

The extent to which inadequate packaging contributes to losses can be debated. Table 17.2 and Figure 17.7 certainly indicate that significant damage is caused by faulty transport equipment and improper handling and loading procedures. On the other hand, it must also be accepted that this is the real world and that packages

Table 17.2
Warehouse damage rate by cause per 100,000 containers.

Cause	Number
Hitting bars at back of racks	24.5
Boxes dropped in aisles	16.1
Protruding nails in pallets	15.8
Fork tine damage	14.4
Unidentified storage damage	14.4
Pallet wings	13.0
Damaged while filling racks	12.8
Damaged while removing from second-level slot	8.6
Hitting merchandise on pallet below	7.8
Ramming by hand truck	5.1
Crushed during stacking	5.0
Leaning stacks	4.8
Corner cases hit by truck or tractor	4.6
53 other identified causes	39.0
Total damaged boxes in warehousing per 100,000	**185.9**

Source: U.S. Department of Agriculture

must survive this test. Damaged product has your name on it. That the fault can be put on someone else is minimal consolation.

Many organizations have a poor or nonexistent system for tracking losses, assessing the financial and business impact and taking corrective action. Without this critical information on file, it can be difficult to quickly assess issues when they become serious in magnitude. For example: Is this a recent problem? Have we seen this problem before? Is it happening at particular locations or during specific seasons? Has something changed in the way we package or distribute? What is the loss value? Is it affecting our business beyond actual dollar amounts? Who reported the problem, and is it a reliable assessment?

Furthermore, when suspecting that there may be a problem, there is sometimes no formal mechanism for investigating and implementing remedial action. Figure 17.8 illustrates an organized method for reporting, tracking and taking action on distribution losses.

Reliable field observations are a key part of damage investigation. Reports by warehouse staff, retailers and others not familiar with the technical aspects of packaging are notoriously spotty. Field observations often are the key to identifying the problem and best done by experienced staff. Where local observation cannot be avoided, standard reporting forms will direct the attention of the inexperienced observer to the critical issues. Such forms should encourage hand sketches and photography.

When excessive damage is being experienced, the first step is to identify the damage mechanism; the time and place where the event (or series of events) results

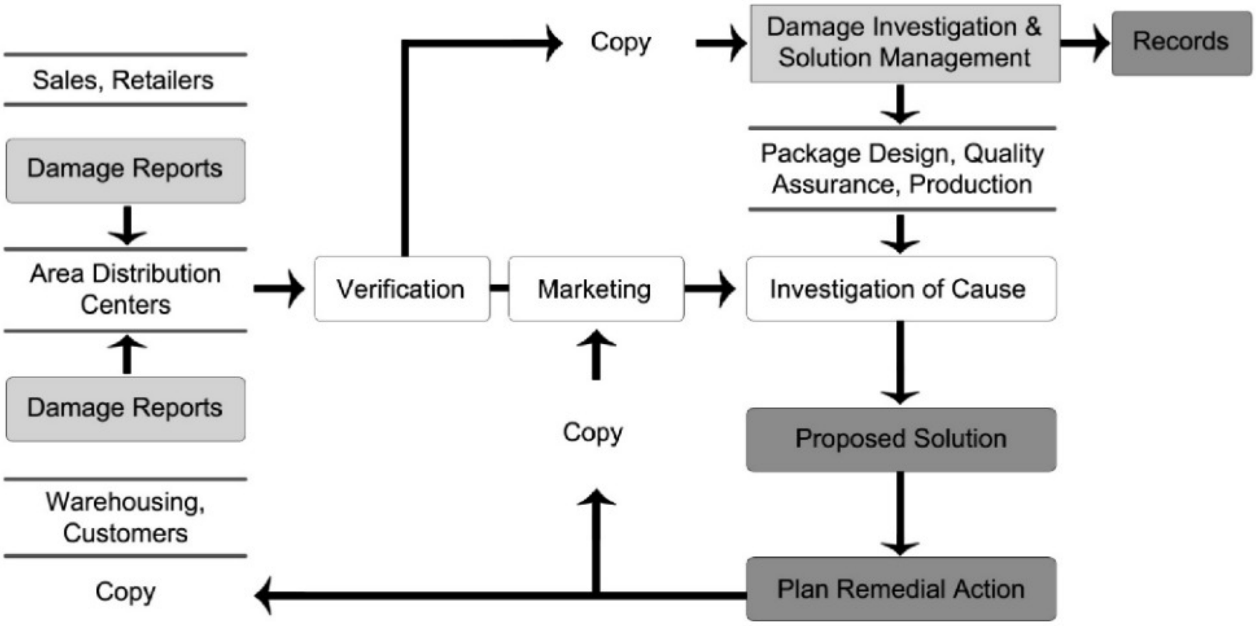

Figure 17.8
A formalized procedure for tracking damage is essential to reducing shipping losses. Depending on the product and organization, the procedure may take different forms.

in the damage. The damage mechanism is correctly identified when damage identical in scope and appearance can be replicated consistently in the laboratory. With the damage mechanism established, remedial actions can be considered. Product distribution balances three components:

Product + Package = Distribution Environment

Where the product and package are not equal to the rigors of distribution, there will be damage. Where the robustness of product and package is greater than what will be experienced in distribution, there is overpackaging.

When considering a remedy for excessive damage, all three distribution components need to be considered to determine the most cost-effective solution. In some instances, it may be determined that correcting a product's fragility is the most cost-effective course. In other situations, it may be possible to change the distribution environment. The final course of action would be to add more protective packaging.

