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Paperboard Grades

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Introduction

Paperboard is a heavyweight paper that has a grammage or basis weight generally greater than $150\,\mathrm{g\,m^{-2}}$ and is thicker than 300 μm. The additional thickness results in a stiffer sheet that is ideal for boxes and containers providing protection for saleable products during transportation, handling, and storage. Paperboard grades include cartonboards, containerboards, and specialty boards, and are used in either food or non-food applications. The English units for paperboard are given in pounds per 1000 square feet (lb/1000 $\mathrm{ft^2}$) and the thickness is measured in points or mils (thousands of an inch).

A box is a rectangular container with or without a top designed to transport and store a variety of goods and products in either liquid or solid form. A box must be strong enough to hold its contents not only during transportation and storage but also during the packaging operation. Because boxes are frequently stored in stacks, compression resistance in their vertical sides is required to avoid bulging and cracking that would result in loss or damage to the product contained within.

Boxes manufactured from paperboard are made to resist compressive forces by using stiff pulp fibers formed into thick sheets. Paperboard meeting these two requirements will have high levels of bending stiffness. Although the stiffness requirement for the pulp fiber is important, the greatest factor affecting bending stiffness is sheet thickness or caliper. Relatively small changes in thickness will result in large changes in bending stiffness since the effect of sheet thickness on stiffness is cubic rather than linear. Pulp selection for greater fiber stiffness leads papermakers to choose naturally thicker fibers such as softwood or hardwoods with noncollapsible, round cross-sections. High yield pulping processes such as thermomechanical pulp (TMP) or semichemical that produce pulp with high percentages of lignin are also desirable for paperboard because of their inherently stiffer fibers. High yield pulps are very desirable for the manufacture of paperboard because the fiber is not only stiff but produces bulky sheets that enhance bending stiffness through both fiber stiffness and sheet thickness. For these two reasons, recycled fiber is also used to a large degree in paperboard manufacture.

Manufacturing Multilayer Paperboard

The same basic paper machines used to produce writing and printing paper are also used to form paperboard. However, modern paper machines are limited in their ability to produce a single-layer paper sheet with a grammage above $150\,\mathrm{g\,m^{-2}}$. There are a number of reasons for this limitation. Primarily, thicker single-layer sheets are more difficult to dewater requiring excessive reductions in machine speed. Furthermore, the increased drainage forces applied to thicker sheets in the forming section would cause greater fines removal from the bottom of the sheet resulting in a rougher surface. The topside of a very thick sheet would also be adversely affected since paper is formed on fourdrinier machines layer by layer from the wire side up, which would allow extra time for the fibers in the top layer to flock and produce a 'hill and valley' appearance. The combination of these two effects would produce an unacceptably two-sided product.

Manufacturing multilayered paperboard from separately formed sheets provides a solution to the above-mentioned problems. The forming section of paperboard machines are composed of two, three, or even four forming sections that bring individual sheets together at the wet press. Paperboard machines are for this reason large and complex having heights that are two to three times greater than single-former machines. Any one of the former sections in a multilayer machine can be either a traditional fourdrinier or a modified fourdrinier equipped with a top-wire unit for additional dewatering capacity. The use of different furnishes in each former produces a final sheet that is engineered for specific stiffness and smoothness requirements.

Although initially forming two to three separately formed sheets of paper, a multilayer machine forms a single sheet of paperboard when the individual sheets of paper are combined together in the wet press. The individual single-layered sheets prior to the wet press are 'vacuum dewatered' with a typical consistency of 20% (80% moisture) and are simply assemblages of fibers held together by capillary forces exerted by the continuous matrix of water surrounding the fibers. When the sheet continues it progress through the wet press and the dryers, this continuous matrix of water is decreased and the fibers are progressively drawn together through surface tension. Eventually, at the end of the drying process with a final moisture content of 4–8%, the surface tension forces between individual fibers will produce pressures sufficiently high enough to form fiber-to-fiber hydrogen bonds resulting in a mechanically strong sheet. During multilayer forming, a single sheet of paperboard is formed from the individual sheets of paper by merging the water matrices of each sheet into a single, hydraulically connected matrix in the wet press. The net result is that the multilayer sheet continues through the wet press and dryer section forming fiber-to-fiber bonds inside layers and between layers as if they were initially formed together. Theoretically, the fiber-to-fiber bonding between separately formed layers will be identical to fiber-to-fiber bonding within a single layer. Differences in interlayer bonding strength (measured by z-direction strength tests) will be found when the individual sheets are wet pressed at moisture contents lower than what is necessary to form a hydraulically connected matrix. (z-direction strength is the maximum tensile force per unit area which a paper or paperboard can withstand when applied perpendicularly to the plane of the test sample.)

