

Key characteristics of linerboard, corrugating medium, and roll stock mechanical condition and their influence on the manufacture of corrugated products, part 1

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In Part 1, the Linerboard/Corrugated Subcommittee presents the knowledge and insight on linerboard and corrugating medium as collected and compiled by committee members over the last five years. Part 2 will pick up with the influence of mechanical conditions.

In October 1984, a group of containerboard producers and corrugated converters met under the auspices of the Papermakers Committee. This meeting resulted in the establishment of the Linerboard/Corrugated Subcommittee, an *ad hoc* assembly of mill and box plant representatives that met biannually over the succeeding years to discuss mutual concerns.

These informal discussions centered mainly on the properties of linerboard and corrugating medium and the characteristics of roll stock mechanical condition that were perceived to have a direct effect on corrugating operations. In 1987, the members of the subcommittee decided that the contributions from both the mill and converting representatives over the five sessions that had been held to that point were valuable enough that a summary of the essential points could be useful to the industry. Thus, over the next 2 1/2 years, using records of previous meetings and with ongoing discussions, the subcommittee members prepared the material that forms the bulk of this report.

Objective

Over the more than five years of biannual meetings that the subcommittee held, the topics discussed were broad ranging. In deciding to summarize the main thrust of the discussions, the subcommittee members limited the objectives to identifying and commenting on the key characteristics of linerboard, corrugating medium, and roll stock mechanical condition that, in the experience of the group, were considered to have an influence on

corrugated manufacturing operations.

Some major properties of linerboard and medium that have little or no direct effect on the runnability of these materials in the converting operation are identified and discussed as well. Although these characteristics fall outside the main thrust of the subcommittee's objective, they are included because they are important to the end-use qualities of corrugated products and must therefore be of concern to both papermakers and converters.

Methodology

The records of the subcommittee meetings up to June 1987 were reviewed. A list of key characteristics, methods used to measure them, and their influence on the corrugating process was drafted. This draft was broken down into three sections—one dealing with linerboard, one with corrugating medium, and one with the mechanical condition of roll stock. Over subsequent meetings, the members of the subcommittee revised the drafts, adding and deleting characteristics, updating test methods, and refining the commentary regarding influences on the converting process.

Format and content

The information on key characteristics is organized as outlined in Table I.

The key characteristics and their influence on the manufacture of corrugated products are detailed in Parts 1 and 2 of this report. For each of the characteristics in Sections I and II (Table I), information is presented in five numbered subsections:

1. A definition of the characteristic
2. Reference to a recognized test method or methods used

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to measure the characteristic

3. A description of the characteristic's influence on the corrugator, other downstream box plant operations, or both
4. Comments describing problems that converters might encounter if the characteristic deviates substantially from some established value or range of values
5. Comments regarding paper mill control of the characteristic.

The subcommittee makes no claim that the information contained here is exhaustive of the subject matter, that the potential problems described are the only possible consequences, or that the experience of converters will be consistent from plant-to-plant with the material characteristics and roll stock conditions described. Manufacturing practices, equipment capabilities, and the skills of operating personnel will all contribute to variations in results. The material here reflects only the knowledge and experience of those who participated in subcommittee meetings and those of their colleagues whom they may have consulted.

Section 3 in Part 2 will cover the information on the mechanical condition of roll stock.

Section 1: Linerboard

A. Moisture content

1. Definition. Moisture content is the amount of water present in linerboard expressed as a percent moisture content and refers to both the overall average moisture content of a roll of linerboard as well as machine-direction (MD) or cross-direction (CD) variation.

2. Test methods. Various hand-held instruments are available to measure conductivity capacitance, which is related to the moisture content of paper. These instruments must be specifically calibrated to yield accurate moisture readings. A reference test method is the "oven dry" method described in TAPPI T 412.

3. Influence. Linerboard moisture content should be uniform throughout a roll, both in the cross-machine and machine directions, at an average level that is neither too low nor too high and which varies relatively little from roll to roll.

Variation can lead to warping of the combined board, which will cause feed problems on kicker-type converting equipment and will cause printing and slotting register variation. Warp can also affect setup, packing, and the sealing of boxes on automatic and semiautomatic packaging lines. Moisture content also can affect bond formation between the flute tips and the facing, the dimensional integrity of lightweight facings, and the folding properties of combined boards.

4. Potential problems. Very low average moisture content can retard the receptivity of the linerboard to adhesive, causing a particular problem on the single-facer, where a "green bond" must be formed quickly. Production speed may have to be reduced to avoid weak ("zipper") bond or loose paper. Scoreline cracking is a function of many paper properties, including fiber length and fiber structure and fibrillation due to refining. Also, combining and converting factors can contribute to this defect. However, excessively low moisture levels in linerboard

I. Outline of the information on key characteristics

Section I: Linerboard

- A. Moisture content
- B. Internal bond
- C. Sizing
- D. Coefficient of friction
- E. Smoothness
- F. Porosity
- G. Bursting strength (Mullen)
- H. Compression
- I. Luminous reflectance/color
- J. Caliper
- K. Basis weight

Section II: Corrugating medium

- A. Water absorption
- B. Porosity
- C. Moisture content
- D. Flat crush (Concora)
- E. Tensile strength
- F. Stretch
- G. Hot coefficient of friction
- H. Soft caliper
- I. Caliper (traditional)
- J. Formation
- K. Basis weight
- L. Compression

Section III: Mechanical condition of roll stock

- A. Roll identification
- B. Roll hardness
- C. Cores
- D. Plugs
- E. Banding
- F. Dish and weave
- G. Mill splices
- H. Roll width
- I. Roll diameter
- J. Arrival condition

may compound the problem. Obviously, there is no single answer to the scoreline cracking problem.

