PACKAGING, CONVERTING

1. Introduction

Well over 90% of consumer goods sold in the United States is shipped, stored, and purchased in some form of packaging (1). The selection of a specific package type by a product manufacturer is based on a number of factors, including the characteristics of the product being packaged; the nature of the shipping and storage environment to which it will be exposed; the physical strengths and properties of the package; regulatory requirements for packaging, eg, by the United Nations, U.S. Food and Drug Administration (FDA), U.S. Department of Agriculture, U.S. Military Regulations, U.S. Department of Transportation, U.S. Uniform Classification Committee, U.S. National Motor Freight Classification Committee, and ISO; consumer preference; and unit packaging cost. In many instances, different packaging types compete for the same packaging application. For example, glass jars, plastic jars, and metal cans may compete with each other, or corrugated boxes, solid fiber boxes, wooden crates, and paper or plastic bags may compete with each other. Assuming there are no regulatory restrictions or consumer preference differences, the choice of a packaging type is dependent on the relative direct costs of the competing packaging products, and the relative indirect costs of the package types throughout the entire filling, shipping, storage, and usage cycle, for example, package-filling line jams, product damage, warehouse stacking life, retail shelf life, moisture resistance, and pilferage.

In order to understand the various packaging options available for a given packaging application, there must be an understanding of the converting process and materials used to produce the various packages and the range of characteristics that can be achieved with each package type. This discussion deals with processes and chemical components involved with the production of the various types of paper-based packaging. Printing ink materials are not included herein (see INKS).

2. Paper and Paperboard Materials

The paper and paperboard materials, hereafter referred to as paper (qv), used to manufacture corrugated boxes, solid fiber boxes, folding cartons, paper bags, fiber drums, and fiber cans, are generally made from natural cellulosic fibers, such as wood fiber, and are typically supplied to the package manufacturing plant in roll form. Although there are many specific grades of paper available commercially, they can be divided into specific categories: coated or noncoated, and regular or wet strength. Many different types of coating are used by the paper and paperboard packaging industry and are discussed later (2).

The strength properties of regular grades of paper are dependent on the strength of the individual fibers and the natural bonding that occurs between the cellulosic fibers (see CELLULOSE). Paper fibers readily absorb moisture when exposed to humid or moist conditions. This absorbed moisture causes the fibers to swell, reducing the individual fiber strength and disrupting physical bonding between fibrils of adjacent fibers. Absorbed water molecules also disrupt hydrogen bonding between the cellulose molecules within the fibers and between the fibers at the bond sites. This bond disruption results in a significant loss of strength properties by the paper. The wet-strength grades of paper are made by adding resin to the paper pulp or the finished paper. The resins act by protecting and strengthening the interfiber bonding sites from the effect of the absorbed moisture. Typically, regular grades of paper lose 94% of their tensile strength when wet, however wet-strength grades of paper, made with 5 wt % resin, lose only 61% of their tensile strength when wet (2,3).

Resin additives that have been used to develop wet-strength characteristics in paper include urea–formaldehyde, melamine–formaldehyde, polyamide–polyamine–epichlorohydrin, polyethyleneimine, dialdehyde starches, insolubilized protein, vegetable gums and extracts, and silicates and silicones (see SILICON COMPOUNDS, SYNTHETIC INORGANIC SILICATES). The degree of wet-strength retention achieved in the paper is dependent on the type of additive, amount of additive application, amount of resin retained in the paper, method of additive application (pulp slurry or finished dry paper), and degree of resin cure achieved. Because of environmental concerns, several aspects must be considered: (*1*) the effect of any resin additive on the ability of paper mills to recycle fibers from used wet-strength packages (3); (*2*) the potential of having unacceptable odors transferred from the resin additive to the packaged product, particularly in the case of food or drug products (methods for measuring odor transfer potential, using gas chromatography–infrared–mass spectroscopy, have been developed (4)); (*3*) possible chemical adulteration of food and drug products by the resin additive, within the meaning of the U.S. Food, Drug and Cosmetic Act; and (*4*) possible release of chemical substances into the atmosphere during packaging manufacturing in terms of any OSHA or U.S. EPA restrictions.

