INTERNATIONAL

Designation: ~~D5639/D5639M – 11 (Reapproved 2015)~~ D5639/D5639M – 20

Standard Practice for Selection of Corrugated Fiberboard Materials and Box Construction Based on Performance Requirements[1]

This standard is issued under the fixed designation D5639/D5639M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice provides information on corrugated fiberboard for the prospective user who wants guidance in selecting attributes of materials and box construction based on performance requirements. These attributes should be part of specifications which establish levels of the qualities a shipping container shall have achieved in order to be acceptable to the purchaser or user. The attributes and qualities should be testable, using standard methods that are recognized by both the buyer and seller. This practice will assist users in developing specifications for corrugated containers through an analysis of performance requirements and subsequent relationships to fiberboard materials and box construction attributes. This practice is ~~intended to provide specific corrugated container performance standards as opposed to packaged product performance evaluation through distribution and handling environments, such as Practice~~meant to complement the box buyer–box manufacturer relationship by having the buyer (user) better understand, discuss, and negotiate needed elements of box ~~D4169.~~design and specification. The full box design process is complex, and it is beyond the scope of this standard.

1.2 The attributes and their levels should be based on the intended use of the box, including the handling and environment it will encounter. Many packaging ~~regulations~~rules include detailed descriptions of the materials that may be used and style, closure, or other construction details of allowed shipping containers. These ~~regulations~~rules are presented as minimum requirements; they may be exceeded for functional reasons, but there is no regulatory reason to do so. Rail and motor freight classifications applicable for surface common carrier transportation have established minimum requirements for certain attributes of corrugated packaging. These may or may not be appropriate for application in the complete distribution system, as they encompass only containerboard or combined corrugated ~~board—not finished boxes—and~~ board — not finished boxes — and are not intended to provide for the distribution and storage system beyond the transportation segment.

1.2.1 The attribute levels contained herein are based on ~~US~~U.S. practice and specifications. Some attributes such as flute dimensions and basis weights may be defined differently in other countries.

1.3 There are ~~two distinctly different methods commonly~~ four common methods used for specifying boxes. ~~The most common approach is to specify materials, such as defining flute, edge crush value, Mullen burst value, and flat crush minimums, containerboard weights and thicknesses. An alternative approach is to define some measure of performance. Mullen burst values can be one of these measures if the user has determined that some minimum burst value is all that is required in their distribution system. The overall compression strength of the box is another, and this measure allows each supplier to achieve the required strength through their own unique combination of materials and processes. A third measure would be to pass some sort of rough handling performance protocol, with Practice D4169 being one example. Unlike material specifications, where definitions of fluting, test methods of ECT, and difficulty of assessing individual components of the box structure exist, compression values of~~

[1] This practice is under the jurisdiction of ASTM Committee D10 on Packaging and is the direct responsibility of Subcommittee D10.27 on ~~Paper and Paperboard Products~~Fiberboard Shipping Containers, Containerboard and Related Structures and Materials.

Current edition approved ~~Oct. 1, 2015~~Oct. 1, 2020. Published ~~October 2015~~December 2020. Originally approved in 1994. Last previous edition approved in ~~2011~~2015 as ~~D5639/D5639M – 11.~~D5639/D5639M – 11 (2015). DOI: ~~10.1520/D5639_D5639M-11R15.~~10.1520/D5639_D5639M-20.

~~the finished box are easily tested and verified using a common test method (Test Method D642). The same can be said of box performance measured against a performance protocol. Using only material specifications to define a box does not guarantee the box will be well made. For example, the best possible material could be used for making a box, but if the score lines are too deep or too shallow, or if the manufacturer's joint is not secured correctly, the box will fail in distribution.~~

~~Conversely, box compression and rough handling performance protocols measures both material and manufacturing quality simultaneously. It is sometimes advantageous to use a combination of both these methods to help assure the outer liner will not easily scuff or break. Though suppliers will need to continue to use material specifications when making boxes, the user would benefit more from employing performance specifications to help guarantee similar box attributes from a variety of suppliers. It should be realized that no two suppliers, especially if they're located in different countries, will use the same materials and processes for making a box. Employing box compression values or performance protocols will help assure the lowest price for specific performance, regardless of the material used.~~

1.3.1 A common approach is to examine boxes currently in use for the specific application and to make a similar or modified version of that box, given that it has a proven performance record. This method, while quite efficient, and fast, does not lead to box optimization based on characterization by end use. This method can lead to overdesign.