Very high average moisture content can lead to excessive CD shrinkage on the corrugator preheaters, particularly on lightweight liners, causing edge misalignment and loss of trim.

Roll-to-roll moisture content variation can cause combined board warp beyond acceptable tolerances. Many industry corrugators are unable to control warp if the initial moisture content difference between opposing facings is excessive (1).

CD moisture streaks within a roll of linerboard can cause "S" warp and bond variation across the machine. MD moisture variations can lead to warp and lineal bonding differences.

Extremely dry edges can cause edge curl, loose bonding at the edges, and increased web breaks as a result of tension differentials at the edges.

5. Paper mill control. For at least 20 years, scanning moisture measuring devices have been used on paperboard machines. In recent years, there have been tremendous advancements in the accuracy and complexity of these systems, with the more modern units under complete computer control providing continuous feedback of data on moisture and basis weight.

These data are used to automatically adjust CD and MD profiles. There has been a corresponding increase in the development of equipment to improve CD moisture profiles. These improvements have included computer-controlled headbox slice adjustment, segmented steam showers, supplementary heaters, and rewetting showers at the dry end of the machine. All of these improvements have contributed to substantial improvements in moisture uniformity. However, since moisture is such an important linerboard property for good corrugating operation, continued improvements are desirable.

Another priority is for data from various scanner installations to be comparable (2).

B. Internal bond strength

1. Definition. Internal bond is a measure of tensile strength of linerboard perpendicular to the plane—i.e., in the *z* direction.

2. Test methods. Internal bond strength can be measured using several different methods. These include "ZDT" (or *z*-direction tensile), which is covered by TAPPI test method T 541, the Scott bond test (T 403), and the Mullen ply bond test (T 522). The Scott bond test is used to measure internal resistance to failure in foot-pounds. Wax pick and fuzz tests are also used to indicate internal bond quality.

3. Influence. The major effects of weak internal bond strength for corrugated products are generally observed at the time the product is used rather than during the combining or converting operations.

4. Potential problems. Low internal bond strength contributes to weakness at the manufacturer's glued joints or at other points where two corrugated board surfaces are glued together. Such joints may fail due to stresses applied during setup, packing, or handling by the product user when one of the facings separates internally at a weak point.

Low internal bond strength may also contribute to peeling or "roll-ups" under friction forces applied to the surface as the board moves through the double-facer on the corrugator, is fed from the bottom of stacks into converting equipment, or is pulled from stack-type compression sections into counter-ejector mechanisms.

5. Paper mill control. Maintaining internal bond strength assists in maintaining burst strength and compression strength.

Sizing

1. Definition. Sizing is a characteristic pertaining to the sheet's ability to resist water penetration and absorption.

2. Test methods. A Cobb test (T 441) and the Hercules size test (T 530) can be used to quantify the degree of sizing. There are various in-house tests that are used as well. These normally depend on the rate of penetration or the quantity of liquid water absorbed by the sheet under standard testing conditions.

3. Influence. Most of the combining, joint-making, and sealing adhesives employed in the manufacture and use of corrugated products are water-based. Thus, the rate at which linerboard will absorb water can affect the quality of corrugator bonding, manufacturer's joints, and the glueability of boxes on packaging lines. Sizing may also affect the printability of linerboards with water-based flexographic inks. While adhesive and ink formulations can be modified to suit either high, moderate, or low levels of substrate sizing, problems generally arise when the range of linerboards used varies widely in sizing characteristics.

4. Potential problems. Linerboards that are slack-sized (very bibulous, or prone to absorb water) on the wire side (bottom) may dewater corrugating adhesives before the gel temperature is reached, leaving insufficient water to swell the starch granules, resulting in a weak, "chalky" bond.

Linerboards that are hard-sized (not bibulous) on the wire side may inhibit penetration of the adhesive into the fiber structure, resulting in a poor bond with little fiber pull.

Weak glue-lap or case-seal bonds that pop open readily can occur when linerboard felt-side surfaces absorb adhesive rapidly, leaving little glue available to form a bond with the surface brought in contact with the one to which the glue has been applied. Linerboards with hard-sized top surfaces can influence the speed with which glued manufacturer's joints and glued or gummed tape case seals can be made.

Printing of the same water-based flexographic ink on surfaces of widely differing absorbencies can result in color variation. Considerably greater amount of ink will be required on the more absorbent surface to achieve the same color density. Less absorbent surfaces may require machine speed reductions to avoid smearing or tracking of the ink.

5. Paper mill control. The stability of variables that impact water absorption generally promote drainage and drying, reduce the variation in finished product physical properties, improve runnability, and increase production rates. Variables that need to be controlled to maintain proper sizing include pulp cleanliness, pH control, and size addition.

Coefficient of friction

1. Definition. The coefficient of friction is the resistance to movement of one sheet of linerboard when placed against another sheet of the same specimen.

2. Test methods. Test methods include TAPPI T 815, which measures slide angle, and T 816, which measures the static coefficient of friction.