3. Corrugated Paperboard Boxes

Corrugated paperboard is a sandwich structure formed by gluing a fluted corrugating medium ply to two linerboard facings. The first corrugated fiberboard shipping containers were used commercially in 1903 (5). Corrugated paperboard sheets are produced in a single, continuous manufacturing process consisting of five operations (Fig. 1). The paperboard from a roll of corrugating medium is shaped into the flute form by passing the paperboard between the nip formed by two steel gear-shaped rolls. An adhesive is applied to one side of the flute tips and a linerboard facing is brought into contact with the adhesive and bonded to the medium to produce a single-faced web. The single-faced web proceeds to the double-facer operation where adhesive is applied to the opposite side of the flute tips and a second linerboard facing is glued to the medium (6). This simplest form of the sandwich structure is called single-wall corrugated fiberboard. Double-wall corrugated fiberboard has two fluted mediums, produced using two single-facers, and three linerboard plies. Triple-wall corrugated fiberboard has three fluted mediums and four linerboard plies (1). Finally, the corrugated board web is scored and slit in a triplex operation to achieve the required box height and to produce the areas which will become the box top and bottom closure flaps. The scored and slit corrugated web is cut in the cut-off knife operation to the required sheet length to produce the specified box perimeter size. The finished box is then formed from the sheets in a discrete process operation where the corrugated sheets are printed, slotted to form the top and bottom flap closures, scored to provide the required box length and width dimension, and folded and fastened to form a continuous box perimeter and the finished box. This perimeter closure is known as the manufacturer's joint and is usually formed by gluing. A small percentage of boxes have stapled or taped manufacturer's joints.

The chemical materials required for this process include the corrugating adhesive, 1–1.2 MPa (150–175 psi) process steam to provide heat to set the corrugator adhesive, possible coatings applied to the surface of the linerboard facings, possible chemicals impregnated into the linerboard and/or medium, the manufacturer's (glue) joint adhesive, and the printing ink (see INKS).

The formation of a uniformly strong and tough (not brittle) corrugator bond between the fluted medium and the linerboard facings is essential to corrugated paperboard package strength and performance. Without this bond to maintain the sandwich structure, the package would be a bag rather than a box. A silicate adhesive was used to form these bonds until the mid-1940s when a starch-base adhesive was developed for this application (see ADHESIVES).

On average, the corrugator starch adhesive in use contains approximately 78% water, 18% uncooked raw pearl starch, 3% cooked and gelled pearl starch, 0.5% borax, and 0.5% caustic. The raw pearl starch is the process adhesive, the cooked pearl starch holds the raw starch granules in suspension in the adhesive slurry, the borax serves as a buffering agent and tackifier by controlling the swelling of the raw starch granules at the bond sites when the adhesive is heated, and the caustic controls the gel point of the adhesive (7–11). The starch adhesive typically is characterized by its solids content, low shear viscosity, and gel point (11–14). A water-resistant corrugator adhesive is often used to make corrugated packages that may be exposed to moisture or high humidity conditions during their use cycle. The water-resistant properties are developed by adding a cross-linking agent to the starch adhesive slurry. The water-resistance agents typically act by cross-linking with the starch adhesive and paperboard cellulose molecules. The corrugating process heat serves to activate the resin. Typical slurry additives used to provide the starch and starch/paper cross-linking include urea–formaldehyde, phenol–formaldehyde, cyanamide–formaldehyde, resorcinol, resorcinol resins, ketone–aldehyde resins, high amylose adhesives, and ketone–acrylamide–formaldehyde copolymer resins (9,11). The selection of an additive to produce a water-resistant corrugator adhesive should include consideration of any U.S. EPA, OSHA, or FDA regulatory concerns, for example, the release of free formaldehyde.