The advantage of manufacturing a multilayer sheet is that key paper properties can be engineered into the paperboard that would not be obtainable by single-layer forming. Special top layers can be incorporated that are white and smooth, therefore, having excellent printing properties. Middle layers can be used that are bulky and thus inherently thicker producing the stiffest possible board. These middle layers can also contain recycle fibers or pulp fibers of lower quality that can be covered or masked by higher quality top and/or bottom layers.

Cartonboard Grades

Cartonboard produces consumer product packaging for food and retail items. The market for these grades is large and product development is great due to dynamic marketplace forces. Folding boxboard (FBB), white lined chipboard (WLC), solid bleached sulfate board (SBS), solid unbleached sulfate board (SUS), and liquid packaging board (LPB) are major types of cartonboard grades. Many of these grades will be pigment coated to produce a highly printable top surface. These paperboards need to be strong and stiff to form the walls of a carton. Because cartons are stacked during storage, compression resistance is also important. In particular, cross-machine direction (CD) stiffness is required to prevent carton bulging since the carton is manufactured with the CD parallel to its height. High-speed converting and mechanized packaging lines mandate excellent runnability; therefore, resistance to curl is also a necessity. Finally, folding these paperboards into containers must occur without cracking, which requires not only good strength, but also good stretch. The ream area for paperboard grades is 1000 ft^2.

Folded Boxboard

Folding boxboard grades are used to make packages for numerous products including: dry foods, liquid foods, frozen foods, confectionaries, cosmetics, detergents, and numerous other items. The grammage range for folding boxboard is 160–450 $g\,m^{-2}$. Folding boxboard is a multilayer sheet having three to four layers. The top and bottom layers are frequently made of bleached chemical pulp. The middle layers consist of either mechanical pulp or recycled fiber for stiffness enhancing bulk. The top layer is usually surface sized for good picking resistance in printing. Because the board must have a smooth top surface for good printability, yet have adequate thickness for good bending stiffness, smoothness is obtained through a combination of limited calendaring and coating. It is important for folding boxboard grades to also have good folding and scoring properties.

White Lined Chipboard

White lined chipboard (grammage range of 200–450 $g\,m^{-2}$) uses recycled fiber in its middle layers, and has many similar applications as folding boxboard except for certain food packaging applications where contaminants in the recycled pulp might spoil or taint the food. WLC grades may sometimes have four sheet layers. The fourth layer is actually an additional top layer used to maximize use of less bright recycled pulps, therefore minimizing the use of expensive highly bleached top layers. The top layer is frequently coated to increase printability and an optional bottom coating may be found.

Solid Bleached Sulfate Board

Solid bleached sulfate board is very similar to folding boxboard and white lined chipboard except that it is a single layer sheet (hence the term 'solid') made of virgin bleached kraft pulp. Hardwood is the predominant furnish but softwood is also used. Contamination and tainting of food and cigarette products is the primary reason for using virgin kraft pulp. SBS board may be coated on one or both sides with the topside receiving as many as three layers of coating.

Solid Unbleached Sulfate Board

Solid unbleached sulfate board is a heavier multilayer board (grammage $<500\,\mathrm{g\,m^{-2}}$) that uses unbleached pulps where extra board strength is required. For this reason, SUS boards are used in beverage and other packages intended specifically for carrying consumer items. Because SUS is not intended to come directly in contact with food, recycled pulps are frequently used in the middle layers. However, the high strength requirements (which includes tear strength) necessitate using kraft pulps in both the top and bottom layers. Sheet strength and surface smoothness are augmented through the application of surface size. Packaging applications for SUS require printing on the topside, which is accomplished by coating the topside two or three times to prevent 'show through' of the darker unbleached furnish. Where it is important to have high quality printing, high-whiteness pigments such as titanium dioxide (TiO_2) are used.

Liquid Packaging Board

Liquid packaging board is a multilayer board having a polyethylene-coated liquid barrier in conjunction with single or multiple layers of virgin chemical pulp. Milk, juice containers, microwave, and ovenable trays are typical uses for this grade. Polyethylene provides not only a liquid barrier, but also the ability to heat seal during container manufacture. The polyethylene is coated on only one side when a moisture vapor barrier is required for long shelf-life, but on both sides for liquid packaging such as milk. Aseptic packaging uses liquid packaging boards that have high cleanliness and purity standards.

Manufacturing Cartonboard Boxes

Cartonboard sheets or reels are converted into boxes through a process that involves cutting and creasing and then gluing the box into the final carton. Additional steps are frequently taken to produce a visually attractive box that may include printing, varnishing, film laminating, foil blocking, and embossing. Because cartonboard boxes are often an important part of the merchandizing of the contained product, rotogravure printing is necessary to provide the highest possible printed quality. Where self-advertising on store shelves is not critical, offset or flexography printing is used instead, or the box may be unprinted.