THE WAREHOUSE

The distribution warehouse is a central collecting point for a particular good or a particular merchandising chain. Finished goods are forwarded to and held at the warehouse until selected and assembled into a customer order. The warehouse environment is not well understood by many shippers.

A typical dry groceries warehouse may contain 80,000 individual stock items. A hardware chain warehouse holds upward of 100,000 stock items. Product arrives at the central warehouse in bulk or unitized, is broken down or re-unitized according to the warehouse's needs, and then arranged for stock-picking. Stock-picking means selecting individual items to fill an order for a particular store or destination. Central warehouses serve large customer areas; in some instances, one or two warehouses may essentially serve the entire nation.

Product may be routed through more than one warehouse. For example, an export product may be moved from a local warehouse to dockside storage, to the cargo ship and on to a receiving warehouse.

A product must fit a warehouse's material-handling system. This often means palletizing loose loads or re-palletizing loads from nonstandard pallets. Depending on the operation, anywhere from 33–70% of incoming product must be handled manually before an order is placed in stock. In addition to being costly, manual handling is a primary source of damage from dropping.

In the picking aisles, stock must be clearly identifiable from every side. Multicolor graphic displays serve only to obscure vital information from the picker. A box labeled "Golden Triangle Farms" does not inform the stock-picker of the contents. Containers should be strong enough to be dragged off the pallet by one end and stiff enough that they don't distort and release their contents when handled in a less-than-ideal fashion. Glue flaps must have enough adhesive to resist abusive handling.

An assembled order may contain items as disparate as eight mirrors, six assorted clocks, 10 boxes of motor oil, four shock absorbers, a stepladder and a box of Mepps #4 fishing lures. These and other items are assembled on a mixed pallet for transport to a small retail outlet. Containers must be easily handled by the picker and should be readily packed onto a mixed-order pallet. Box orientation on mixed-load pallets will tend to be on a "best fit" basis, regardless of "This Side Up" and "Do Not Stack" labels. It may be possible to pack a trapezoidal container efficiently on your pallet, but odd shapes do not pack well in a mixed-product pallet load. Use boxes with a rectangular cross-section wherever possible.

UNIT LOADS

Pallets

It is simpler to move one 1,000-kg load than it is to move 1,000 1-kg loads. Most product is unitized on pallets, a platform that can be picked up by the tines of a forklift truck.

Another technique stacks loads on slip sheets of tough fiberboard or plastic. The truck used with slip sheets has a clamp mechanism that grasps a protruding edge of the sheet and pulls it and the load onto a platform attached to the truck. Slip sheets are economical, lightweight and occupy little space. However, the equipment is not universally available, is more expensive and slower to operate.

A third method of handling a large group of assembled objects is with a clamp truck, a mechanism that picks up loads by exerting pressure from both sides of the load. Clamp trucks use no added materials, but the geometry and character of the load must be such that it can be squeezed between the truck's clamps. Each method has advantages and disadvantages.

Pallets are universally adaptable to a variety of handling situations and locations. However, pallets are costly, take up space and can be difficult to dispose of. Most pallets are made of wood, and the choice of wood species has a great impact on cost and durability. Denser, stiffer woods are more durable and often more expensive. However, well-made hardwood pallets are the most durable and cost-effective option of the many material choices available. One consideration for wooden pallets (and any wooden packaging for that matter) is the requirement for fumigation or heat treatment to prevent the spread of insect infestations. Today, most countries have instituted regulations requiring treatment for all incoming wooden packing materials.

Other materials usually are selected for reasons other than durability. Metal pallets often are used in the pharmaceutical industry for their non-absorptive qualities and the ability to be steam-cleaned. The many variations of plastic pallets share similar cleanability and splinter-proof properties. On the downside, neither is as easy to repair as a wood pallet, and both are more costly options than good-quality wood pallets. As a result, plastic and metal pallets often are reserved for in-house handling.

There is some market for pallets made of heavy paperboard and corrugated board stock. These units are lightweight, inexpensive and easily recyclable in the normal paper recycling stream but not suitable for some types of heavy loads and not as durable as other options. Plus, there is the ever-present danger of pallet failure if they inadvertently get wet.

There are many possible pallet sizes and designs; however, for standardized distribution, certain configurations dominate. By convention, a pallet's size is stated length first, with length defined as the top dimension along the stringer or in the instance of a block pallet, the stringer board. (See Figure 17.9)

About a third of all pallets are nominally 48 by 40 inches, the standard set by the Grocery Manufacturers of America. This size is very close to the international 1,200-by-1,000-millimeter (mm) size. The next most common size is 48 by 48 inches as might be used for carrying four 200-L (55-gallon) steel drums.

