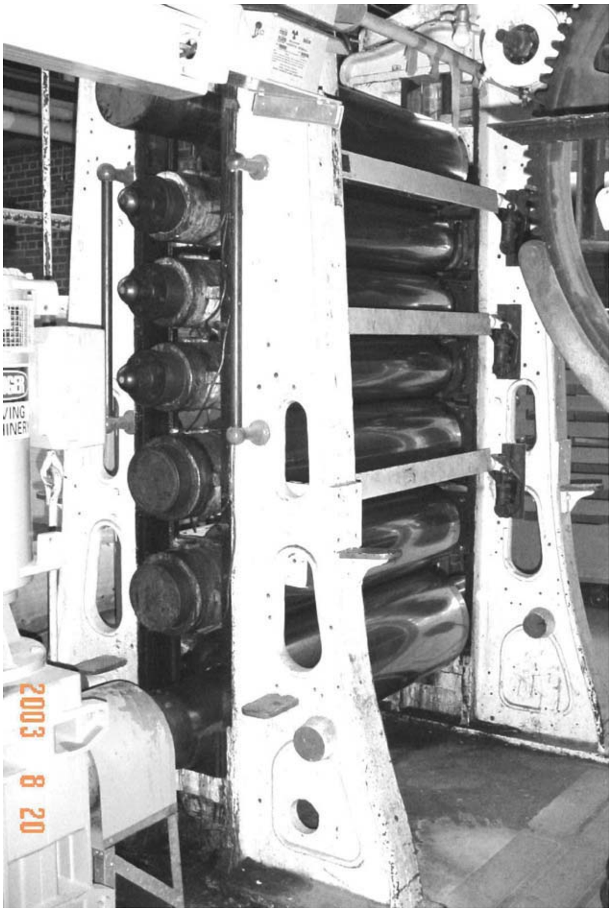

Figure 20 Calender of the pilot papermachine at SUNY College of Environmental Science and Forestry. The sheet passes through multiple nips to smooth the surface of the sheet.

the sheet and can correct some of the irregularities in the sheet. The effect of calendering on the sheet depends on a number of variables, including the sheet moisture, the type of coating applied at the size press, the calender stack loading, temperature, and number of nips.

Reel

The final step of the paper machine is to collect the paper that is produced on a reel (**Figure 4**, item 800). From here, the paper is rewound into smaller rolls needed for shipping or further processing in the finishing and converting operation. The type and amount of processing done after the reel depend on the grade of the paper and the customer specifications.

See also: **Packaging, Recycling and Printing**: Packaging Grades; **Papermaking**: Paper Grades; Paper Raw Materials and Technology; Paperboard Grades; The History of Paper and Papermaking; Tissue Grades. **Pulping**: Chemical Pulping; Mechanical Pulping.

Further Reading

Biermann CJ (1996) *Handbook of Pulping and Papermaking*. San Diego: Academic Press.
Borch J, Lyne MB, Mark RE, and Habeger Jr, CC (eds) (2002) *Handbook of Physical Testing of Paper*, vol. 2, 2nd edn. New York: Marcel Dekker.
Britt KW (1975) *Handbook of Pulp and Paper Technology*. New York: Van Nostrand Reinhold.
Clark Jd'A (1985) *Pulp Technology and Treatment for Paper*, 2nd edn. San Francisco: Miller Freeman.
Dieson M (1998) *Papermaking Science and Technology*. Atlanta, GA: Tappi Press.
Gavelin G (1998) *Paper Machine Design and Operation*. Vancouver, BC: Angus Wilde.
Hunter D (1978) *Papermaking: The History and Technique of an Ancient Craft*. New York: Dover Publications.
Karlsson M (2000) *Papermaking*, Part 2, *Drying*. Atlanta, GA: Tappi Press.
Kline JE (1991) *Paper and Paperboard: Manufacturing and Converting Fundamentals*. San Francisco: Miller Freeman.
Kojio M (1999) *Papermaking: Finishing*. Atlanta, GA: Tappi Press.
Levlin J-E and Söderhelm L (1999) *Pulp and Paper Testing*. Atlanta, GA: Tappi Press.
Mark RE, Habeger Jr, CC, Borch J, and Lyne MB (eds) (2002) *Handbook of Physical Testing of Paper*, vol. 1, 2nd edn. New York: Marcel Dekker.
Patrick KL (1999) *Primer of Pulping and Paper Making: Technologies and Production Practices*. San Francisco, CA: Miller Freeman Books.
Paulapuro H (2000) *Papermaking* Part *1: Stock Preparation and Wet End*. Atlanta, GA: Tappi Press.
Savolainen A (1998) *Paper and Paperboard Converting: Papermaking Science and Technology*. Atlanta, GA: Tappi Press.
Smook GA (1982) *Handbook for Pulp and Paper Technologists*, 3rd edn. Vancouver, BC: Angus Wilde.
Smook GA (1992) *Handbook of Pulp and Paper Terminology: A Guide to Industrial and Technical Usage*, 2nd edn. Vancouver, BC: Angus Wilde.
Thorp BA (ed.) (1991) *Pulp and Paper Manufacture*, vol. 7. *Paper Machine Operations*. Atlanta, GA: Tappi Press.