1.3.2 A second common approach is to estimate the compression strength necessary for a box at the bottom of a stack of boxes to totally support the anticipated load. A safety factor, F, is calculated from the expected environmental hazards that are anticipated in storage and shipping. A minimum initial box compression, as measured by Test Method D642 is determined using the weight on the bottom box and the F factor, see 8.3. Then engineering principles are used to select material combinations based on material characteristics such as caliper, edge crush value, and flat crush to meet that requirement.

1.3.3 The third approach may be used when the box application has product support sufficient to meet anticipated compression requirements, therefore the board structural requirements are focused on protection and containment. Mullen burst values can be one of these measures for this category of box if the user has determined that a minimum burst value is the main metric required in their distribution system. In this case, total weight per box allowable per carrier rules may be higher than would be expected based on expected predicted compression strength, safety factor, and board combination used. See 7.2 – 7.2.2.2 and 8.2.1.

1.3.4 The fourth approach may be used when the box is intended for single parcel shipment of high value or hazardous materials, where there can be a compression requirement but most often the performance attributes required are toughness as measured by drop and impact resistance, see 8.2. A means of gaining confidence that a box in this category will function properly in its intended distribution environment is to test the box using some sort of rough handling performance protocol such as Practice D4169 or ISTA 3 Series: General Simulation Performance Tests.

1.3.5 Using material specifications to define a box does not guarantee the box will be well made. For example, the best possible material could be used for making a box, but if the score lines are too deep or too shallow, or if the manufacturer's joint is not secured correctly, the box will fail in distribution. All proposed constructions and designs should be vetted by means of a process of samples, testing, prototype packing and shipping. Only once a construction has been proven to work across a range of anticipated end use conditions should it be approved for normal production.

1.4 Corrugated containers for packaging of hazardous materials for transportation shall comply with federal regulations administered by the U.S. Department of Transportation (Code of Federal Regulations, ~~CFR 49).~~Title 49).

1.5 *Lists and Descriptions of Performance and Material Characteristics and Related Test Procedures*—For further information on the development of performance-based specifications, please refer to the sections on Specifications and Test Procedures of the Fibre Box Handbook.

1.6 The values stated in both SI and inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate ~~safety~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D585 Practice for Sampling and Accepting a Single Lot of Paper, Paperboard, Fiberboard, and Related Product (Withdrawn 2010)[3]
D642 Test Method for Determining Compressive Resistance of Shipping Containers, Components, and Unit Loads
D685 Practice for Conditioning Paper and Paper Products for Testing
D996 Terminology of Packaging and Distribution Environments
D1968 Terminology Relating to Paper and Paper Products
D2658 Test Method for Determining Dimensions of Fiberboard Boxes
D4169 Practice for Performance Testing of Shipping Containers and Systems
D4727/D4727M Specification for Corrugated and Solid Fiberboard Sheet Stock (Container Grade) and Cut Shapes
D5118/D5118M Practice for Fabrication of Fiberboard Shipping Boxes
D5168 Practice for Fabrication and Closure of Triple-Wall Corrugated Fiberboard Containers
D5276 Test Method for Drop Test of Loaded Containers by Free Fall
D7386 Practice for Performance Testing of Packages for Single Parcel Delivery Systems
E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

2.2 *TAPPI Methods:*

T 411 Thickness of Paper, Paperboard, and Combined Board[4]
T 803 Puncture Test of Corrugated Fiberboard[4]
~~T 808~~T 809 Flat Crush Test of ~~Corrugated Fiberboard-Flexible Beam Method~~Corrugating Medium (CMT Test)[4]
T 810 Burst Test of Corrugated Fiberboard[4]
T 811 Edgewise Crush Test of Corrugated Fiberboard[4]
T 825 Flat Crush Test of Corrugated Fiberboard-Fixed Platen Method[4]
T 836 Bending Stiffness, Four Point Method[4]
T 839 Edgewise Compressive Strength of Corrugated Fiberboard Using the Clamp Method (Short Column Test)[4]