The two broad categories of pallet design are stringer and block. (See Figure 17.9) A range of variations is available within each design type:

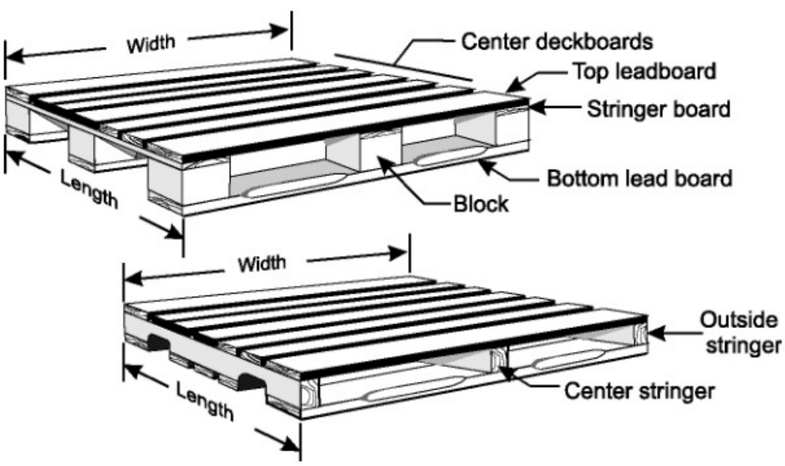

Figure 17.9
A block pallet (left) and a stringer-type pallet (right).

- Reversible pallets have similar top and bottom decks. Nonreversible designs have different top and bottom decks, with only the top deck designed to be a load-carrying platform.
- Wing pallets have the stringers inset so the deck boards overhang. This allows the pallets to be handled by slings. Pallets can be single wing or double wing, depending on whether one or both decks overhang the stringers.
- Two-way entry pallets have solid stringers and can be entered only from the two ends.
- Block-type pallets are four-way entry since any equipment can enter the pallet from all four directions. A partial four-way has notches cut into the stringer bottoms. A forklift's tines can enter from any direction, but a hand truck can enter from only two directions.

In addition to providing a product platform, the pallet is a buffer against the handling environment. A forklift driver placing a pallet into position cannot see the exact placement location: He stops when he hits something.

Viewed in this context, practices such as deliberate pallet perimeter overhang can only lead to problems, and warehouse operators condemn this habit. The Food Marketing Institute holds pallet issues responsible for about half of all observed damage and cites poor pallet footprint as the single largest cause of shipping damage. Of this damage, 50% is attributed to poor pallet stability and 35% is attributed to pallet overhang.

Pallet maintenance programs are essential. A common and easily remedied problem is fasteners working their way out of the wood.

Unit Load Efficiency

Warehouse floor space is rented by area, and the more product that can be put into that area, the better. Trucks loaded with lightweight product should fill the available volume completely to carry the maximum amount of product per trip. Area and cube utilization should be every packager's concern.

Optimum area and cube utilization begins with the primary package's design. Every packaging design activity is part of a larger packaging system, and the primary package's design and dimensioning are a critical component of a cost-effective distribution system. When a designer commits to the primary package's configuration, other system parameters are locked in:

- The possible arrangements of cartons in a shipper.
- Each of which will use a different dimension corrugated shipping box.
- Some arrangements will use less corrugated board than others.
- Some shipper sizes will have better pallet-area efficiency than others.

Arrangement refers to packing patterns used when placing primary packages into a shipper. (See Figure 17.10) Traditionally, the problem was solved through intuition, experience and a few nominal calculations. However, small cartons, packed

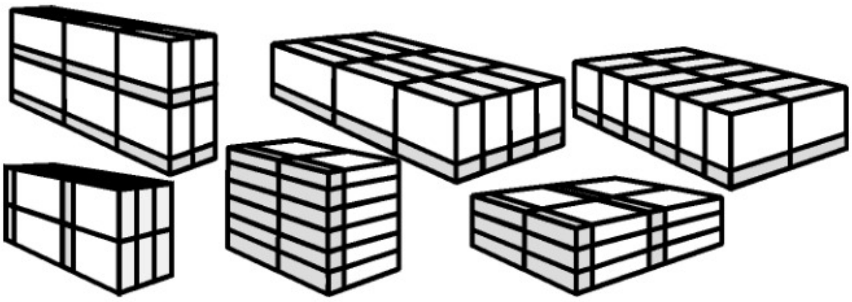

Figure 17.10
Six of the many possible ways of arranging 12 primary packages, in this case, cartons, in a corrugated box.

24 to a shipper, may have more than 1,000 possible orientation and palletizing patterns. Available computer "arrangement" programs can calculate all the implications of size decisions in minutes. Typical input data for a palletizing-efficiency computer program are:

- The dimensions, mass and geometry of the primary container.
- Allowable orientations in the shipper.
- Allowed primary design changes, if required (Small dimensional changes can have a dramatic impact on the final solution.)
- Data about the proposed shipping container (for example, required stacking strength, compatibility with mechanical handling systems, compatibility with modular unit loads).
- Data pertaining to palletizing requirements (for example, clampable patterns, stacking levels, etc.).

Typical output data for such a program might provide the following information:

- Optimum dimensions for the primary container.
- Optimum packing orientations for selected primary containers.
- Inside and outside box dimensions for each selected box type.
- Number of units per pallet for each primary/box option.
- Area and cube utilization for each primary/box option.
- Recommended pallet patterns, including "walk-around" views.
- Dimensional details of the pallet pattern.
- Material areas used in primary, divider and box construction.
- Relative cost factors for each construction.
- Relative compression values for corrugated board constructions.

Table 17.3
Distribution efficiencies of motor oils.

Bottle Type	Box Blank Area (sq.in.)	Box Cost	Bottles per Pallet	Bottle Weight (grams)
A	920	56	576	69
B	1,020	62	576	65
C	1,003	61	480	61
D	995	58	600	64
E	1,069	65	576	63
F	1,210	74	384	56
F(mod)	1,066	65	432	56
G	844	52	947	60
H	1,090	67	432	73

- Proposed maximum warehouse stacking heights.
- Proposed selection of possible board combinations.
- Proposed loading patterns in carrier vehicles.