Paper Grades

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Introduction

Paper is a sheet of dried cellulosic fibers and noncellulosic components formed from an aqueous suspension on a fine mesh screen. The ideal forming process deposits fibers on the screen in randomly oriented layers with a uniform mass distribution. Paper can make an enormous number of useful products. Approximately 2000 years ago, the Chinese invented paper as an inexpensive writing material. Because paper was also lightweight, flexible, and opaque, it became the material of choice for letters, manuscripts, and books, and it eventually replaced such writing materials as papyrus, parchment, and textiles. Paper later evolved to serve many other uses by changing the initial papermaking stock formulation, such as varying the type of fibers and additives, their relative proportion, and the total amount of these ingredients.

The term 'grade' signifies the manner in which one type of paper differs from another. Different papers can have different uses, appearances, qualities, and components. For example, paper can make books or boxes. Paper can be white or brown, smooth or rough, thin or thick, light or heavy. Virtually any plant can make paper, and virtually any noncellulosic material can be added to make specialty papers. Furthermore, different manufacturing processes can produce different grades of paper. This article will explore three typical categories of paper grades: printing, writing, and specialty grades.

Grade-Determining Paper Properties

Physical and strength properties of paper are important determiners of many paper grades. These properties include: grammage, caliper, density, strength, smoothness, porosity, lignin content, and pulp type. These properties are interrelated, and this section will describe the nature of this interrelationship and the fact that different stock formulations and production techniques can yield the same paper properties. For instance, uncoated supercalendered paper can successfully substitute for lightweight coated paper as long as the key material properties are identical.

A sheet of paper has dimensions of width and length dictated by its use. In general, the length is longer than the width. A common typewriter sheet size in North America is 8.5 inches × 11 inches (215.9 mm × 279.4 mm), while the equivalent size in Europe is ISO A4 (210 mm × 297 mm). The weight of a sheet determines the most basic physical measurement of paper: grammage or basis weight. Grammage is the ratio of sheet weight to area, and has units of grams per square meter ($g\,m^{-2}$). Basis weight is essentially the same measurement but uses English or United States Customary System (USCS) units. Basis weight is the weight in pounds of a ream or 500 sheets cut to a size specified by its ultimate use. A ream is an awkward and confusing measurement since the total area defined is different for many types of paper. Reporting basis weight in pounds per ream area (for example 34 pounds per 1000 square feet) can reduce potential confusion.

When all else is constant, changing the grammage of paper results in a change in thickness or caliper. Thicker paper will have correspondingly greater strength, bending stiffness and opaqueness. Paper having a grammage greater than $150\,g\,m^{-2}$ is usually termed paperboard. In the English system of units, paperboard is any sheet thicker than 12 points (1 point = 1 mil = 0.001 inch).