Printed boxes, unlike magazines and books, experience considerable abrasion during their use as a product package, which requires surface protection through either varnishing or plastic film lamination. Varnishing is accomplished through coating during the printing process. The varnishes of choice are usually aqueous dispersions that are cured on-line with ultraviolet light. Varnishing provides a gloss to the surface of the box further enhancing its attractiveness. When a more durable or glossier surface is required, off-line film lamination is also used.

Quality printing requires cartonboard grades to have a relatively high brightness from either the pulp or an applied surface coating. Printing also requires high smoothness, which is obtained from coating the sheet and using hardwood furnishes.

Cartonboard boxes are specifically designed for each product and have no standard sizes. Products such as cigarettes, camera film and software are sold in boxes that have unique sizes and designs, which may include intricate product-inspection windows or cutouts. These potentially complex designs are produced by die-cutting a cartonboard sheet in either a flat-bed or a rotary press that has cutting rules in the shape of the unfolded box mounted to a cutting die, which is then applied through the sheet against a counter die. The cutting rules or knives that are attached to the cutting die have compressible rubber gaskets on either side. These rubber gaskets hold the sheet motionless to produce an accurate cut and then expand to cleanly eject the sheet after the cutting compression stroke has taken place. Any cutouts are prevented from accumulating in the cutting die area by keeping them connected to the sheet through small 'nicks' or perforations that are produced with notched cutting rules. Cutouts are then removed in a stripping step that breaks the nicks and collects the waste material.

Die-cutting requires cartonboard sheets to have good strength properties to produce a clean cut. Poor fiber-to-fiber bonding, a function of low sheet strength, will result in fiber linting or dusting. Low-strength sheets are also more subject to tearing after cutting and exhibit poor runnability on converting machines. Moisture content is also important for converting machine runnability. Excessively dry sheets are harder and will wear out the die-cutting rules sooner. Drier sheets will also produce more cutter lint or dust.

Cartonboard sheets must also be creased to form folding boxes. Creasing is a step that occurs simultaneously with die-cutting on flat-bed machines, but after cutting on rotary machines. A folding crease is formed with a creasing rule that has a rounded edge rather than a cutting edge. Creasing rules are attached to the cutting die together with the cutting rules; however, the creasing rules work in conjunction with a creasing channel located directly opposite them on the counter die. A properly working creasing rule will form a sufficiently deep and narrow crease that will allow the cartonboard sheet to precisely fold where intended and produce a sharp attractive box corner. The creasing rule will be pressed against the side of the sheet that is intended to form the inside of the box.

Cartonboard grades that exhibit good creasing properties have good tensile strength and elasticity in order to survive the out-of-plane deformation during creasing. When a box is folded along its crease, the inside portion of the crease will undergo compression while the outside of the crease will undergo tension. Cracking will occur when the elastic limit is reached and the sheet fails in either tension or compression. In general, the compression limit is reached before the tension limit. Cartonboard sheets that resist cracking tend to have multilayered construction that delaminate around the crease with the inside layers buckling rather than undergoing compression failure.

Corrugated Containerboard Grades

Corrugated containerboard boxes are lightweight structures that can transport significant internal weight and withstand buckling and collapsing when multiple container units are stacked on top of each other. Corrugated containerboard boxes are manufactured by gluing a fluted corrugated medium between two strong outer linerboard faces. In this manner, maximum thickness is obtained with minimum weight to ensure high bending stiffness. Corrugated containerboard may also have two or even three corrugated layers sandwiched between alternating layers of linerboard when extra strength and rigidity is required.

Linerboard's primary characteristic is high bending stiffness and is usually produced with two or more plies from high-quality kraft or recycled pulp. To maximize bending stiffness, pulp fibers that will produce the highest tensile strength are placed in the outer or top layer that comprises about 30% of the total sheet. For example, the top layer will have the highest percentage of virgin fiber while the lower base layer will have a higher percentage of recycled pulp. As another example, the top layer may be a kraft pulp cooked to a lower degree of lignin content and refined to a higher degree than the bottom layer. Typically, compression testing such as the edge crush, flat crush, ring crush, and short-span compression is useful in predicting linerboard performance in the final containerboard product. Burst testing, which measures tensile strength in an empirical manner, has also been used to assess linerboard strength, but is now considered inferior to compression testing. Dry strength agents such as starch may be applied at a sizing press to increase linerboard's surface strength, and resin sizing may be applied in the headbox to enhance water resistance and wet strength. Printable top plies are made from bleached chemical pulps (either hardwood or softwood) that are sometimes pigment coated for more demanding printing requirements. The grammage range for linerboard is 125–350 $\mathrm{g\,m^{-2}}$. Linerboard made from at least 85% virgin kraft pulp is called 'kraft linerboard.' Linerboard meeting the requirements of Rule 41 of the Consolidated Freight classification in the US is called 'test linerboard,' and meets either a minimum bursting strength or a minimum edge crush strength. Because kraft linerboard easily exceeds either minimum strength criteria, the term 'test linerboard' is usually applied to linerboard containing predominantly recycled pulp. Modern linerboard machines are multi-ply machines using twin-wire/gap-forming technology. Many new machines are being outfitted with the latest in shoe or extended nip wet presses.