3. Influence. How slippery the linerboard surfaces are can be critical to the efficiency and safety of corrugating and product-use operations from roll handling through the handling of packed containers. Most of the problems arise with linerboards that are too slippery, but those with too high resistance to slip can also create difficulties.

4. Potential problems. Low slide angle, or low coefficient of friction, can cause problems in the handling of roll stock with clamp trucks. Extremely slippery surfaces can lead to telescoping of rolls when they are picked up with the core axis vertical during the unloading

of cars, transfer to roll storage, or delivery to the corrugator. Slippery board can also lead to instability of stacks of combined board, boxes during movement through the converting plant, or both. Product users also experience problems with the stability of unrestrained units of filled containers during handling and transport. In addition to potential waste due to damaged roll stock, combined board, and customer product, these conditions may represent a potential safety hazard to personnel.

High slide angle, or high coefficient of friction, can cause excess drag on the corrugator double-facer as the board moves over the hot plates. High friction also can lead to feed problems on machines that are kicker fed from the bottom of piles. Excess drag can exceed the resistance of the board edge to the force of the kicker, causing jam-ups. Surface peeling also may occur.

5. Paper mill control. Maintaining a consistent target for the coefficient of friction prevents slipping at the winder and the reel. It also reduces the tendency for rolls to telescope during handling and banding. It is therefore a desirable papermaking property. The use of secondary fiber in producing linerboard is one of the contributors to "slippery" liners, as a result of wax contamination.

Smoothness: (for preprint and more sophisticated graphics)

1. Definition. Smoothness is a measure of the uniformity and evenness of the linerboard top sheet.

2. Test methods. Smoothness can be measured using a Sheffield tester instrument using TAPPI Test Method T 538. It measures the air flow between the test specimen backed by a flat glass on the bottom side and pressurized concentric annular lands on the top side. The rate of air flow is related to sample smoothness and is usually dependent on grade.

3. Influence. The smoothness of linerboard surfaces may influence the ability of the corrugated converter to print the surface.

4. Potential problems. Rough linerboard surfaces may lead to printing definition problems and ink coverage problems. Increasing printing pressure to force ink into surface irregularities distorts rubber printing dies, affecting the precision of the image and causing ink squeeze-out. Excessive pressure also crushes the fluted structure of the combined board, reducing stacking strength.

5. Paper mill control. The smoothness of linerboard surfaces is a function of many papermaking variables, among which are furnish, refining, formation, wet pressing, and calendering. Papermakers must balance changes in these variables, directed at improving smoothness, against possible negative effects on important sheet strength properties and other surface characteristics such as the coefficient of friction, absorbency, and appearance.

Porosity

1. Definition. Porosity is the measure of how easily air can pass through a sheet of paper.

2. Test methods. Porosity can be measured using a Gurley tester (T 460) or Sheffield tester (T 524). Both measure resistance to air flow. The first measures the time needed to pass a given volume of air through the sample.

The second measures the rate at which air passes through the sample. Other devices such as the Bendtsen and Bekk instruments also can be used.

3. Influence. The porosity of linerboard affects the rate at which air, vapor, and (to some extent) liquids will pass through or will be absorbed into the substrate. Thus, porosity can have an effect on corrugator operations by affecting the rate at which moisture, in the form of water vapor, can be removed from the liners or how receptive the linerboards are to adhesive. It can also affect converting operations with respect to ink and glue absorption rates. In product use, porosity can affect vacuum-type box setup equipment and case sealing operations.

4. Potential problems. "Closed" linerboards (high Gurley numbers, low Sheffield numbers) create more difficulty in removing excess moisture on corrugator preheaters because the low porosity inhibits the movement of water vapor through the sheet. Low porosity may also inhibit liquid penetration into the surface, leading to bonding problems, particularly at the single-facer. The retardation of liquid ink penetration into low-porosity liners may lead to machine slowdowns to avoid smearing, and high hold-out of adhesive can increase compression time requirements on the gluing operations for both the converter and the product-user.

Highly porous linerboards (low Gurley numbers, high Sheffield numbers) can create (a) corrugator bonding problems through dewatering of the adhesive before gelation, (b) glueability problems through excessive absorption of glue before closure takes effect, and (c) variation from the color expected of a liquid ink or an increase in ink consumption to achieve that color. Very porous linerboards also have contributed to problems on product-user setup equipment employing vacuum cups to lift or square boxes. Excessive air flow through the facing inhibits the creation of sufficient suction.

5. Paper mill control. Producing a less permeable sheet by reducing freeness reduces drainage and therefore can reduce production. Porosity can be influenced by furnish mix (softwood vs. hardwood vs. recycled fiber content), degree of cooking, degree of refining, headbox consistency, sheet formation, and wet pressing.

Bursting strength (Mullen)

1. Definition. Bursting strength is a measure of the force required to break through a given area of combined board as pressure is applied to one side. Bursting strength is commonly referred to as Mullen.

2. Test methods. Bursting strength can be measured by TAPPI Test Method T 807.

3. Influence. The bursting strength of linerboard has no discernible direct effect on corrugated combining or converting operations.

4. Potential problems. Major bodies of packaging regulation, such as the Uniform Freight Classification, specify minimum bursting strength as one of the criteria for various grades of combined board. The bursting strength of combined board is a direct function of the component linerboard strengths. Thus, facings with Mullen tests below specified minimums may result in combined board that fails to meet grade requirements. Excessive loading of the pressure roll at the single-facer

during the combining operation also may reduce combined board bursting strength.