When caliper is held constant, changing the grammage of paper results in a denser sheet. Increasing density also results in increasing sheet strength with an accompanying loss in air volume. Sheet densification in papermaking occurs primarily through pulp refining, wet pressing, and calendering. Refining of pulp mechanically releases cellulose–cellulose hydrogen bonds inside the fiber walls by creating cellulose–water hydrogen bonds as water is drawn into the cell wall material. The net effect is a swollen fiber with a network of water-filled capillaries that exert considerable pressure inside the sheet during drying. The resulting surface tension pulls cellulose structures together both within and between fibers eliminating air spaces. As water in the capillary evaporates, the dimensions of the capillary decrease producing increasing surface tensions until the capillary disappears and the cellulose surfaces bond. Wet pressing enhances this bonding effect by mechanically reducing pore size before the dryer section thus increasing the average capillary pressure during drying. Calendering after drying collapses compressible air pores in the dry sheet without the same degree of hydrogen bonding and thus does not produce the same strength-enhancing effect. Calendered papers are smoother because of the reduced size of the surface pores. Calendered paper when compared to uncalendered paper at the same thickness will have a higher grammage or basis weight due to the increased density.

Paper has a surprisingly large percentage of air volume. Bulky groundwood paper has 63% air volume, while dense glassine (pergamyn) has only 13%. It is not surprising that glassine is the strongest class of paper since the underlying reason for the strength is maximally hydrogen-bonded cellulose. However, glassine is semitransparent and does not make good printing and writing paper. Transparency or its opposite, opacity, relates to the volume of air in paper. More precisely, opacity relates to the distribution of numerous small air pores with a large total surface area. Surprisingly, cellulose is a clear, transparent material, while paper composed of pure cellulose is a semiopaque white material. The appearance of whiteness comes from the visual effect of light scattering from the pore surfaces. This is identical to the visual appearance of either table salt or sugar: both appear white until microscopic examination reveals numerous clear crystals. Thus, paper is a matrix of transparent cellulose with a distribution of light-scattering pores.

For pure cellulose paper, increased opacity means a larger quantity of light scattered from the surfaces of numerous small pores. Correspondingly, increasing pore volume decreases the volume of cellulose thus reducing sheet strength. To produce equally strong yet more opaque papers, papermakers use inorganic fillers such as clays and calcium carbonates to increase the available light-scattering surface area inside the pores without sacrificing the volume and density of cellulose required for strength.

Pulp fibers play an important role in the structure of the paper sheet. The primary source of papermaking pulp fibers comes from wood because of its superior technical and economical factors when compared to other sources of plant fiber. Wood provides both short, fine fibers from hardwoods and long, coarse fibers from softwoods. Furthermore, wood fibers have lignin interpenetrating the cellulose material producing a controlled absorption of water. Different pulping methods yield different amounts of lignin. Chemical pulping has the least amount of lignin while mechanical pulping has the most. Lignin-free chemical pulps are pure pulps, free of biological contaminants, with quality high enough for food applications. Chemical pulps also have the highest absorption capacity.

Unrefined softwood chemical pulps (such as softwood kraft) by themselves do not make strong fine paper. These fibers floc excessively and produce bad formation with rough surfaces, high sheet porosity, and low sheet strength. Refining will increase sheet strength, reduce porosity, and reduce surface roughness, but only to a degree. Shorter, finer hardwood fibers are required to provide paper with superior properties. In paper, softwood fibers are the reinforcing elements producing adequate strength, while hardwood fibers fill in the spaces between the larger softwood fibers producing high-opacity, smooth paper.

Mechanical pulps with higher lignin contents produce inexpensive paper that has limited permanence. Lignin restricts the amount of fiber-to-fiber hydrogen bonding that can develop in the paper machine's dryer section. For this reason, mechanical pulps produce bulkier paper that has lower strength potential than refined chemical pulps. However, mechanical pulp produces paper that has greater porosity and opacity because of the greater number of pores left after drying. Smoothness is also a feature of mechanical pulps that results from the mechanical fracturing of wood yielding a large number of fines. These papers yield excellent surfaces for printing.