Corrugating medium, used as the fluting between two linerboard layers, is a single-layer uncalendered sheet with a grammage range of 112–180 $\mathrm{g\,m^{-2}}$. Compression resistance rather than tensile strength is particularly important for corrugated medium, because, as a composite structural material, corrugated containerboard boxes will fail at the box corners in an identical compression mode when either excessive external loads or excessive internal loads are present. In general, failure occurs in either condition because the containerboard is bending outwards and the linerboard on the inside of the bend is compressed to failure. The primary role of the corrugating medium in preventing containerboard failure is to provide adequate separation of the linerboard faces such that the degree of bending is minimized during loading. For this reason, the portion of the flute that spans from one linerboard face to the other must be stiff enough to resist compressive collapse. This particular property can be obtained in relatively low-cost, minimally refined, semichemical pulps where the fibers are naturally stiff due to the presence of lignin. Recycled pulps also having characteristically stiff fibers can be successfully used in this grade. These pulps produce sheets with bad formation and low tensile strengths. Handsheets made from these pulps are specified to be formed at 150 $\mathrm{g\,m^{-2}}$ rather than

$60\,g\,m^{-2}$ to compensate for their lack of wet handling strength. Corrugating medium is also produced with a high machine-direction fiber alignment to enhance compression resistance in the direction of fluting.

Manufacturing Corrugated Containerboard

Producing corrugated containerboard requires converting machinery that combines separate rolls of linerboard and medium into a glued structure. The simplest structure is one sheet of linerboard glued to single sheet of corrugated medium and is known as single faced corrugated. Gluing an additional sheet of linerboard to the corrugated side of single face produces a single wall corrugated board. Gluing either two or three single faced corrugations together with a final linerboard face produces a double wall or triple wall corrugated board respectively.

During the production of single face corrugated, linerboard is unrolled and preheated to a temperature of 160–190°C in a unit known as a 'single facer.' In this unit, medium is also unrolled and preheated, but is passed over a corrugating roll to form the flutes or corrugations. During this operation, the medium must be held securely by either pressure or vacuum in the fluting roll to maintain the shape of the flutes. Glue, generally starch, is applied to one side of the flute tips, and then pressed firmly to the underside of the linerboard instantaneously bonding them together. The bond line formed by the glued tips is observable through the linerboard, and is preferably used as the inside surface of corrugated boxes. Single face is flexible, bending easily at the glue lines. As a material by itself, single face is used as a packing material due to its ability to wrap around items such as bottles providing them with excellent crush protection during shipping.

Single wall corrugated boards are produced in a converting machine where the single facer unit is coupled with a 'double facer' or 'double backer' unit. In this unit, the single face material is again preheated and glued to the remaining unbonded flute tips. The prepared single face is then pressed to another preheated linerboard sheet, which produces the rigid containerboard. Less pressure is applied in the double facer than in the single facer to avoid crushing the corrugations. However, because of the reduced pressure the linerboard glued in this manner does not have the same observable glue line as the single face material, and is more suitable for use as the printable outside surface of a containerboard box. Once the single wall board is produced, further heating to set the glue must take place over hot plates in order to convey the board flat through slitters and scorers before being cut into the final board sheet. Converting machines capable of producing double and triple wall container board operate in a similar manner to that just described with the exception that flutes on the corrugation side of a single face board can be glued to the linerboard side of a second single face board to form the final multilayer construction. Final boxes are manufactured using similar die-cutting, creasing, and printing techniques as described above for boxboard.

See also: **Packaging, Recycling and Printing**: Packaging Grades; Paper Recycling Science and Technology; Printing. **Papermaking**: Paper Raw Materials and Technology; World Paper Industry Overview. **Pulping**: Bleaching of Pulp; Physical Properties.

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Tissue Grades

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Introduction

'Tissue' is a generic name for a variety of light-weight paper products. In normal use, the word refers to the