The impact of cube and area utilization can be critical. Table 17.3 compares eight competitive motor oil bottles packed 12 to a box. F(mod) is the theoretical outcome of changing one bottle dimension by 3 mm (1/8 inch). Some bottles are more competitive than others.

Figures such as 80% area utilization are difficult to visualize in concrete terms. Consider a product that is palletized in such a manner that 50 mm (2 inches) of space exists on all sides. This amounts to a pallet utilization of 82.5%. When compared on a large scale with a fully utilized (100%) pallet:

- 1,175 pallets are needed instead of 1,000.
- Stretch-wrapping is needed for 175 extra pallets.
- Forklift trucks operate 17.5% longer.
- 175 more places are needed in the warehouse.
- The additional pallets make up six additional tractor-trailer loads.

A thorough system analysis (including losses) can lead to substantial savings. A major business equipment manufacturer found that it had a poor shipping experience because of the hundreds of different package sizes in the product line. The company designed a modular system, and all products were designed to fit one of 17 standard box sizes. In addition to a significant inventory reduction, the company gained substantial transport savings, since larger, more-stable pallet loads could be built with the modular system. More-secure pallet loads resulted in further savings through reduced product damage.

Stabilizing Unit Loads

Unit loads often need to be stabilized to retain load geometry and order during shipping and handling. Strapping, usually polypropylene or nylon, is used mostly for heavier goods. Care must be taken that strapping does not cut into the corrugated container, impairing strength qualities. Corner guards should be used to prevent cut-in where strapping or cord is used.

Shrink-wrapping is rarely used for load unitizing due to high installation and energy costs. Today's material of choice is stretch-wrapping. A good stretch-wrap application consists of two overlapped wraps extending 50 mm (2 inches) down the pallet to bind the load to the pallet. The wraps should overlap about 40% up the pallet side. Three overlapping wraps extending 50 mm (2 inches) past the top of the load finish the pallet. The added top wraps provide extra securement at the point in the load most likely to move.

While hand-wrapping a pallet may save capital investment, machine-wrapping provides better material control and typically reduces material costs. Machines with pre-stretch features reduce material costs still further. More costly open netting is used where air circulation is essential.

Load stability can be increased through the use of high-friction printing inks and coatings or by the application of adhesive-like compounds, designed to produce a high-tack local bond. One variation is the use of a bead of hot-melt adhesive formulated to have relatively poor cohesive strength. The bead forms a readily sheared bond between two box surfaces. However, systems that bond boxes together have caused handling problems and are not a popular load-stabilizing method with some warehouses.

Caps and trays made of fiberboard or corrugated board are used to provide shape to unstable loads and bottom protection against rough pallet surfaces, and, when used on top of a load, to increase the platform quality for the next pallet. Tier sheets improve available compression strength and increase stability by distributing weight and encouraging layers to act as a unit.

GOOD DISTRIBUTION PRACTICE

Industry Guidelines

Many studies have been conducted on the problems of packaging for distribution. One study, undertaken by the Food Marketing Institute, Grocery Manufacturers of America and National American Wholesale Grocers' Association, recommended that shippers use preshipment testing procedures developed by ASTM International or ISTA to determine container performance level. Other pertinent suggestions are as follows:

Container dimensions. Containers should not be a perfect square in any two dimensions. The recommended maximum and minimum dimensions for shipping containers are:

Figure 17.11
A pallet without any stabilizing material should be able to hold an angle of 5 degrees.

Minimum container dimension	102 mm (4 in.)
Maximum width	610 mm (24 in.)
Maximum height	457 mm (18 in.)
Maximum length	762 mm (30 in.)
Maximum length: heavy products	610 mm (24 in.)
Maximum weight	20.5 kg (45 lb.)

Pallets. Pallet loads should have a footprint of 48 by 40 inches (+0 inch/–1 inch), *measured at the first customer receiving point*. Optimum pallet heights may be 45 or 59 inches, depending on rack sizes and how stock is picked. Unracked pallets should not exceed 83 inches. The targeted minimum storage capability of a pallet load is 30 days at 32°C (90°F) and 80% R.H., stacked two loads high. Pallet load-stabilizing materials such as stretch-wrapping often are removed at the warehouse receiving dock. The load is then moved to its storage location. For this reason, loads must have reasonable stability even without the stabilizing material. (See Figure 17.11)

Bagged Product. Products in bags are more frequently damaged than products in any other type of packaging. Some recommended ways to avoid damage are:

- Place a slip sheet between the pallet and the first bag layer.
- If the product will be double-stacked, use a cap or another slip sheet.
- Use bag material having a slip angle of at least 30 degrees.
- Stabilize bag pallet loads, preferably with stretch-wrap.
- Use square-ended bag designs for more stable configurations.
- Ensure bag closures are strong enough that the bag can be picked up by one "ear".

Shrink-Wrapped Trays. Shrink-wrapped trays are an alternative to corrugated boxes. The following considerations apply to this type of packaging:

- Choose shrink-wrap that retains tension up to 65°C (150°F).
- Place seams at the sides or top to avoid fouling in conveyor systems.

- Use nesting designs or tray covers if primary containers are irregular to make them stackable.
- Make the tray at least 75 mm (3 in.) high.
- If there is more than one layer of product in the package, use a separate tray for each layer.