Lignin gives paper a yellow–brown color. Brightness is an optical test that measures the percentage of blue light reflected from the surface of paper. Brightness is sensitive to the presence of lignin in paper because the yellow color of lignin will absorb blue light. Chemical pulps tend to have dark brown colors due to the chemical modification of lignin even though the quantity of lignin may be very low when compared to brighter mechanical pulps. Bleaching of both mechanical pulps and chemical pulps is performed to increase brightness and improve the overall whiteness of paper.

Printing and Writing Grades

Printing and writing grades represent about 30% of the paper consumed in the world. The number of printing and writing grades is large and increasing due to both customer and technological demands. In general, where quality requirements are secondary to price mechanical pulps are used. Chemical pulps are used when higher quality is desirable and higher prices can be justified. Many grades are also coated and calendered to improve surface smoothness for higher printability. In general, printability can be defined as the combination of paper properties that result in a good printed image. Printability is a complex property related to the optical and strength properties of paper. It is also related to the manner in which ink chemically and physically interacts with the material substances of the paper. Furthermore, all printing grades have a high 'runnability' requirement, which refers to the efficiency with which the paper can run through the printing presses. Runnability is related to the strength properties of the paper sheet.

Uncoated Mechanical Grades

Newsprint is the grade used for the publication of newspapers, advertising supplements, magazines, telephone directories, and other similar publications. This type comprises uncoated papers with inorganic filler less than 8%, but may receive special calendering. Standard newsprint can range in grammage from 40–49 $g\,m^{-2}$ with a nominal caliper of 85 μm (3.3 mil or points). Lightweight newsprint may have a grammage as low as 28 $g\,m^{-2}$. The mechanical pulp used in this grade includes groundwood (SGW or GWD), pressurized groundwood (PGW), thermomechanical (TMP), and chemithermomechanical (CTMP). Recycled fiber (RCF) content may also be high depending upon region. Many manufacturers will add up to 30% chemical softwood pulp to ensure good runnability in printing presses. Newsprint needs to have good formation with a smooth, bright surface and be adequately thick for good opacity to avoid ink showthrough. Color printing in modern newspapers has necessitated one-stage chemical bleaching to improve brightness. Special grades such as those used for telephone directories may have dyes added to change the color of the sheet. The cut sheet size for newsprint grades is 24 inches × 36 inches (610 mm × 914 mm) giving a ream area of 3000 square feet (279 m^2).

Supercalendered (SC) papers are uncoated papers that have been supercalendered to achieve a high-gloss/nonglare finish and are used in magazines, catalogs, and other applications using rotogravure or offset printing. The amount of gloss is dependent upon the furnish ingredients. Filler content in these grades can reach as high as 35%. Fillers used include kaolin clay, talc, and calcium carbonate. Grammage can range from 39 to 80 $g\,m^{-2}$, but a range of 52–60 $g\,m^{-2}$ is typical. Furnish composition is 70–90% mechanical and 10–30% chemical pulp. Groundwood, pressurized groundwood, and thermomechanical pulps are the typical mechanical pulps used. Less premium grades of supercalendered paper have higher groundwood percentages and lower chemical pulp percentages. Recycled pulp may replace a portion of the mechanical pulp in these lower grades. Because these papers have exceptional brightness (68–70%), opacity (90–91%), smoothness, and strength they compete well with lightweight coated papers.

Coated Mechanical Grades

Coated mechanical grades are printing papers used for the production of magazines, catalogs, advertising flyers, and other printed materials that require high-quality four-color printing but still have a throwaway quality. The coating substance consists by weight: 80–95% pigment, 5–20% adhesive binder, and less than 2% miscellaneous additives that control the properties of the coating during and after application. Coating weights from 5 to 25 $g\,m^{-2}$ per side are applied with a thickness of 5–25 μm. Coating pigments may include: clay, calcium carbonate, titanium dioxide, aluminum hydroxide, barium sulfate, silicon dioxide, talc, zinc oxide, and plastic pigments. Sheet surface quality and production speed mandate the coating techniques used. Typical coating techniques include roll applicators with blade, rod, or air jet metering to control thickness.