A typical single-wall corrugated paperboard product has approximately 4.5 kg/m^2 (1.0 lb/msf) of regular starch adhesive solids applied in the single-facer operation and approximately 5.4 kg/m^2 (1.2 lb/msf) starch solids applied in the double-backer operation. Water-resistant adhesive application rates are approximately twice those of regular adhesives. This water-base corrugating adhesive adds considerable moisture to the linerboard facings and medium. Paperboard exhibits hygroexpansivity characteristics with changing moisture content. This dimensional instability can result in a warped (bowed) corrugated sheet if the two outer linerboard facings are at different moisture content levels at the time that corrugated bonds set. Warp is a serious quality defect (15).

The double-back bond is formed as the corrugated board web travels sandwiched between a weighted fabric belt and a steam heated cast-iron plate. Typical double-backers are 24.4 m in length and double-face bond sites are under the influence of both heat and pressure as the bond sets for ~4.8 s minimum (16,17). Typically, the single-facer bond is under heat and pressure only as it passes through a pressure nip formed by the lower corrugating roll steel flute tips and the steel pressure roll. The single-face bond must develop sufficient adhesive tack in this nip, referred to as a green-bond, to hold the medium and linerboard facing together until the final cured bond strength is developed (6,18,19).

Attempts have been made to use cold-set adhesives in the corrugating operation, such as poly(vinyl acetate) and modified, precooked starch formulations, but these have not achieved any appreciable degree of commercial acceptance (20). The use of a polyethylene film applied to the inside surface of the linerboard facing, which serves as a hot-melt corrugator adhesive, has achieved some commercial usage. However, its use is limited to the small, specialty product niche of fast-food hamburger cartons (see COMPOSITE MATERIALS, THERMOSET POLYMER-MATRIX, POLYETHYLENE).

Chemical treatments commonly applied to corrugated paperboard packaging materials include additives that impart various degrees of water resistance, humidity resistance, oil and grease resistance, product abrasion resistance, product corrosion resistance, adhesion release properties, flame-retardant properties, nonskid properties, and static electricity control properties to the finished package (1,2).

Surface coatings and pulp slurry additives to impart linerboard and/or medium product abrasion resistance, adhesion release properties, corrosion resistance, flame-retardant properties, oil and grease resistance, and static electric control are typically applied by the paper mill during production of paperboard (2). Abrasion resistance and adhesion release properties are typically achieved by the use of silicone surface applications. The silicone may be applied directly to the paperboard surface or the paperboard surface may first be clay coated or polyethylene (PE) film laminated to achieve better silicone holdout properties on the paperboard surface. Maximum release levels of 20 g/cm (TAPPI UM-502 test method) have been reported for paperboard products consisting of silicone applied to a PE film that is laminated to the paperboard surface (21). Corrosion resistance may be achieved by controlling the finished paperboard extraction pH through the addition of buffering chemicals, and by minimizing the residual reducible sulfur content of the paperboard. Flame-retardant properties are typically achieved by the pulp slurry addition of chemicals such as antimony pentoxide (see FLAME RETARDANTS: AN OVERVIEW). Oil and grease resistance properties are typically achieved by a surface application of fluorocarbon or stearato chromic chloride materials which act by reducing the ability of the oil and grease to wet the treated paperboard surface. The control of static electricity is typically achieved by the pulp slurry or paperboard surface application of a grounding material, such as graphite.

Although the nonskid and moisture/humidity resistance properties of a corrugated fiberboard package can be achieved by the use of pretreated linerboard and medium materials, they are generally achieved by the application of treatment chemicals during the package-making process. Increased nonskid properties are achieved by a surface application to the double-face linerboard of a material which increases the coefficient of friction. The nonskid agent is applied in the double-face section of the corrugator by the use of an applicator roll. It may be applied to the total surface of the corrugated board or only to the surface areas that become the box closure flaps. The coefficient of friction of untreated linerboard is 0.2 to 0.5. The nonskid application increases the coefficient of friction to the range of 0.5 to 0.8. The nonskid materials applied to the linerboard consist of aqueous colloids of silica or alumina (22).