5. Paper mill control. Having a specified level of Mullen to target machine operation is useful in maintaining a uniform product for the customer. Because there are minimum levels required for various purposes, the papermaker is constrained at times by this variable in overall linerboard production. For a given basis weight or product grade, machine operations must be balanced to maximize this property in conjunction with other desirable properties such as internal bond strength and edgewise compression.

Adjustments to parameters such as formation and densification to achieve desired levels of edgewise compression can impact negatively on Mullen and other properties.

In recent years, there has been some debate among linerboard producers, converters, carriers, and product users as to whether Mullen should be retained as a criterion for linerboard production.

Compression

1. Definition. Compression correlates with the vertical stacking strength potential of the combined board.

2. Test methods. There are two commonly used methods for measuring compression resistance in containerboard. Ring crush, the older and more widely established method, is a measure of the force that is required to collapse a 6-in. ring of containerboard that is 1/2 in. high. Ring crush is normally measured so that the crushing occurs in the cross-machine direction. Ring crush can be measured by T 818 and T 822. The test result is normally expressed in pounds, which is effectively the pounds required to crush the strip.

In recent years, another test method called the "short span compression test," more commonly known as the "STFI test," has come into use. A narrow sample strip, normally cut so that the CD compression strength is measured, is clamped in two pairs of mechanical jaws aligned together and separated by a narrow gap. One pair of jaws mechanically advances toward the other pair until the specimen fails in compression. Multiple readings are taken, and the average is calculated. This average value, usually called the "STFI value," is closely related to the vertical stacking strength of combined board. The STFI values are measured by T 826.

3. Influence. Ring crush or STFI value has no recognized direct effect on corrugated combining or converting operations.

4. Potential problems. Failure to meet specified minimums of ring crush or STFI value on particular linerboard grades may result in boxes that will not meet stacking strength expectations.

5. Paper mill control. Achieving adequate compression strength is highly dependent on such variables as the formation of the paper, the rush-drag ratio, and the degree of refining and pressing.

Luminous reflectance and color

1. Definition. Luminous reflectance and color are measures of linerboard appearance. The brightness of a surface is the luminous reflectance of a single wavelength of light incident at a specified angle and is generally

associated with the whiteness or lightness of the board. Color is a multi-dimensional characteristic involving both lightness and chromaticity.

2. Test methods. Luminous reflectance or brightness may be measured by T 527. A color measure reference is T 524 (Hunter $L^*a^*b^*$).

3. Influence. The color and brightness of linerboards can have a major effect on the appearance of corrugated containers, particularly with respect to the ability to achieve or maintain the correctness of shade when printing with standard flexographic inks.

4. Potential problems. Variations in the color or brightness of linerboards from mill source to mill source, mill run to mill run, or within a mill run from a single source can cause undesirable differences in the appearance of boxes supplied to a customer. Differences in the color or brightness of a linerboard from that of the material on which standard inks are matched also can lead to difficulties in matching the customer's color or shade with standard Glass Packaging Institute inks. Extremely low reflectance can adversely affect the ability to print barcodes in conformance with standards established by the ANSI or other bodies.

5. Paper mill control. To achieve a stable product, uniform operating conditions must prevail not only in the paper mill, but all the way back in the process through the pulp mill. Achieving this stability has little operational effect beyond the need for uniformly balanced production.

J. Caliper

1. Definition. Caliper is a measure of the thickness of a sheet of linerboard.

2. Test methods. Thickness is measured according to T 411.

3. Influence. The thickness of linerboard, if uniform, has no significant effect on the combining or converting operations in a box plant except with board of very low caliper. An example would be abnormally thin 26 lb, or lighter, liners for which the pressure roll stops would have to be reset. However, variations in thickness, particularly in the cross direction, can have a decided influence on the corrugator operation.

4. Potential problems. Uneven linerboard caliper can lead to poorly wound roll stock and varying hardness across the roll. This can cause web tension differentials as rolls unwind and can contribute to warp.

5. Paper mill control. The caliper reflects the uniformity of the product, both across the machine and in the machine direction. Absolute caliper relates to refining, basis weight control, wet pressing, and smoothness and tends to be specific to the machine and furnish. If CD caliper profiles are not uniform, the caliper variations can have an effect on the ability to build a good reel, which, in turn, will adversely affect the quality of the finished rolls of paper and ultimately the converter when combining board into a finished product.

A papermaker's ability to achieve a caliper value can relate to the basis weight control, the pressing-dewatering balance throughout the machine, and the calendering. When using breaker stacks and calenders to improve surface smoothness, caliper is generally reduced.

K. Basis weight

1. Definition. Basis weight is a measure of the weight per unit area. For linerboard, it is generally expressed as pounds per thousand square feet or grams per square meter at a specified moisture level. The industry has generally shifted from purchasing linerboard on a weight basis to purchasing on an area basis.

2. Test methods. On-line machine gauges are normally used to control basis weight. Basis weight for individual rolls can be calculated from the roll weight and area if the moisture content is known. TAPPI T 410 is the reference test method.

3. Influence. Nonuniformity of basis weight can cause problems principally through the effects the variation induces in other properties such as moisture content, porosity, and roll stock quality.