Table 1 American Forest & Paper Association coated grades classification courtesy of the AF and PA

Quality	*Brightness*
Number 1	85.0–87.9
Number 2	83.0–84.9
Number 3	79.0–82.9
Number 4	73.0–78.9
Number 5	≤72.9

Coated papers are categorized primarily by brightness in the classification of the Technical Association of the Pulp and Paper Industry (TAPPI). **Table 1** lists the six American Forest & Paper Association (AF&PA) quality categories. Coated mechanical grades contain 50–70% mechanical pulp (GWD, PGW, TMP, or CTMP), and 30–50% chemical pulp. With 4–10% filler pigment content, these papers may have 24–36% total pigment content.

Coated mechanical grades are grouped into three main grammage classes: lightweight (LCW), medium weight (MWC), and high weight (HWC). LCW paper has a grammage range of 35–80 $g\,m^{-2}$, with a coating weight range 5–12 $g\,m^{-2}$ per side. MWC paper has a grammage range 70–130 $g\,m^{-2}$, with a coating weight range 12–25 $g\,m^{-2}$ per side. HWC paper has a grammage range 100–135 $g\,m^{-2}$ and may be double or triple coated. HWC are used in higher-quality publications and advertising. Other special grades exist such as ultralightweight coated (ULWC), machine finished coated (matte surface), and film coated offset (FCO). The cut sheet size for mechanical coated grades is 25 inches × 38 inches (635 mm × 965 mm) giving a ream area of 3300 square feet (306 m^2).

Uncoated Fine Printing Grades

Fine paper furnishes should have less than 10% mechanical pulp. Blends of chemical hardwood and softwood pulp with up to 25% filler are used. Papermakers sometimes apply the term ‘free sheet’ or the especially confusing term ‘wood free sheet’ to these grades to denote the absence of mechanical pulp, which gives the paper an archival quality. Alkaline or neutral papermaking conditions further enhance the permanence of these papers. High percentages of hardwood are necessary to achieve good formation in the paper, while fillers, such as calcium carbonate, are necessary for good opacity. On-machine calendering and soft-nip calendering provide surface smoothness. Size pressing may also enhance surface smoothness.

Another term for uncoated fine printing paper is uncoated offset paper used for book publishing, copy paper, and electronic printing. The important properties for offset papers are good internal bonding, high surface strength, dimensional stability, lack of curl, and low linting potential. Offset paper is surfaced sized with starch at $0.5–2\,g\,m^{-2}$ per side. The grammage range is from 32 to $300\,g\,m^{-2}$. The cut sheet size is 25 inches × 38 inches (635 mm × 965 mm) giving a ream area of 3300 square feet ($306\,m^2$).

Uncoated book paper has a high requirement for appearance and printability. The brightness requirement is usually high. Color may run from blue–white to a natural yellow shade but must not change for the entire production run. Color may have to be consistent over several production runs so that different book printings will appear identical. Common surface finishes or textures are antique, eggshell, machine, English, and supercalendered. High opacity is crucial with low grammage sheets (i.e., $<75\,g\,m^{-2}$). Usually low gloss level is specified. High-quality book paper is known as text paper.

Bible paper is an example of a very low basis weight uncoated book paper ($20–45\,g\,m^{-2}$). Because of its low weight, bible paper must be strong for good printability, but more importantly, it must be opaque. Highly refined chemical pulp is used to give excellent strength and high loadings of calcium carbonate are required for opacity. Frequently, non-wood pulps such as cotton, flax straw, and linen are used to provide superior strength.

Writing papers are a wide range of quality papers designed for pen and ink, typewriters, and personal printing uses. Some writing papers have well-identified brand names and watermarks. These papers may have very distinctive textures and colors. Many different types of pulps are used in this category for aesthetic reasons, and they may be made to simulate handmade papers. Tablet papers are part of this grouping. In general, they are hard sized for low-viscosity pen inks. The grammage range is from 48 to $90\,g\,m^{-2}$. The cut sheet size is 17 inches × 22 inches (431.8 mm × 558.8 mm) giving a ream area of 1300 square feet ($120.7\,m^2$). Bond is a durable writing paper intended for stationery, legal documents, and other archival uses. Bond paper is manufactured from non-wood fibers such as cotton to increase its strength, durability, and permanence. Bond paper requires excellent printability. Onionskin paper is a lightweight ($26–37\,g\,m^{-2}$) bond paper that has exceptionally low opacity and is used where low bulk is necessary. Other similar bond-type writing papers include: parchment, vellum, wedding, and ledger.