EVALUATING DISTRIBUTION PACKAGING

Preshipment Testing

Knowledgeable packaging engineers have recognized for some time that preshipment testing reveals inadequate product design or packaging long before it starts costing money through damage and customer dissatisfaction. Many procedures and devices have been developed for use in evaluating distribu-tion packaging. Some of these are material characterization tests (such as the ECT or gas permeability of a flexible laminate), but the packaging engineer usually wishes to evaluate not a single material property, but the suitability of a system.

First, the product itself should be studied to ensure that it has no inherent design faults that will make distribution difficult. These should be remedied before considering packaging. Once the product is as durable as practically possible, determine and quantify the product's unavoidable fragility. These fragilities are compared with the anticipated distribution environment demands.

Where there are shortcomings, protective packaging must be provided. As a final check, several prototype packages should be submitted to a laboratory to evaluate suitability for the intended distribution environment.

Agencies Sponsoring Preshipment Test Methods

Preshipment test procedures and container performance requirements are prepared by many agencies. Only the most important are listed here.

ASTM International (ASTM)

ASTM has more than 30,000 members and publishes voluntary consensus standards on a variety of subjects in its annual standards books. Standard test methods and procedures related to packaging are developed through Committee D10 on Packaging, which meets twice a year to consider new proposals and upgrade old standards. Most packaging test methods are published in Volume 15.10, General Products, Chemical Specialties and End Use Products. Volumes 08.01 and 08.02 deal with plastic materials and contain some methods related to plastic packaging materials and containers.

Most of the work of ASTM D10 is focused on how to conduct specific tests such as drops, vibration and compression rather than on overall package performance standards. The two exceptions are the widely used ASTM D4169, Standard Practice for Performance Testing of Shipping Containers and Systems and ASTM D7386, Standard Practice for Performance Testing of Packages for Single Parcel Delivery Systems. Both are general simulation test protocols.

International Safe Transit Association (ISTA)

ISTA's mission is to empower organizations and their people to minimize product damage throughout distribution and optimize resource usage through effective package design. The foundation of this effort is the development of test procedures that define how packages should perform to ensure protection of their contents and form the basis of most preshipment testing conducted globally. ISTA has more than 1,000 corporate members that include product manufacturers, package suppliers, retailers, carriers, universities and independent test laboratories.

Preshipment performance testing subjects a packaged product to a series of tests that evaluate the protective ability of the packaging in terms of the product's susceptibility to damage and the intensity and type of hazards in the transport environment. ISTA tests range from simple non-simulation tests that challenge the robustness of the product and package to simulation tests that are based on actual field measurement of hazard levels.

Carrier Classifications (United States)

The Uniform Freight Classification (UFC) is prepared by rail interests under authority from the U.S. Department of Transportation. It describes tariffs, ratings, rules and regulations pertaining to the transport of goods by rail. Rule 40 (containers other than fiberboard), Rule 41 (solid or corrugated fiberboard containers), Rule 54 (barrels, drums, pails or greaseproof-waterproof tubs) and Rule 55 (synthetic resin containers, inner or shipping) primarily describe material characteristics but also list some package performance requirements.

The National Motor Freight Classification (NMFC) is similar in scope to the UFC but applies to movement over the road. It is maintained by the National Motor Freight Traffic Association.

National Motor Freight Classification (NMFC) Rule 180

Both NMFC and UFC require container materials to meet minimum specifications as detailed in Item 222 and Rule 41 of their respective carrier rules. In 1995, NMFC approved Rule 180, an alternative to Item 222, which would allow shippers using truck common-carriers to use any material as long as the package passes a series of performance tests. The rule applies to all less-than-truckload (LTL) package shipments except drums, pails and bags.

The performance requirements are a two-part sequence: a compression/vibration test simulating over-the-road travel followed by an impact/handling test simulating the hazards of loading and unloading trailers. The tests are based on a similar series of packaging performance tests developed by ASTM International.

Railway Association of Canada

The Railway Association of Canada's regulatory affairs team acts as the voice of the rail industry when rules and regulations affecting the sector are being written. The team works collaboratively with a variety of transportation departments and agencies in Canada and collaborates with provincial regulators. Generally, Canadian authorities try to maintain reciprocity with the United States.

Canadian General Standards Board (CGSB)

The CGSB is accredited by the Standards Council of Canada. A CGSB committee convenes whenever industry or government perceives a need to publish a Canadian standard of practice. The committee normally consists of producers, users and other interested parties who meet until a consensus standard can be issued. CGSB (an office of the federal government) arranges for the meetings and publishes the standard.

CGSB packaging standards are issued under the 43-GP series. They include standards for dangerous goods packaging and other specialized packaging and container systems. CGSB usually references an ASTM test procedure and then specifies the test's severity or level.

In principle, CGSB is for the service of industry. In practice, the industry tends to support standards developed through industrial associations or the better-known standards bodies. CGSB standards, therefore, are inclined to be convened by the government for issues in which the government has a specific interest.

Hazardous Materials (U.S.) and Dangerous Goods (International) Packaging Regulations

While routine package-shipping tests are typically voluntary and based on statistically likely occurrences, dangerous or hazardous goods code tests are mandatory in most cases and based on a "catastrophic incident" concept. A plastic bottle filled with shampoo may have to withstand a number of drops from 0.5 meter (m) (20 inches), but if the same bottle were used to contain an infectious substance, it would be required to survive a 9-m (30-foot) drop.

The United Nations (U.N.) publishes Transport of Dangerous Goods: Recommendations of the Committee of Experts on the Transport of Dangerous Goods. Many countries and organizations have adopted the performance standards outlined by the U.N. in total.