4. Potential problems. Nonuniform basis weight that leads to variations in moisture content or porosity and which affects the winding qualities of the roll stock can cause a number of problems. Linerboard basis weights that differ from the nominal grade requirements may directly affect those users who utilize container tare weight in determining net content weights when packing their products.

5. Paper mill control. Maintaining a uniform target basis weight will benefit the customer as well as the manufacturer. Uniformity in both the cross direction and the machine direction will help ensure well built reels, which will translate into well built rolls for the customer. The more uniform the small-scale and large-scale basis weight profiles, the easier it will be to maintain uniform moisture and other properties. Nearly all test properties are to some extent dependent on the basis weight of the board.

Section 2: Corrugating medium

A. Water absorption

1. Definition. Water absorption is the rate at which water is absorbed by corrugating medium.

2. Test methods. The float and water drop tests, as described in T 819, are test methods. "Water Absorbency of Bibulous Papers" (T 432) and "Water Absorption of Paperboard" (T 596) are also referenced but are not recommended.

Note: Almost all corrugating mediums, when first manufactured, start out being very absorbent. During aging in the presence of oxygen, however, a self sizing can occur, starting with the exposed wraps and working gradually inward as oxygen very slowly penetrates and is absorbed by one layer after the other. This makes it likely that the outside wraps (as well as those nearest the core) will be more resistant to water, or, in other words, less absorbent. Since the bulk of a medium roll is corrugated with little exposure to the atmosphere as the roll unwinds, it is recommended that water absorption testing be performed at the corrugator, as quickly as possible, on medium samples taken at least 3 in. deep into the roll and away from the core and at least the same distance away from either edge.

3. Influence. Absorptivity influences the ability of corrugating medium to accept water, from either the steam showers or the corrugating adhesive.

4. Potential problems. Extremely high absorptivity (low numerical test value) can cause poor bonding due to excess absorption of water from the adhesive into the medium before the gel temperature is reached, leaving insufficient water to swell starch granules completely. High adhesive consumption results from attempts to compensate, leading to warp, blisters, soft board, etc.

Extremely low absorptivity (high numerical test values) can cause poor bonding due to lack of penetration into the substrate. Low absorptivity can also inhibit penetration of shower steam, causing potential problems with proper flute formation (high-low).

Converters can obtain good bonding and flute formation on mediums of either high or low absorptivity by tailoring adhesive properties or shower steam quality and volume to those conditions, as long as the medium is fairly consistent. Wide variations in absorptivity within a roll, or from roll to roll, cannot be tolerated, however, because adhesive properties for a given batch are fixed and operators may not become aware of problems soon enough to take appropriate corrective action before a quantity of rejectable board is run.

5. Paper mill control. The rate at which corrugating medium absorbs water can be a difficult property for mills to control because of the self-sizing property already described. The severity of this self-sizing depends mainly on the type of pulping process used, the type of furnish, and the degree of washing and cleaning. In 1982, an Institute of Paper Science and Technology (IPST) study was completed on the self-sizing characteristics of the four major pulping processes for medium (3). This study indicated that green liquor mediums showed the highest rates of self sizing, followed in decreasing order by neutral sulfite, alkali carbonate, and finally recycled fiber.

An anionic chemical surfactant is a typical wetting agent used to increase the medium's water absorptivity. These products are usually added at a rate of between 1 and 5 lb/ton of fiber, depending on the severity of the self-sizing problem or the customer's specifications. These wetting agents can increase the water absorptivity and reduce the degree of self sizing but can not eliminate self sizing altogether.

Personnel in each mill have to study their own absorption rates and their degree of self-sizing. They must make a compromise decision between starting with a water absorption rate so low that newly made corrugating medium rolls cause starch dewatering problems and starting with one so high that older rolls absorb too little water. This compromise is made even more difficult by the tendency for very absorbent mediums to self-size hardly at all, while highly sized corrugating mediums become even more sized with age. In other words, the higher the initial size, the greater the potential for extreme self-sizing, which makes a mid-range target hard to hit and maintain.

Corrugating plants can do something about this problem by turning over their corrugating medium roll stocks as quickly as practical. One well-run corrugating plant, after monitoring self-sizing very closely, decided to make a real effort to use all corrugating medium rolls before the rolls became three months old.

Porosity

1. Definition. Porosity is the measure of how easily air can pass through a sheet of paper.

2. Test methods. The Gurley Densometer is one of several test instruments that can be used. TAPPI T 460 is the applicable test method when the Gurley instrument is used. Other instruments are Sheffield, Bendtsen, and Bekk.

3. Influence. Even though porosity is a measure of air resistance of corrugating medium, its influence is similar to that of water absorptivity. That is, porosity influences the ability of medium to accept moisture from either steam showers or corrugating adhesive.

4. Potential problems. Extremely high porosity (low numerical test values) indicates an open sheet that can allow too rapid penetration of water from adhesive before starch reaches the gel temperature, resulting in insufficient water to completely swell starch granules. High adhesive consumption results as operators try to compensate for this problem.

Extremely low porosity (high numerical test values) indicates a closed sheet that can inhibit penetration, resulting in a weak bond. Low porosity can also affect the runnability of corrugating medium. This low porosity makes it difficult for moisture vapor to penetrate, inhibiting the softening of the medium, which is necessary to provide and maintain good flute formation.