An important area for uncoated fine paper is copy paper and digital printing papers. These papers require good brightness (80–96%) and opacity, and must resist curling and cockling when subjected to heat from thermo-type printers. They must also be well sized to resist ink wicking in inkjet-type printers. Grammage range is $70–90\,g\,m^{-2}$.

Coated Fine Printing Grades

Coated fine paper grades are required for demanding printing applications. Products include magazines, books, and commercial printing. Grammage range is $55–170\,g\,m^{-2}$. General categories of coated fine papers include: low coat weight ($55–135\,g\,m^{-2}$) with a total pigment content of 20–35%, standard coated ($90–170\,g\,m^{-2}$) with a total pigment content of 35–45%, and art paper ($100–230\,g\,m^{-2}$). Art paper has a highly finished and smooth surface with a coating weight of $20–40\,g\,m^{-2}$ per side or greater.

Specialty Grades

Specialty grade papers fit into a niche market where their enhanced value compensates for their low production volumes. All paper products begin as specialty grades until their production volumes make them commodity grades. Paper is extremely versatile and the number of paper products that fit into a specialty-grade category is prodigious making it difficult to completely describe the wide range of existing products. Paper's versatility is derived from the manner in which light, liquids, and air interact with it. Paper is also versatile because it is strong, yet light and flexible.

Paper's ability to carry an image led to its widespread use as a printing and writing material. However, the image carried need not be informational. Wallpaper is an example of this use. In practice, it is easier to create an image on paper using printing technologies and then apply the paper to surfaces that cannot be printed. Wallpaper is a decorative use of paper. High density laminates used for counter tops are another example of the decorative use of paper. Much like wallpaper, a sheet of paper with a color, pattern, or image is used in conjunction with other paper sheets that are saturated in resin polymers to form a waterproof veneer material that forms a very durable working surface. This technology is frequently used at lower densities in furniture-making to produce artificial woodgrain surfaces on top of compressed chipboard. Wallpaper is also an example of the use of paper as a carrier substrate. A carrier substrate can be defined as the employment of paper in a secondary role to assist the application of the primary product. In the case of wallpaper, the primary product is the decorative color, pattern, or image. It should also be mentioned that the backside of the wallpaper is coated with an adhesive glue to adhere the paper to the wall. Thus, the wallpaper acts not only as a carrier for the image, but as a carrier for the adhesive.

Many other materials can be carried on or in paper. Moist paper towels for hygienic purposes, household-cleaning tissues, and polish-saturated wipes are examples. It is also possible to imbed flower seeds in rolls of paper for planting purposes. Litmus paper is an example where paper carries chemicals for use in measuring pH. Medical test papers such as those used to determine blood sugar levels in urine are an extension of this principle.

An interesting use of paper as a carrier substrate is the manufacture of automobile brake pads. In this grade, paper is formed with a high loading of abrasive inorganic material and then saturated with phenolic resin. The sheet is glued to a metal backing and cured to form the brake pad surface that will provide the frictional forces to stop a moving automobile. A related range of products, where the abrasive is applied to the surface of the sheet rather than through the bulk, are sandpaper, finishing paper, and the base paper for grinder belts. Photographic paper carries the emulsion that forms a photograph when developed (before the acceptance of paper as the ideal carrier material, glass and metal plates were used). Release paper used as backing for self-adhesive labels is still another example. In many instances, the labels themselves are made of paper.