2.3 *Government Documents:*

CFR 49 Code of Federal Regulations, Title 49 §178.516 – Standards for Fiberboard Boxes[5]

2.4 ~~*Other Publications:*~~*Carrier Rules:*

~~Fibre Box Handbook[6]~~
~~Edge Crush Test, Application and Reference Guide for Combined Corrugated Board, Fibre Box Association[6]~~
National Motor Freight Classification ~~Item 222~~ Item 222[6]
Uniform Freight Classification ~~Rule 41~~ Rule 41[7]

2.5 *Other Publications:*

ISTA Testing Guidelines, Testing Procedures[8]
Fibre Box Handbook[9]

3. Terminology

3.1 *Definitions*—For general definitions of packaging and distribution environments, see Terminology D996. For paper and combined board related terms see Terminology D1968.

4. Significance and Use

4.1 This practice assists users in selecting appropriate performance characteristics of corrugated fiberboard or box construction, or both, commensurate with ~~the user's need~~their user's needs for packing and distribution of goods. This practice describes several

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the ~~standard's~~standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from Technical Association of the Pulp and Paper Industry (TAPPI), 15 Technology Parkway South, Norcross, GA 30092, http://www.tappi.org.

[5] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, http://www.access.gpo.gov.

~~[6] Available from the Fibre Box Association, 25 Northwest Point Blvd., Suite 510, Elk Grove Village, IL 60007.~~

[6] Available from the National Motor Freight Traffic Association (NMFTA), 1001 N Fairfax St, Suite 600, Alexandria, VA 22314-1748.

[7] Available from National Railroad Freight Committee, Tariff Publishing Officer, 151 Ellis Street, NE, Suite 200, Atlanta, GA 30335.

[8] Available from ISTA Distributing Confidence, Worldwide TM 1400 Abbott Road, Suite 160 East Lansing, MI 48823; www.ista.org

[9] Available from the Fibre Box Association, 500 Park Blvd, Suite 985, Itasca, IL 600143.

attributes of fiberboard and boxes which relate to various hazards encountered in distribution and describes test parameters which may be specified by the user to ensure sufficient strength in the box for containment, storage, handling, transport and protection of contents.

4.2 The user should specify only those attributes and related tests which are required for ~~satisfactory~~ performance ~~in the user's~~ to the users satisfaction including their operations and distribution cycle(s). When using ~~packaging regulations as a~~ the carriers' packaging rules as the major basis for developing specifications, the reason for the ~~existence of the regulation~~ rule and its function and importance should be understood. As previously stated, rules and regulations may be exceeded and should be when the minimum specifications are inadequate for the full effects of the distribution ~~cycle.~~ cycle, etc.. If the user decides to employ box compression strength or a rough handling performance protocol as the overriding specification, it should be noted that all minimum standards required by various organizations shall also be met or ~~surpassed.~~ surpassed if using the related certificate. These minimum standards can be stated in the box drawing so as to ensure adherence to ~~regulations~~ rules and regulations. If a Box Manufacturer's Certificate (BMC) is printed on the box, then the ECT or Mullen Burst/Basis Weight values shall meet or exceed the minimum requirements for size and weight of the packaged product.

4.3 See Appendix X7 for several examples of specification determinations.

5. Sampling

5.1 Selection of a sampling plan depends on the purpose of the testing. The sampling plan from Appendix X2.2.2 of Practice D585 is recommended for acceptance criteria. An example of acceptance and rejection criteria based on various lot sizes may be found in Appendix X1. For purposes of other than acceptance criteria, use Practice E122.