5. Paper mill control. Porosity does not usually vary much on any one corrugating medium machine. However, there can be large variations in this property from one machine to another, even within the same mill system. Some of the newer twin-wire machines produce a sheet with such uniform formation that porosity has to be closely monitored and steps have to be taken at times to disrupt the formation somewhat in order to keep the sheet from getting too closed or the Gurley porosity from becoming too high. Recycled sheets also tend to have higher than normal Gurley porosities, particularly those with a high content of OCC (old corrugated containers).

The furnish, the cook, the degree of refining, the consistency at the headbox, and the type of pressing all can affect porosity as well but not to the same degree as the factors described previously. Fortunately, unlike water absorption, this property will not change much with age and is therefore easier to control. However, there are usually some machine limitations, in that a machine with a tendency for high porosities cannot make a low-porosity grade, or vice-versa.

Moisture content

1. Definition. Moisture content is the amount of water in paper, expressed as a percent moisture content, and it refers to both the overall average moisture content of a roll of corrugating medium and to MD and CD variation.

2. Test methods. Various hand-held instruments are available to measure conductivity capacitance, which is related to the moisture content of paper. These instruments must be specifically calibrated to yield accurate moisture readings. A test method used is the "oven dry" method described in TAPPI T 412.

3. Influence. The moisture content of medium directly affects its ability to achieve good flute formation and to accept additional moisture either from the steam showers

or from the corrugating adhesive.

4. Potential problems. Dry corrugating medium does not allow penetration readily, leading to poor bonding, particularly at the single-facer, which leads to low production speeds, excessive application of adhesive, or both. It is also more difficult to precondition to the point where the medium will form easily at desired speeds, leading to high-low flutes and fracturing.

Wet medium can absorb water from adhesive too readily, leading to excessive adhesive consumption, which will result in warp, blisters, and soft board. Very wet medium can cause flank fracturing in the corrugating process.

Converters can adjust operating parameters to run satisfactorily with mediums at either end of a fairly wide moisture range, as long as the mediums are consistent. Variation in moisture within a roll or from roll to roll creates waste before adjustments can be made. CD moisture variation can also cause warp, particularly with board combinations using lightweight facings and on thinner cross-section boards (B & E Flutes).

5. Paper mill control. For at least twenty years, scanning moisture profiles have been used on paperboard machines. However, in the last five years, we have witnessed a tremendous advance in the accuracy and complexity of these systems. The more modern units are now completely controlled by computer, and they continually feed back their scanning data on moisture and basis weight to various production units on the machine, which then automatically use these data to make both CD and MD profile adjustments. There has also been a corresponding increase in the development of equipment to help improve the CD moisture profile, such as headboxes with computer-controlled slice adjustments, segmented vacuum chests capable of increasing or reducing the drainage across very narrow segments of the wire section, and segmented heaters and rewetting showers at the dry end.

All of these have contributed greatly to the substantial improvement in the moisture uniformity of most commercial corrugating mediums. However, since moisture is such an important property for good corrugating, more work still needs to be done. Work should be continued on increasing the reliability of these complicated, interconnected computer systems and on improving the accuracy of the backup systems when they are down.

Another priority should be for the manufacturers of the various scanning profilers and their customers to come to a mutually acceptable agreement on what the individual sample size should be for both width and lineal footage. As it is today, with all the variations in machine speed, scanner speeds, widths of scanner boxes, and machine widths, it is next to impossible to compare the moisture variations of one machine with another. As it is now, one machine with a 2-sigma moisture variation of 0.95 may really have worse moisture variation than another with a 2-sigma of 1.75, because of huge differences in unit sample size. Until we can accurately compare one machine to another, we will never be able to really communicate on moisture variations that are acceptable.

Flat crush of corrugating medium (Concora)

1. Definition. "Concora" flat crush refers to the crushing resistance of a laboratory-fluted strip of corrugating medium.

2. Test methods. The "Concora" flat crush test is described in TAPPI T 809.

3. Influence. Rigidity of the fluted structure is one of the key characteristics of corrugated board. The Concora test provides a laboratory procedure to predict the flat crush resistance of combined board from the Concora value obtained in the laboratory on the corrugating medium.

4. Potential problems. Mediums of very low "Concora" values result in combined board with resistance to crushing of the fluted structure below that necessary to avoid deterioration from the effects of rider rolls, feed rolls, pull rolls, and other downstream processing forces, even if those nip point forces are carefully controlled. Mediums of very high Concora values may cause flute formation problems or score cracking problems on downstream equipment.

5. Paper mill control. The importance of this property has diminished somewhat over the last decade, possibly due in part to the published results of a number of studies which indicated that Concora strengths over a certain value were not really very beneficial and in fact could be detrimental. Its loss in importance also seems to correspond with an increase in the importance of CD ring crush or STFI value, both of which are not always completely compatible with Concora because of differences in the fiber orientation in these tests.

On the paper machine, Concora is usually improved by an increase in cutting-type refining, a reduction in headbox consistency (the proportion of fiber to water in the headbox) and higher wet pressing. Concora can be reduced by dry calendering, high moisture, and anything else that reduces fiber-to-fiber bonding (z -direction tensile strength). Unfortunately, one of the major methods for improving Concora—increased cutting (a type of refining)—has a negative effect on properties such as tensile, stretch, and porosity. Therefore, as is often the case in paperboard manufacturing, a compromise has to be reached.