Moisture/humidity resistance is achieved in the corrugated board by the addition of a sizing agent to the linerboard and/or medium, or by the application of a surface coating to the linerboard which acts as a moisture barrier. The sizing material can be added either on the corrugator or in an off-line dipping and cascading process. The surface coating approach can be done on the corrugator by the use of a roll or a flooded nip applicator, or in an off-line curtain coating operation.

The most commonly used corrugator-applied sizing material is a lower melting point paraffin wax; the most commonly used off-line sizing material is a higher melting point paraffin wax. The most common corrugator-applied coating is an aqueous emulsion of a wax or acrylic polymer, and the most common off-line coating is a modified higher melting point/microcrystalline wax blend (1,10,23–25). Some of the properties of the various wax applications materials are shown in Table 1 (10,26) (see WAXES).

Poly(vinyl acetate) emulsions or hot-melt adhesives are typically used to form the manufacturer's or glue lap joint of the box. The main criteria for the adhesive is that it provide a strong and tough final bond and that it set up quickly enough to allow fast box production speeds. Production rates in excess of 240 boxes per minute are not uncommon in the industry.

Sales declined in the United States by 11% to $\$22 \times 10^9$ in 2004 from a high of $\$24.5 \times 10^9$ achieved in 2000. U.S. competition is high due to excess capacity. Outsourcing, eg, to China is impacting U.S. companies. Alternative products such as reusable plastic containers, stretch- and- shrink wrap, and intermediate bulk containers have been less competition than in previous years (27).

4. Solid Fiber Paperboard Boxes

A solid fiber paperboard package is a sandwich structure composed of inner plies called filler stock and outer plies called facings. Solid fiber differs from corrugated in that the inner plies are not fluted. Solid fiber packaging is typically used where toughness is important. Many solid fiber packages are reusable.

The solid fiber sheets are produced in a continuous process using a machine called a paster. Between two and six rolls of filler stock and facings are unwound onto the paster, coated on one side with an adhesive, and brought together in an unheated pressure roll nip to bond the plies together. The solid fiber web then passes through slitting and cut-off devices, similar to those described for the corrugated paperboard boxes, to form the proper sheet size needed to make the package. Die cutters are typically used to cut the specific package shape from the sheets because of the toughness of the solid paperboard material.

The paster is a nonheated operation. The most common paster adhesive formulation consists of poly(vinyl alcohol)–clay–starch blends (10). A 100% area adhesive coverage is used. The rate of bond strength development of the adhesive is an important commercial concern and rapid bond formation rates are desirable.

Various types of surface coating materials can be used with solid fiber paperboard to achieve desired package properties. The coatings and treatments described for corrugated paperboard apply to solid fiber paperboard as well. Various solvent and aqueous-based polymeric emulsion coatings are also commonly used (see EMULSIONS).

When selecting a particular paster adhesive, coating material, and coating process for solid fiber packaging, the fact that solid fiberboard lacks the open-flute structure (to facilitate exit of moisture from internal plies of paperboard) should be considered. It is generally desirable to minimize the amount of process water added with the adhesive or coating with solid fiber products. Moisture trapped in the filler plies can result in pin holes or blisters in the coating and/or warp of the sheet (15).

5. Paper Bags

Paper bag packaging includes multiwall bags, for consumer and commercial packaging applications, as well as grocery sacks and retail bags. Bags and sacks are manufactured in a continuous operation from rolls of paper. The paper web is folded and glued at a seam to form a continuous tube, which is cut to the required length for the specific bag size. The bag bottom is then folded and glued closed (10).

Grocery sacks typically are made from regular or wet-strength grades of paper material. Multiwall sacks are typically made from combinations of paper, plastic film, and composite material plies. The various plies used in multiwall bags can have special coatings or additives to achieve specialized and unique properties for any given packaging application. The types of properties sought include water and moisture resistance, oil and grease resistance, adhesion release properties, nonskid properties, air permeability, and gloss and color (1). Chemicals used to achieve these characteristics are the same as those used for corrugated paperboard boxes.