Some countries (such as Canada and the United States) have regulations covering the packaging of dangerous goods that predate the U.N. issuance and are not in total agreement with it. Moves have been made to bring the national standards of both countries into line with the U.N. standards.

In the United States, the Code of Federal Regulations, CFR Title 49 Part 178 describes performance requirements of containers for hazardous materials. In Canada, the transport of dangerous goods is the responsibility of Transport Canada. Actual performance standards are issued by CGSB.

The International Maritime Organization and the International Air Transport Association issue performance standards for their respective transport modes. In general, U.N. regulations are followed; however, there are important exceptions that are more stringent.

Determining the exact required test procedure can be difficult for some combinations of package and product. Care should be taken to identify the product and hazard level precisely.

International Organization for Standardization (ISO)

ISO is an international consensus standards body. ISO standards are particularly important to those countries that do not have established national documents. North America, while contributing heavily to ISO standards, tends to refer to national or ASTM documents.

Preshipment Testing Equipment

Vibration Tables

Vibration tables are used to assess product and package responses to the various ranges of vibration that will be experienced in the field. There are two basic types:

Repetitive-shock vibration tables operate at about 1.1 *G* (acceleration), 1-inch amplitude and about 4.5 hertz. These tables are used in tests specified by the Dangerous Goods Code and in procedures recommended by ISTA and by ASTM D4169. Although very limited in their ability to simulate vibrations as encountered in the distribution environment, these fixed amplitude tables are useful for determining relative scuff resistance.

Variable-frequency vibration tables are programmable to sweep through all common transport frequencies between 3 and 100 hertz. Capable of representing the true distribution environment more realistically, these tables are useful for searching out resonance susceptibility in the packaged and unpackaged product and to locating stack resonance points for stacked packages. Programmable tables also can be set up to cycle through actual recorded road travel random vibrations. Chapter 18, Shock, Vibration and Compression discusses the problem of vibration in more detail.

Types of vibration test systems are described in the following standards:

D999, Vibration Testing of Shipping Containers

D3580, Vibration (Vertical Sinusoidal) Test of Products

D4728, Random Vibration Testing of Shipping Containers

D5112, Vibration (Horizontal Linear Sinusoidal Motion) Test of Unpackaged Products and Components

D4169, Performance Testing of Shipping Containers and Systems

ISTA 1-, 2-, 3- and 6-Series Test Protocols

Drop Testers

The principal feature of all drop-test devices is the ability to produce repeated drops at selected orientations and from selected heights without imparting rotation or other influences. Drop heights can be selected from drop probability tables, from standards set by ISTA or ASTM or by the requirement of a dangerous or hazardous goods code.

Drop testers are described in the following standards:

ASTM D5276, Drop Test of Loaded Containers by Free Fall

ASTM D1083, Mechanical Handling of Unitized Loads, Large Shipping Cases and Crates

ASTM D3071, Drop Test of Glass Aerosol Bottles

ASTM D5487, Standard Practice for Simulated Drop Tests of Loaded Containers by Shock Machines

ASTM D5265, Bridge Impact Testing

ISTA 1-, 2-, 3- and 6-Series Test Protocols

Horizontal and Incline (Conbur) Impact Machines

The incline impact machine simulates horizontal shocks such as those experienced in rail shipment. The shock can be controlled by changing the impact velocity and by using impact programmers. By using suitable backloads during the test, the effects of dynamic horizontal compression also can be assessed. With modifications, the incline impact machine can determine the durability of pallets to repeated forklift entries.

Incline impact tests are specified by ISTA and ASTM preshipment test methods and are described in the following:

ASTM D880, Incline Impact Test for Shipping Containers

ASTM D1185, Pallets and Related Structures Employed in Materials Handling and Shipping

ASTM D4169, Standard Practice for Performance Testing of Shipping Containers and Systems

ISTA 1-, 2-, 3- and 6-Series Test Protocols

A more controllable method of producing horizontal shocks is with horizontal impact machines, which accelerate the load along a horizontal track and into a programmable backstop.

ASTM D4003, Programmable Horizontal Impact Testing for Shipping Containers and Systems

ASTM D5277, Performing Horizontal Impacts Using an Inclined Impact Tester

ISTA 3H, Mechanically Handled Bulk Transport Containers

Environmental Chambers

Good packaging laboratories simulate a wide range of climatic conditions with environmental chambers. Typically used for preconditioning packages prior to physical testing, the chambers can help determine the ability of a plastic pail to survive drops at subzero temperatures or identify whether a corrugated box loses stack strength at high humidity.

Such chambers also are used to accelerate aging for such things as long-term storage tests and environmental stress-crack tests on plastic containers (ASTM D2561, Standard Test Method for Environmental Stress-Crack Resistance of Blow-Molded Polyethylene Containers).

All standard paper tests should be conducted at 23 ± 2°C and 50% R.H. ± 2%. The highest humidity normally recommended for routine testing is 85%. Beyond this humidity, it becomes very difficult to control the temperature with the accuracy needed to prevent condensation. To simulate a particular environmental condition, the conditions listed in Table 17.4 are the normal choices:

Table 17.4
Recommended standard atmospheric conditions as provided in ASTM D 4332.