6. Conditioning

6.1 All test specimens shall be preconditioned, conditioned, and tested in accordance with Practice D685.

7. Fiberboard Attributes

NOTE 1—Corrugated fiberboard is commercially available in three wall constructions, and four common flute structures. The user should specify desired wall construction and flute structure based on performance requirements, though one should realize that definitions of flute size and shape vary from one manufacturer to another and from one country to another. As an example, if compression strength is the major specification criteria — paper weight, flute size, and wall construction selection are often based on price for performance factors. One manufacturer may use lighter weight and or lower strength containerboard to form multi wall corrugated board while another manufacturer may use heavier and or stronger containerboard to form single wall corrugated board. While both corrugated boards may meet strength requirements, it should be noted that they may not operate the same in subsequent conversion, erecting, filling, and handling operations.

7.1 *Flute Structures*—~~Corrugated fiberboard is commercially available in three wall constructions, and four common flute structures. The user should specify desired wall construction and flute structure based on performance requirements, though one should realize that definitions of flute size and shape vary from one manufacturer to another and from one country to another. In contrast, if compression strength is the specification, then paper weight, flute size, and wall construction are all based on price for performance, perhaps allowing one manufacturer to use thin weak paper to form double wall while another uses better quality paper and processes to use single wall.~~ Singlewall board is used for lighter contents where some structural rigidity, compression strength, resistance to puncture, and cushioning is needed. Doublewall board is used for heavier contents requiring a greater degree of structural rigidity, compression strength, and resistance to puncture. Triplewall is used for the heaviest contents where maximum structural rigidity, compression strength, and resistance to puncture are required.

7.1.1 Minimum basis weights for facings for mullen and puncture grades are spelled out in carrier rules. Facing basis weights for ECT grades are not specified in the shipping regulations and may vary between suppliers and at times from a single supplier. While facing weight is not specified by rule at a particular level for ECT grades, it is not good practice for the facing weights or flute structure to vary from run to run for any specified construction, mullen or ECT focused. Variation in weight can affect box tare weight, height of loads of unused boxes and fit of filled boxes in stacked loads. The basis weight selected for the initial design should be specified and used repeatedly in future orders unless the specifications are changed.

NOTE 2—Once a board combination is agreed upon between the box supplier and their customer, it is suggested that the contract shows that the board composition shall not be changed for subsequent orders without consultation with the box customer. If changes to the board composition are proposed, new performance testing procedures may be required.

7.1.2 ~~*Construction*—Singlewall board is used for lighter contents where some structural rigidity, compression strength, resistance~~

~~to puncture, and cushioning is needed. Doublewall board is used for heavier contents requiring a greater degree of structural rigidity, compression strength, and resistance to puncture. Triplewall is used~~ Combined board caliper for a given board combination should not vary by more than a range of 3–4 mils from run to run. Consistency in thickness is necessary to ensure efficient mechanical erection, filling and sealing. Further, lower than expected caliper is often indicative of crushed flutes and reduced panel stiffness which adversely affect box performance, see 7.5 and 7.7~~for the heaviest contents where maximum structural rigidity, compression strength, and resistance to puncture are required.~~. The expected caliper selected for the initial design should be specified and used repeatedly in future orders unless the specifications are changed.

7.1.3 *Flute* ~~*Structure—*~~*Types—A*-flute offers the highest top-to-bottom compression strength, but low resistance to flat crush. *B*-flute has high flat crush resistance but lower top-to-bottom compression than *A* or *C*.*B*-flute is the most common flute type used in Europe. *C*-flute is by far the most common flute type used in the United States with average resistance to flat crush and top-to-bottom compression. *E*-flute generally replaces solid boxboard, has excellent flat crush resistance, is used mostly for graphics and consumer products, but seldom used for corrugated transport shipping containers. It should be noted that the Fibre Box Association (FBA) no longer attempts to define flutes precisely due to the large range of profiles and heights being made around the world. The current version of the Fibre Box Handbook, ~~(2005),~~2015, states the following (paraphrased): *A*-flute has about 33 flutes/ft, *B*-flute has about 47 flutes/ft, *C*-flute has about ~~39~~38 flutes/ft, and *E*-flute has about 90 ~~flutes/ft."~~flutes/ft. Please note the following table from Specification D4727/D4727M~~–07 provides only~~ – 17 provides an approximate range of values:

	Flutes/ft	Flutes/m	Flute Height [in.]	Flute Height [mm]
A-Flute	30 to 39	98 to 128	0.1575 to 0.2210	4.00 to 5.61
B-Flute	45 to 53	147 to 174	0.0787 to 0.1102	2.00 to 2.80
C-Flute	35 to 45	115 to 148	0.1300 to 0.1575	3.30 to 4.00
E-Flute	70 to 98	229 to 321	0.0445 to 0.0550	1.13 to 1.40

7.2 *Burst Strength—*~~This attribute relates to the tensile strength and stretch elongation of the fiberboard. It also provides rupture strength as protection against rough handling.~~The burst attribute is commonly related to corrugated board toughness, tear and resistance to puncture, rough handling of boxes. Boxes without adequate toughness can display score cracking and flap breakage.

7.2.1 Burst strength is measured by the burst (Mullen) test utilizing TAPPI Method T 810 and is specified in the carrier ~~regulations~~rules for the various grades of singlewall and doublewall combined board.

7.2.2 There is no direct relationship, such as a formula, to relate box handling performance to needed burst strength. However, as a function of box size and weight of the filled package, minimum burst strength requirements for corrugated packaging used in surface common carrier transportation in the United States are published in the rail and truck classifications and are shown in Table X2.1. The burst values shown in Table X2.1 are the minimum values not the expected average burst values for the grades. For example a nominal 200 lb/in.^{2} burst specification is expected to average 220–240 lb/in.^{2}. These requirements may or may not be appropriate for the ~~user's~~user's applications.

7.2.2.1 The weight limits shown in Table X2.1 are for individual packages. The calculated safety factor, F (see 1.3.1 and 8.3.3) for boxes with these construction, product weights and box dimensions are in the range of 1–2. These weight limits may be reasonable for boxes which have product support for compression resistance.

7.2.2.2 The weight limits shown in Table X2.1 are too high for corrugated fiberboard boxes that must support the entire load in stacked storage and shipping applications. The weight limits provided in the freight rules table do not apply to how much load the boxes can support over time. For boxes providing the total compression resistance, box designers must use calculations (see 7.4 and 8.3.3) to determine suitable board construction, ECT, and box size for a given product weight.

7.3 *Resistance to Puncture—*This attribute relates to the ability of the fiberboard to resist both internal and external forces. It also relates to the rough handling integrity of the finished container.

7.3.1 Resistance to puncture is measured by the puncture test utilizing TAPPI Method T 803 and is specified in the carrier ~~regulations~~rules only for the various grades of triplewall (TW) combined board.

7.3.2 There is no direct relationship, such as a formula, to predict rough handling performance of a box based on the puncture resistance of the fiberboard from which it is made. Shippers and carriers, however, have used various puncture grades successfully for years as noted in Appendix X3. Table X3.1 lists suggested puncture strengths versus maximum gross weights and size. These requirements may or may not be appropriate for ~~the user's application.~~ all user's applications. It is important to note that as the basis weight of the facing increases to obtain higher puncture resistance, ECT increases. As ECT increases, BCT increases.

Therefore as puncture is a function of basis weight, BCT is also a function of ECT and basis weight. The ECT values for triplewall boxes shown in the carrier rules have never been verified. For TW applications, the buyer should contact the supplier to obtain the appropriate minimum and average ECT values for the grade being specified.

NOTE 3—The 1100 TW grade for military applications is a special case that has a performance history. It has a minimum ECT value of 155 lb/in.

7.4 *Edgewise Crush Resistance (ECT)*—This attribute of corrugated fiberboard boxes relates directly to the finished box compression strength (for RSC boxes, see 8.1) through the ~~well-known simplified~~ a formula published in ~~1963~~ the August 1963 issue of Paperboard Packaging by the Institute of Paper Chemistry (now the ~~Institute of Paper Science and Technology, or IPST) and~~Renewable Bioproducts Institute.) part of Georgia Tech. It is commonly known as the McKee Formula. ~~Another widely used~~ Another, simplified, version of the McKee ~~Formula, known as the modified version,~~ Formula was developed by George Maltenfort, and it too was published in the August 1963 issue of Paperboard Packaging. The simplified version utilizes the exponent values of box perimeter and board thickness instead of the square root function, and the resultant box compression will be about 5 % less compared to the simplified square root method. The modified version is included in commercial software programs for use by transport packaging designers.