Because the porosity of paper can be controlled to a high degree by the selection of fiber type, additive, and processing, using paper as a filter material represents an important specialty grade sector. Paper filters are used to protect a wide range of automotive equipment as well as air handling, water purification, and electronic devices. Relative to the cost of the protected device, the paper filter is lowcost but can be sold for a premium. Coffee filters and tea bags are examples of these types of papers used daily by many people. Tea bags are made from a mixture of long banana leafstock (abaca) and synthetic fibers. The very open and thin sheet that is formed effectively filters the tea leaves from leaving the bag. It should be noted that air, water, and oil can all be filtered through paper because of the large quantity of surface area that provides ample surface free energy to adsorb and remove contaminants from the filtered fluid. Another home use for paper filters is the vacuum cleaner bag.

Food packaging at the wholesale and retail levels requires specialty grades. Cleanliness is very important to prevent tainting and spoilage. Recycled pulp, which may have significant contaminants, is not permitted to contact food. Generally, only chemical pulps are used. Sometimes the resulting paper is treated with fungicide to prevent molds as in fruit wrapping papers. Paper that contacts food often needs to be greaseproof. This property is provided by high density, low porosity paper such as glassine. Low opacity papers are used to wrap breads and bakery items to allow visual inspection of the product.

Many food products such as sugar and flour are packaged in bags made of sack kraft paper. These sacks need to be strong and resist rupture during handling. Sack paper also needs to be porous to permit air escape during rapid filling. Paper manufacturers will microcrepe sack kraft to increase elongation and enhance toughness. Square-bottomed kraft paper sacks are used as grocery bags. These bags are popular with consumers because they are recyclable. These bags need to have a high tensile strength to avoid rupture when filled with purchased items. A recent development to improve handling is the introduction of glued handles made of the same kraft paper.

Cigarette papers are required to be thin (16–24 $g\,m^{-2}$), strong, and porous. They are made from various textile fibers to ensure a white ash after burning. To achieve high opacities these papers are highly filled with calcium carbonate. Currency papers are also made from textile fibers for durability, but currency papers are also required to have high printability. Currency papers and related security papers must be refined enough to produce a good watermark. Many other security features are also incorporated to provide unique identification features.

See also: **Packaging, Recycling and Printing**: Paper Recycling Science and Technology; Printing. **Papermaking**: Coating; Overview; The History of Paper and Papermaking; World Paper Industry Overview. **Pulping**: Bleaching of Pulp; Chemical Additives; Chemical Pulping; Chip Preparation; Environmental Control; Fiber Resources; Mechanical Pulping; New Technology in Pulping and Bleaching; Physical Properties.

Further Reading

Biermann CJ (1996) *Handbook of Pulp and Papermaking*, 2nd edn. San Diego, CA: Academic Press.

Brandon CE (1981) Properties of paper. In: Casey JP (ed.) *Chemistry and Chemical Technology: Pulp and Paper*, pp. 1715–1972. New York: Wiley-Interscience.

Clark JDA (1985) *Pulp Technology and Treatment for Paper*, 2nd edn. San Francisco, CA: Miller Freeman.

Glassman A (1985) *Printing Fundamentals*. Atlanta, GA: Technical Association of the Print and Paper Industry.
Lebtinen E (ed.) (2000) *Papermaking Science and Technology: Pigment Coating and Surface Sizing of Paper*: Helsinki: Fapet Oy.
Oittinen P and Saarelma H (eds) (1998) *Papermaking Science and Technology: Printing*: Helsinki: Fapet Oy.
Parker JD (1972) *Sheet-Forming Process*. Atlanta, GA: Technical Association of the Pulp and Paper Industry.
Paulapuro H (ed.) (1998) *Papermaking Science and Technology: Paper and Board Grades*: Helsinki: Fapet Oy.
Scott WE and Abbott JC (1995) *Properties of Paper: An Introduction*, 2nd edn. Atlanta, GA: Technical Association of the Pulp and Paper Industry.
Smook GA (1992) *Handbook for Pulp and Paper Technologists*, 2nd edn. Vancouver, Canada: Angus Wilde.

Paperboard Grades

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Introduction

Paperboard is a heavyweight paper that has a grammage or basis weight generally greater than $150\,g\,m^{-2}$ 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 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 $150\,g\,m^{-2}$. 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.