Simulated Environment	Relative Temperature	Humidity
Cryogenic	–55 ± 3°C	—
Frozen food storage	–18 ± 2°C	—
Refrigerated storage	5 ± 2°C	85 ± 5%
Temperature, humid	20 ± 4°C	85 ± 5%
Tropical	40 ± 2°C	85 ± 5%
Desert	60 ± 3°C	15 ± 2%

Environmental conditioning is described in:

ASTM D685, Conditioning Paper and Paper Products for Testing

ASTM D4332, Conditioning Containers, Packages or Packaging Components for Testing

ISTA 7D, Temperature Test for Transport Packaging

ISTA 7E, Testing Standard for Thermal Transport Packaging Used in Parcel Delivery System Shipment

Compression Testing

Compression strength is directly related to warehouse and vehicle transport stacking ability. Compression testing is used to determine a package's load-carrying abilities. Sizes vary from small, for measuring the compression strength of plastic bottles, to units large enough to measure the stacking strength of entire pallet loads. Fixed-platen testers tend to cause the specimen to fail at its strongest point. Swivel platens tend to cause the specimen to fail at its weakest point.

Compression tests can be dynamic, using hydraulically or mechanically driven platforms, or static, wherein a dead load is stacked on a subject container and the system observed over a period of time. Compression tests are required by most pre-shipment test procedures and described in:

ASTM D642, Determining Compressive Resistance of Shipping Containers, Components and Unit Loads

ASTM D2659, Column Crush Properties of Blown Thermoplastic Containers

ASTM D4577, Compression Resistance of a Container Under Constant Load

ISTA 1-, 2-, 3- and 6-Series Test Protocols

Shock Machines

Shock machines are used to develop fragility boundary curves and to determine *G* levels used to calculate cushioning requirements or to assess a product's design fragility. (See Chapter 18, Shock, Vibration and Compression) A shock machine consists of a rigid table that can be raised and dropped onto a programming device. By controlling the programming device and the drop height, different *G* levels, pulse durations and pulse shapes (sine, square wave, etc.) can be achieved.

Tests using shock machines are described in the following:

ASTM D3332, Mechanical Shock Fragility of Products Using Shock Machines

ASTM D4168, Transmitted Shock Characteristics of Foam-in-Place Cushioning Materials

ASTM D5487, Standard Practice for Simulated Drop Tests of Loaded Containers by Shock Machines

Other Test Methods and Standard Practices

The following are other selected standards related to packaging materials:

ASTM D6198, Standard Guide for Transport Package Design; ASTM D4649, Standard Guide for Use of Stretch Films and Wrapping Application; ASTM D5118, Standard Practice for Fabrication of Fiberboard Shipping Boxes

ASTM D5168, Standard Practice for Fabrication and Closure of Triple-Wall Corrugated Fiberboard Containers

ASTM D4919, Standard Practice for Testing of Hazardous Materials Packagings; ASTM D3951, Standard Practice for Commercial Packaging

ASTM D1974, Standard Practice for Methods of Closing, Sealing and Reinforcing Fiberboard Boxes

ISTA Standard 20, a design and qualification process that provides the structure and path to design, test, verify and independently certify insulated shipping containers

ISTA Responsible Packaging by Design (RPbD), a step-by-step process management standard for the design, testing and qualification of responsible (sustainable) packaging

ISTA Preshipment Testing Procedures

In the late 1940s, the Porcelain Enamel Institute's members were experiencing considerable shipping damage in appliances. Using the test equipment of the day, they conducted studies to identify a standard preshipment test procedure that would assess the protective characteristics of packaging. A requisite was that damage created in the lab should closely duplicate what was observed in the field. The developed procedure was found to be useful by other industries and soon was widely adopted.

These test methods continue in use today because they are quick, economical and simple. However, as knowledge of the shipping environment increased, drawbacks became apparent. Damage that could not be duplicated by the basic ISTA methods was observed frequently, and it was recognized that the testing equipment had a limited ability to simulate distribution hazards. In response to the need for more flexible and predictive preshipment testing methods, ISTA has developed simulation tests based upon measured field data from the distribution environment. It also has published several focused preshipment tests.

Preshipment testing is a valuable tool in the development of a suitable distribution package or for resolving specific problems. Whatever tests are chosen, the damage observed in the laboratory should be similar in appearance to that observed in the field.

ISTA Testing Procedures

Briefly, for Procedure 1A, packages under 68 kg (150 lb.) are subjected to 14,200 vibratory impacts on a repetitive shock vibration table moving in a 25.4-mm (1-inch) rotary motion at a cycle rate that just causes the package to momentarily lift off the table. The actual cycle rate will vary slightly but is in the general range of 4 hertz. Subsequently, the package is dropped 10 times from a height determined by the package weight. As an option, packages weighing more than 27.7 kg (61 lb.) can be tested on an incline impact machine.

Table 17.5
3A—STANDARD Packaged-Product Test Sequence.

Sequence Number	Test Category	Test Type	Test Level	For ISTA Certification
1	Atmospheric Preconditioning TEST BLOCK 1	Temperature and Humidity	Ambient	Required
2	Atmospheric Conditioning TEST BLOCK 1	Controlled Temperature and Humidity	Temperature and Humidity chosen from chart	Optional
3	Shock TEST BLOCK 3	Drop	9 Drops—height varies with packaged-product weight	Required
4	Vibration TEST BLOCKS 4 & 7 for Standard TEST BLOCKS 5 & 7 for Pails and Short Cylinders	Random With and Without Top Load	Overall G_{rms} levels of 0.53 and 0.46	Required
5	Vibration TEST BLOCKS 2 & 8	Random Vibration Under Low Pressure	Truck or Truck & Air dependent	Optional
6	Shock TEST BLOCK 9	Drop	8 Drops—height varies with packaged-product weight. Includes drop on hazard	Required

Procedure 1B is similar but intended for packages or loads weighing more than 68 kg (150 lb.). This illustrates the simplest ISTA tests intended to challenge the integrity of the product-package combination. An example of a more complex test, based upon knowledge of the actual hazards and levels found in a specific type of distribution, can be found in Table 17.5, Table 17.6 and Figure 17.12.