Tensile strength

1. Definition. Tensile strength is the strength of paper under tension.

2. Test methods. A test method is described in TAPPI T 494.

3. Influence. Tensile strength affects the ability of corrugating medium to withstand the stresses of flute formation and resist tearing and breaking from acceleration and tension forces as the medium web follows its path from the roll, through the splicers, and around the various idler rolls.

4. Potential problems. Extremely low MD tensile strength can lead to web breaks under normal tension stresses applied through splicer activation, by roll stand braking systems, and by acceleration forces resulting from single-facer speed changes. Low MD tensile strength can cause medium to completely break more easily as small edge tears pass around various idler rolls. Web breaks increase waste, lost time, and quality problems associated with intermittent corrugator operation (warp,

misalignment, etc.).

Recent work by the Institute of Paper Science and Technology indicates that low MD tensile strength can lead to high-low flute formation and fractured flutes.

5. Paper mill control. In most chemical pulp mills producing corrugating medium, personnel have found that they need to add some long fiber to their pulp to attain the required amount of tensile strength. This can be in the form of virgin kraft fiber if the pulp mill happens to be conveniently close to a kraft linerboard mill or in the form of recycled long fiber if the mill is a standalone operation. Naturally, a recycled medium producer does not really have to worry about this property because of its large percentage of long fiber.

Tensile can be increased on the machine by an increase in hydration refining, another type of refining in which the fibers are mostly brushed and unravelled as opposed to cutting. Increased wet pressing will also help the tensile strength because it increases the degree of fiber-to-fiber bonding strength.

Stretch

1. Definition. Stretch is the maximum tensile strain developed in a test specimen before rupture.

2. Test methods. The TAPPI method for tensile strength, T 494, is also used for stretch.

3. Influence. Stretch influences the flute formation characteristics of medium.

4. Potential problems. Recent Institute of Paper Science and Technology work indicates that high stretch values favor a decreased presence of high-low flutes and higher running speeds before flute fracturing.

5. Paper mill control. The degree of tensile stretch has taken on increased importance because of the recently published IPST study indicating that higher MD stretch values decrease the tendency for high-low flutes on conventional finger-type single-facers (4).

Stretch is usually increased by the same factors that aid tensile strength, such as long fiber and hydration refining. However, it can also be increased by reduced machine draw tensions and by applying a small amount of wax or lubricant to the sheet.

Hot coefficient of friction

1. Definition. The coefficient of friction is the ratio of the frictional force resisting movement of the surface being tested to the force applied normal to that surface. The test is performed at elevated temperatures in the range of 360–370°F.

2. Test methods. No test method is presently available for reference. A TAPPI provisional method is being balloted.

3. Influence. The hot coefficient of friction has an influence on flute formation (high-lows and flute fracture).

4. Potential problems. Lower hot friction values have a beneficial effect on runnability.

5. Paper mill control. There is a recently developed test that has taken on importance because of the IPST work (4). That study also showed that low values for hot coefficient of friction aid in the reduction of high-low flutes on conventional finger-type single-facers.

Hot coefficient of friction is such a new test that there is not a great deal known about the various properties that

affect it. However, recycled OCC (old corrugated containers), added as part of the furnish, lowers this property. The same effect is not usually noticed with recycled double kraft-lined clippings. It is assumed that this is due to waxes and other contaminants in the OCC that act as lubricants. More and more corrugating medium mills are spraying the web with a lubricant, and at least one is applying wax using the wax bar technique that a number of corrugators have used for years to reduce friction on both linerboards and corrugating mediums.

Soft caliper

1. Definition. Soft caliper is a test developed by the Institute of Paper Science and Technology as a measure of the true thickness of the medium.

2. Test methods. This test is too new as yet to be made into an official TAPPI method. However, it is similar to regular caliper test, T 411, with the exception that the measuring anvils are both covered with a soft rubber cushion that can be deformed by the abnormal peaks in thickness caused by roughness. In this way, the cushion cancels out their effect, giving a much truer value for the actual effective thickness of the sample.

3. Influence. The true effective thickness or caliper influences such factors as the forming of the medium between the corrugating rolls and its response to various nip clearances such as corrugating roll flank and tip clearances, the clearance between the glue roll and the corrugating roll, and finger clearance. On rough mediums, soft caliper can be over 40% lower than regular caliper, while on much smoother mediums it can be only 17% lower. Therefore, errors in measuring the true or effective caliper can arise if only regular caliper measurements are used.

4. Potential problems. Mediums with low effective calipers (soft caliper) tend to form and retain their flute profiles with much less stress, which can result in fewer high-lows and fractures, particularly at the higher running speeds. On the other hand, mediums with higher soft caliper may run into fewer problems than might be expected, because of the tendency to set the normal roll clearances of the single-facers at one high setting to avoid the necessity to change this setting for mediums of heavier weight.

Again, good runnability and good bonding can be obtained with the complete range of calipers available if the corrugator and adhesive are adjusted for this given level. The problem arises when there are excessive variations either roll to roll from the same supplier or, what is much more frequent, among several suppliers whose media are different in soft caliper.

5. Paper mill control. Like porosity, soft caliper will usually not vary much on a particular machine. However, the property can vary quite significantly from one machine to another, even within the same mill. Machines with some of the more modern high-intensity wet presses are producing mediums with low levels of soft caliper. Low soft calipers will also be found on machines which still dry calender their corrugating medium. Soft caliper can also be lowered somewhat through increased refining.