NOTE 4—Compression values for other box designs, see 8.1, are often estimated by ratio of RSC compression values to compression values of the specific design under consideration. The buyer should contact the supplier for details on expected BCT of the selected design.

7.4.1 The simplified McKee Formula is:

$$BCT = (5.87) \times (ECT) \times \sqrt{(BP) \times (T)} \tag{1}$$

where:

BCT = estimated average top to bottom compression test strength of an RSC box, kN [lbf],
ECT = edge crush test, kN/m [lb/in.],
BP = inside box perimeter (sum of twice inside length and twice inside width), m [in.], and
T = combined board thickness (caliper), m [in.].

When solving for ECT using this formula, rearrange as follows:

$$\text{Estimated average } ECT = \frac{\text{Required BCT}}{5.87 \times \sqrt{BP \times T}} \tag{2}$$

See Appendix X4 for example and limitations of formula use.

7.4.2 The exponent version of the McKee formula is:

$$BCT = 5.87 \times ECT \times T^{0.508} \times BP^{0.492} \tag{3}$$

where the terms are the same as for the simplified version. See ~~Appendix~~ Appendix X4 for an example of this formula in practice. The normal range of box compression values at standard conditions as a function of ECT is shown by wall type in the following table:

Singlewall	2225–6675 N [500–1500 lb] (at perimeter 1.422–2.235 m [56–88 in.]) – fits a 1.220 × 1.015 m [48 × 40 in.] pallet
Doublewall	6675–13 345 N [1500–3000 lb] (at perimeter 1.422–2.235 m [56–88 in.]) – fits a 1.220 × 1.015 m [48 × 40 in.] pallet
Triplewall	15 570–33 360 N [3500–7500 lb] (at perimeter 4.267 m [168 in.]) – fits a 1.220 × 1.015 m [48 × 40 in.] pallet

7.4.3 Edgewise crush resistance is measured by the edgewise crush test (ECT) utilizing TAPPI Method ~~T 811.~~T 811 or T 839.

NOTE 5—These two tests yield slightly different test values; however, for the purposes of this document either can be used to generate a rough estimate of box compression strength. The difference between the two results is not important.

7.4.4 Although, as shown in 7.4.1, ECT directly relates to finished box compression strength, the rail and truck classifications have minimum ECT requirements as an ~~alternate to~~ option other than minimum Burst Strength/Basis Weight requirements as shown in Table X4.1. ~~These requirements may or may not be appropriate for the user's application.~~

7.4.4.1 Please note that the tables show that ECT and mullen grades can be used to address the same package weights and sizes.

NOTE 6—This does not mean to imply that Burst and ECT are interchangeable, or that a relationship exists to convert from one to the other. Burst may be more important for rough handling while ECT may be more important for stacking.

7.4.4.2 Both ECT and mullen grades have compression strength aspects and burst aspects. The key difference is between the two grade types is that mullen grades are not made with a focus on ECT strength and ECT grades while having a focus on ECT strength do not require the use of the same combined facing weight as is specified for mullen grades for similar box sizes and product weights. The net outcome is that the two grade types are roughly equivalent in general performance, but the ECT grades are more likely to be uniform and optimized in the compression aspect of performance and in cost while the mullen grades are likely to perform better in rough handling situations.

7.4.4.3 These requirements may or may not be appropriate for the user's application.

7.4.4.4 The ECT values as shown in Table X4.1 are the minimum values not the expected ECT average value for the grades. For example the grade showing a minimum of 32 lb/in. ECT is expected to have an actual ECT value of 35–41 lb/in. Box design is based on the expected average values, not the minimum values. As tables in the shipping regulations and in Appendix X4 show only the minimum required ECT value per grade, it is good practice for the buyer to obtain average the ECT value(s) from the manufacturer and to include that information in the box specifications.

7.4.4.5 The approximate range of average ECT values for Singlewall (SW), Doublewall (DW), and Triplewall (TW) are:

Singlewall	4.730–13.500 kN/m [27–77 lb/in.]
Doublewall	8.755–18.385 kN/m [50–105 lb/in.]
Triplewall	11.735–28.015 kN/m [67–160 lb/in.]