A typical test sequence is shown in Table 17.5 from ISTA 3A for Parcel Delivery Systems.

The vibration breakpoints for a pick-up and delivery vehicle shall be programmed into the vibration controller to produce the acceleration versus frequency

Table 17.6
TEST BLOCK 3 First Sequence Drop.

SHOCK–DROP					
Complete the following test sequence for each type of package that has a check in the box: ☑ Standard ☑ Small (DO NOT test in bag) ☑ Flat ☑ Elongated					
Step	***Action***				
1	Follow the table below to determine the height and orientation for the first 9 drops.				
	Drop Number	**< 32 kg (70 lb.)**	**32–70 kg (70–150 lb.)**	**Standard, Flat, Elongated, Small (not in bag)**	**Two-Dimensional Envelopes and Mailers (not in bag)**
	1	460 mm (18 in.)	300 mm (12 in.)	Edge 3-4	Edge 4
	2	460 mm (18 in.)	300 mm (12 in.)	Edge 3-6	Edge 6
	3	460 mm (18 in.)	300 mm (12 in.)	Edge 4-6	Edge 5
	4	460 mm (18 in.)	300 mm (12 in.)	Corner 3-4-6	Corner 4-6
	5	460 mm (18 in.)	300 mm (12 in.)	Corner 2-3-5	Corner 2-5
	6	460 mm (18 in.)	300 mm (12 in.)	Edge 2-3	Edge 2
	7	460 mm (18 in.)	300 mm (12 in.)	Edge 1-2	Edge 5
	8	910 mm (36 in.)	600 mm (24 in.)	Face 3	Face 3
	9	460 mm (18 in.)	300 mm (12 in.)	Face 3	Face 1
2	The shock test is now complete. Go to TEST BLOCK 4 (Vibration Under Dynamic Load).				

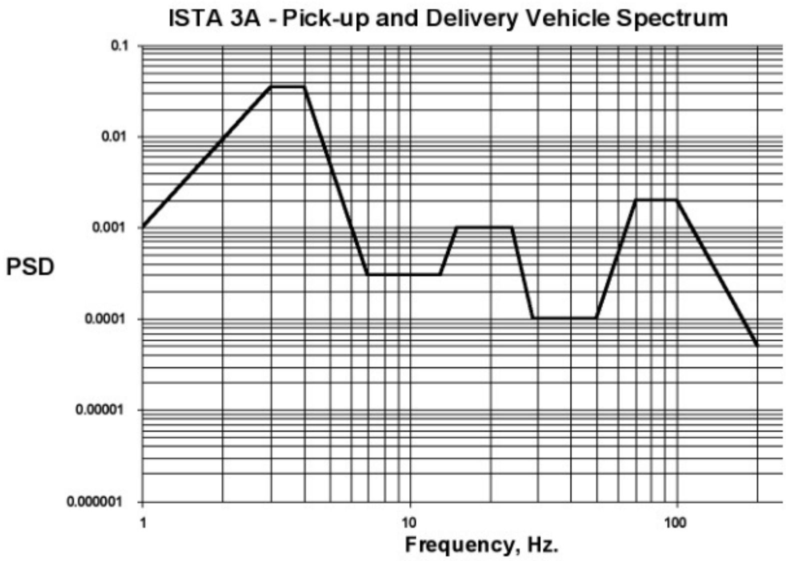

Figure 17.12 Pick-up and delivery vehicle simulation.

profile (spectrum) shown in Figure 17.12. This profile has an overall G root-mean-square acceleration (Grms) level of 0.46 and requires a theoretical stroke of 58.72 mm (2.312 in.) peak-to-peak to run this vibration profile.

ISTA has organized its test protocols into Series, as follows:

1 Series: Non-Simulation Integrity Performance Tests

Challenge the strength and robustness of the product-package combination. Not designed to simulate environmental occurrences. Useful as screening tests, particularly when used as a consistent benchmark over time.

- 1A Integrity Testing for Packaged-Products Weighing 150 lb. (68 kg) or Less
- 1B Integrity Testing for Packaged-Products Weighing Over 150 lb. (68 kg)
- 1C Extended Integrity Testing for Individual Packaged-Products Weighing 150 lb. (68 kg) or Less
- 1D Extended Integrity Testing for Individual Packaged-Products Weighing Over 150 lb. (68 kg)
- 1E Integrity Testing for Unitized Loads
- 1G Integrity Testing for Packaged-Products Weighing 150 lb. (68 kg) or Less Utilizing Random Vibration
- 1H Integrity Testing for Packaged-Products Weighing Over 150 lb. (68 kg) Utilizing Random Vibration

2 Series: Partial Simulation Performance Tests

Tests with at least one element of 3-Series type General Simulation performance tests, such as atmospheric conditioning or mode-shaped random vibration, in addition to basic elements of a 1-Series type Non-Simulation Integrity test.