The adhesives (qv) used to form tube seams and bag bottoms include unborated dextrin, borated dextrin, casein, latex–casein, latex, poly(vinyl acetate), vinyl acetate copolymers, and hot-melt materials (10,28). Dextrin and casein adhesives are more commonly used in the production of grocery sacks; vinyl acetate-type adhesives are commonly used in all paper multiwall bags. The hot-melt adhesives are typically used to tack the plies of the multiwall bag together and to form the seam and bottom joints when polymer film plies or coated paper plies are used in bag construction.

6. Folding Cartons

Folding cartons are used extensively for point-of-purchase packaging and generally include high quality print graphics. The paperboard material typically used has smooth surface properties and often is clay coated. The paperboard roll stock is printed and/or coated, cut into sheets of an appropriate size, and die cut into individual package blanks, which are then folded and glued to form the finished package (10).

The over-coatings that are applied are used to achieve barrier and gloss properties. The exact chemical composition of the coatings varies greatly depending on specific packaging needs. Common coating types include paraffin wax, polyethylene and vinyl acetate copolymers, and organic solvent-based coatings and lacquers (10).

The seam closure on a folding carton is typically made using a latex, poly(vinyl acetate), vinyl acetate copolymer, or hot-melt adhesive (28). The choice of adhesive depends on a number of factors, including the nature of any coating used on the package and the production speeds required.

There have been attempts to replace folding cartons, but there are few alternatives. Benefits include a greater ability to make products stand out on shelves, greater recycling opportunities, and the use of water-based inks (29).

The estimated folding carton sales for 2005 is $\$9.7 \times 10^9$ (30).

7. Fiber Drums and Cans

Fiber drum packaging and fiber can packaging are included together because of the similarity of their production processes. Both types of packaging are produced by wrapping plies of paperboard into a tube form. Two basic winding processes, convolute and spiral, are in use. Convolute winding is a discrete process where only one roll of paperboard is used at a time. The paper ply is wound so that it is layered upon itself and only one side seam, where the starting edge and ending edge of the paperboard meet, is produced. A 100% area adhesive coverage is used. The winding is done on a mandrel having the same diameter as that of the desired package. The finished tube must be removed from the mandrel before the next tube can be started. Spiral winding is a continuous process where multiple rolls of paperboard, plastic film, foil, and/or composite materials can be wound at the same time. Each ply is wound at an angle so that the side edges abut. Adjacent plies are slightly offset so that the seams for each of the plies is not at exactly the same position. Spiral winding therefore produces packages with multiple side seams which spiral around the tube perimeter. A 100% area adhesive coverage is used. Spiral winding is done on a mandrel having the same diameter as the desired package. The mandrel is lubricated so that the finished tube can move continuously down the mandrel to a rotary knife that cuts the tube to the proper length for the required package height. In general, fiber drums are produced using the convolute winding method, and fiber cans are produced using the spiral winding method.

The web materials used to form drums and cans can be customized to each packaging application. The materials are selected based on the package properties of moisture and humidity resistance, nonstick resistance, or barrier properties required. The adhesives used to bond the plies together include silicates, poly(vinyl alcohol), and poly(vinyl acetate) (10). Silicate adhesives are most commonly used in the manufacture of drum packages.

BIBLIOGRAPHY

"Packaging, Converting" in *ECT* 4th ed., Vol. 17, pp. 1008–1017, by J. J. Batelka, Consultant; "Packaging, Converting" in *ECT* (online), posting date: December 4, 2000, by J. J. Batelka, Consultant.