7.4.5 Recent research calls into question the accuracy of performing edge crush testing on *E*-flute fiberboard.[10]

7.5 ~~*Minimum Uncombined Flute Height—*~~*Combined Board Caliper—*The overall thickness (caliper) of corrugated fiberboard is an important material attribute relating ~~directly to finished box compression strength. Since thickness consists primarily of the flute structures,~~to acceptable conversion, box forming/erecting, filling and palletizing. Caliper is also related to ~~minimum~~finished ~~flute heights may be specified,~~box panel stiffness and box ~~not~~compression ~~including any linerboard (facings).~~ strength.

7.5.1 ~~To determine minimum flute heights, use the corrugated fiberboard manufacturer's target flute heights,~~Maximum theoretical caliper is a function of the height of the flute formed on the corrugator and the thickness of the ~~minus~~materials ~~4 %.~~used. Actual caliper is also impacted by paper compressibility, roll wear and loss of thickness to crushing among other factors.

7.5.1.1 Corrugated board flute height is determined by the flute profile of the corrugating rolls used. Each of the flute types has a range of possible flute height and a most common value. Common values for *A*,*B*, and *C*-flute are 4.675, 2.465, and 3.630 mm [0.184, 0.097, and 0.143 in.], respectively. However, these values can vary significantly by roll manufacture. The box supplier can supply the flute height used in their specific process.

7.5.2 ~~Users specifying box compression strength or a rough handling performance protocol need not specify and control flute heights, ECT, or flat crush parameters, though the supplier must. Instead of focusing on components of the box, the user~~Expected combined board caliper and allowable variation in caliper for the specific box application may be reported by the box supplier. See 7.1.2~~will focus more on the performance of the final box, though some users will need to also require minimum outer liner basis weights, or perhaps Mullen burst values, to avoid problems in distribution.~~. The expected caliper and expected variability may be included in the box supply contract if appropriate, particularly when automated equipment is involved.

7.5.2.1 The minimum typical acceptable caliper can be calculated by using expected caliper minus maximum crushing deformation (see 7.7.1). Caliper loss greater than this amount indicates board crushing, which can result in loss of board stiffness and a reduction in box compression strength.

7.5.3 *Test Method—*~~First measure the~~ The thickness of the combined board structure can be measured using TAPPI Test Method T 411.~~Then measure the thickness of each facing (linerboard), without soaking apart, and subtract the thickness of the facings to obtain flute structure(s) height. All readings shall be taken at least 25 mm [1 in.] from any score line, cut edge, or printed area.~~

[10] ~~C. Wilson and B. Frank, *TAPPI Journal*, June, 2009.~~Wilson, C., and Frank, B., *TAPPI Journal*, June 2009.

7.6 ~~*Flat Crush Resistance—*~~*Combined Board Stiffness—*This attribute is an indication of the rigidity of the flute structure which is in turn directly related to crush resistance during box fabrication and overall box rigidity.

7.6.1 ~~Combined singlewall fiberboard should meet the following minimum flat crush requirements for corrugating medium weighing 0.882 g/m~~Measures of board stiffness:~~^{2} [26 lb/in^2]:~~

~~Flute~~	~~Flexible Beam Method, kPa [lbf/in.^{2}]~~
~~A~~	~~130 [19]~~
~~B~~	~~200 [29]~~
~~C~~	~~165 [24]~~

7.6.1.1 Estimate impact at the plant or customer – by caliper loss, see 7.5 and 7.7.

7.6.1.2 Flat crush strength as measured by TAPPI T 825 is a measure of flute rigidity of corrugated board. Low flat crush can indicate low resistance to crushing by the corrugating medium (Concora, TAPPI T 809), leaning flutes, (a corrugator problem), and or crushed flutes(corrugator and finishing problems). Low Flat Crush can impact the flexural stiffness of corrugated board which can negatively affect box compression as well as box performance in automatic case erection, filling and sealing operations. Box clamp unit handling can also be negatively affected by low flat crush. Combined singlewall fiberboard should meet the following minimum flat crush requirements for corrugating medium weighing 0.882 g/m^2 [26 lb/in^2]:

Flute	kPa (lb/in^2)
A	186 (27)
B	283 (41)
C	234 (34)

7.6.1.3 Laboratory use of 4 point bending (TAPPI T 836) to quantify board stiffness is beyond the scope of this document.