Caliper (traditional)

(This is traditional caliper, as opposed to the newly developed "soft caliper." Traditional caliper is measured

with standard hard anvil gauges.)

1. Definition. Caliper is a measure of the thickness of a sheet of corrugating medium.

2. Test methods. Thickness is measured according to TAPPI T 411.

3. Influence. If it is uniform, the thickness of medium has no significant direct effect on the combining or converting operations in a box plant. Variations in thickness, however, particularly in the cross-direction, can have an influence on the corrugator operation.

4. Potential problems. Uneven medium caliper can lead to poorly wound roll stock and to variations in hardness across the roll. This can cause web tension differentials as rolls unwind, which can lead to increased web breaks.

5. Paper mill control. The caliper of the board reflects the uniformity of the product both across the machine and in the machine direction. While an individual paper machine tends to have caliper that varies within a fairly narrow range, the caliper is not easily controlled on a paper machine. Caliper generally depends on the configuration of the paper machine, the furnish, and the paper machine operating characteristics. Variations in caliper will have a detrimental effect on the ability to build a good reel and thus on finished rolls of paper, and it will have an adverse effect when the converter attempts to combine linerboard and medium into a finished product.

A papermaker's ability to achieve a caliper value is related to the control of basis weight, the balance of pressing and dewatering throughout the machine, and calendering.

Formation

1. Definition. Formation is the measure of the uniformity of fiber distribution.

2. Test methods. There is no TAPPI test method for this property. However, there are a number of formation testers available, and special standard samples are used in some mills to visually compare and rate formation.

3. Influence. Formation, because it is actually a true measure of the uniformity of the medium, affects the degree of variation of almost all properties. This consideration alone would qualify formation as an important property. However, formation is gaining even more attention because of recent work at the Institute of Paper Science and Technology indicating that it may also be a factor both in high-low flute formation and in corrugator bonding.

4. Potential problems. The IPST study mentioned previously suggests that poor paper machine formation may contribute to the development of high-lows and flute fracture. Also, formation appears to correlate with maximum single-face bond speed, the highest speed that can be obtained before debonding occurs. The better the formation, the higher the maximum achievable bond speed (4).

5. Paper mill control. Some of the newer twin-wire machines result in excellent formation. Good formation is also achieved on regular fourdrinier machines with longer forming aprons or longer wire sections. Formation can also be improved by running with lower pulp consistencies or by more refining (especially refining by cutting). Uniform headbox flows also contribute a great deal to better

formation. Recycled mediums generally exhibit relatively poor formation, but poor formation can be found on some chemical pulp mediums as well.

Basis weight

1. Definition. Basis weight is a measure of the weight per unit area. For medium, basis weight is generally expressed as pounds per thousand square feet or grams per square meter at a specified moisture level. The industry has generally shifted from purchasing medium on a weight basis to purchasing on an area basis.

2. Test methods. On-line machine gauges are normally used. Basis weight for an individual roll can be calculated from roll weight and area only if the moisture content is known. TAPPI T 410 is the reference test method.

3. Influence. Nonuniformity of basis weight can cause problems, principally through the effects that the variation induces in properties such as moisture content, porosity, and roll stock quality.

4. Potential problems. A nonuniform basis weight that leads to variations in moisture content or porosity and which affects the winding qualities of the roll stock can cause a number of problems. Basis weight that differs from the nominal grade requirements may directly affect those users who utilize container tare weight in determining net content weights when packing their products.

5. Paper mill control. Maintaining a uniform targeted basis weight will benefit the customer and the manufacturer. Uniformity in both the cross direction and the machine direction will help ensure well built reels, which will translate into well built rolls for the customer. The more uniform the small-scale and large-scale basis weight profiles, the easier it will be to maintain uniform moisture and uniformity in other properties. Nearly all test properties are to some extent dependent on the basis weight of the board.

Compression

1. Definition. Compression is the resistance to a force operating on the edge of a strip of medium or on the cross section of a small segment of medium. This property correlates with the vertical stacking strength potential of combined board. Compression is normally measured so that the crushing occurs in the cross-machine direction.

2. Test methods. Three common test methods are used for measuring the compression resistance of medium:

1. Ring crush, T 818 and T 822. The force required to collapse a 6-in. ring of medium 1/2 in. high is measured.
2. Concora fluted crush test, T 824. A 1/2-in. by 6-in. strip is fluted in the Concora fluter. The fluted strip is placed in a fluted scissors fixture and is crushed.
3. Short span compression test (STFI), T 826. A narrow sample strip is clamped in two pairs of mechanical jaws aligned together and separated by a narrow gap. One pair mechanically advances toward the other until the compression failure point of the specimen is detected. Multiple readings are taken, and the average value is determined and reported as the "STFI" value.

3. Influence. Ring crush, CFC-O, or STFI has no recognized direct effect on corrugated combining or converting operations.

4. Potential problems. Failure to meet specified minimums of ring crush, CFC-O or STFI on particular medium grades may result in boxes that will not meet stacking strength expectations.

5. Paper mill control. Adequate compression strength is highly dependent on such variables as the formation of the paper, the rush-drag ratio, the degree of refining, and pressing. Papermaking techniques that may be used to improve compression may cause reductions in "Concora" flat crush, and caliper. Thus, achieving desired levels of compression can be in competition with other properties. □

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