CITED PUBLICATIONS

1. *Fiber Box Handbook*, Fiber Box Association, Rolling Meadows, Ill., 1992.
2. C. E. Libby, ed., *Pulp and Paper Science and Technology*, Vol. II paper, McGraw-Hill Book Co., Inc., New York, 1962.
3. *Wet Strength in Paper and Paperboard*, TAPPI Monograph Series No. 29, Technical Association of the Pulp and Paper Industry, Atlanta, Ga., 1965.
4. P. A. Tice and C. P. Offen, *Tappi J.* **77**(12), 149–154 (Dec. 1994).
5. G. J. Daly, *The Corrugated Container Industry*, Harry J. Bettendorf, Oak Park, Ill., 1971.
6. J. J. Batelka, *Corrugating Medium—Its Influence on Box Plant Operations and Combined Board Properties and Package Performance*, Institute of Paper Science and Technology, Atlanta, Ga., 1993.
7. T. Pickens, *Southern Pulp Paper* **46**(3), 12–14 (Mar. 1983).
8. R. H. Williams, C. H. Leake, and M. A. Silano, *Tappi J.* **60**(4), 86–89 (Apr. 1977).
9. *Starch Based Corrugating Adhesives and their Application*, Harper/Love Adhesives Corp., Charlotte, N.C., 1980.
10. J. C. W. Evans, ed., *Trends in Paper and Paperboard Converting*, Lockwood Trade Journal Co., New York, 1965.
11. W. O. Kroeschell, ed., *Preparation of Corrugating Adhesives*, TAPPI Press, Atlanta, Ga., 1977.
12. Technical information sheets, Vol. 1: Series 0100-0300, *Coating and Graphic Arts Division*, TSI-0304-05, Technical Association of the Pulp and Paper Industry, Atlanta, Ga., 1989.
13. Ref. 12, TSI-0304-06.
14. Ref. 12, TSI-0304-08.
15. Ref. 12, TSI-0304-07.
16. *Compression and Converting Properties of Board*, Continuing Education Center, Institute of Paper Science and Technology, Atlanta, Ga., 1988.
17. Ref. 7, pp. 28–31.
18. J. J. Batelka, *Tappi J.* **75**(10), 94–101 (Oct. 1992).
19. J. J. Batelka, *Tappi J.* **77**(7), 71–73 (July 1994).
20. J. J. Becher, G. R. Hoffman, J. W. Swanson, and R. C. McKee, *Development of Cold-Set Adhesive*, Project 2696-11, Report One to the Fourdrinier Kraft Board Institute from the Institute of Paper Science and Technology, Atlanta, Ga., Nov. 1973.

21. *Release Paper and Unsupported Release Film*, H-P Smith, Chicago, Ill., 1981.
22. *Recommended Practices: General Notes on Anti-Skid Treatments for Fibreboard Shipping Containers*, Fiber Box Association, Rolling Meadows, Ill., 1992.
23. L. Roth and J. Weiner, *Waxes, Waxing and Wax Modifiers*, Bibliography Series No. 198, Institute of Paper Science and Technology, Atlanta, Ga., 1961.
24. Ref. 23, Suppl. I, 1967.
25. Ref. 23, Suppl. II, 1973.
26. Ref. 12, TSI-0206-01.
27. M. Spaulding, *Converting Magazine*, www.convertingmagazine.com/current issue, Sept. 2004.
28. *Adhesive Selection Chart*, McGraw-Hill Book Co., Inc., New York, 1971.
29. Ref. 27, May 2004.
30. *Industry Facts, 2005*, Paperboard Packaging Council, Alexandria, Va.

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Table 1. **Wax Sizing Materials**

Property	Corrugator wax	Dip/cascade wax	Off-line coating wax
congealing point, °C	50–57	63–68	66–71
application temp, °C	78–84	90–93	129–163
elongation, % at 23°C	1–3	1–3	50–85
viscosity, mPa·s(= cP) at 177°C	150–180	150–180	50
application rate, wt %	3–10	45–55	7–9

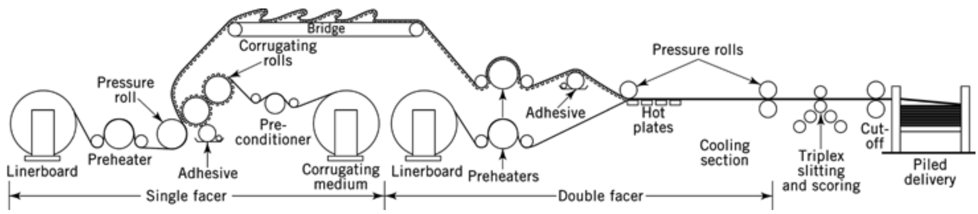

Fig. 1. Schematic of a corrugator (simplified and condensed).