~~7.6.2 Flat crush resistance is measured by the flat crush test (*FCT*). The above values are measured by using the flexible beam test method of TAPPI T 808. An alternate method utilizing the fixed beam, TAPPI T 825, is also available but will produce values about 20 to 30 % higher.~~

7.7 *Crush—*Excessive crush of fiberboard in its thickness direction from feed rolls or excess printing impression will reduce the bending (stiffness) of the board structure. This reduces compression strength of the finished box and can adversely affect automatic packing equipment and warehouse stacking performance.

7.7.1 The following are suggested *maximum* crush deformations for singlewall (SW) boards due to feed rolls and printing:

~~A-flute~~	~~0.25 mm [0.010 in.]~~
~~B-flute~~	~~0.15 mm [0.006 in.]~~
~~C-flute~~	~~0.20 mm [0.008 in.]~~
A-flute	0.25 mm [0.010 in.]
B-flute	0.15 mm [0.006 in.]
C-flute	0.20 mm [0.008 in.]

7.7.2 For doublewall (DW) boards use 75 % of the combination of flute structure allowances, for triplewall (TW) use 50 % (that is, ~~AAA~~AAA-flute~~-flute~~ has maximum allowable crush of 0.30 mm [0.012 in.]).

7.7.3 *Test Method—*Using TAPPI Test Method T 411 measure the board sample at least 25 mm [1 in.] from any score line, cut edge, or printed area. Then measure it in the printed area and subtract from the first reading to determine amount of crush deformation.

~~7.7.4 Users specifying compression strength can avoid specifying overall crush and print crush, leaving this detail to the manufacturer to control while achieving the minimum compression strengths required for all boxes produced. Manufacturers who control these kinds of attributes the best will benefit from lower costs to meet minimum performance requirements.~~

8. Finished Container Attributes

8.1 *Box Style*—A wide variety of box styles are available to the user ranging from the most common Regular Slotted Container ~~(~~(RSC,~~RSC)~~ International Box Code 201) to specialized styles configured for particular applications. The more common styles are depicted in Practice D5118/D5118M, Figures 1 through 14 and in the Fibre Box Handbook. In addition, rigid boxes formed by automatic in-plant equipment may be appropriate and include the following styles: Bliss, Bliss with tri-fold ends; Bliss with internal flange; Bliss with triangular corner posts; Bliss with integral "H" divider; Tray with side flange sealed flaps; Tray, six corners glued; Tray with triangular corner posts; and Tray split minor. The user should specify the style which is most economical in view of requirements for packing, closure, protection, handling, storage, and transportation.

8.2 *Containment Strength*—The basic purpose of a corrugated box is to contain the product in such a way that the product can be moved safely through the entire distribution cycle.~~ A method of determining containment strength of a box is to conduct drop tests which stress its fibers and structure in a manner similar to that imposed by various environmental hazards. This test is appropriate for common carrier trucking and small parcel shipments, but may not be appropriate for unitized or full truckload or railcar-load shipments.~~

8.2.1 Boxes stored or shipped in stacks which have internal product support for compression strength but which also need toughness to contain heavy or irregular shaped contents are often made with containment grades for this type of shipment.

8.2.2 ~~The test method recommended for measurement of containment strength of corrugated boxes is a free fall drop of loaded containers in accordance with Test Method~~Boxes with high value or hazardous material contents that are shipped by common carrier trucking or in small parcel shipments are often evaluated using drop ~~D5276~~. ~~See~~tests. These ~~Appendix X5 for drop sequence and suggested drop heights. A different drop test procedure may be selected from Test Method~~ tests stress its fibers and structure in a manner like that imposed by various environmental hazards. This type ~~D5276, Annex A2; or one may also create different sequences of drop and orientations based on experience including multiple test specimens each tested differently in sequence and drop height.~~of testing may not be appropriate for unitized or full truckload or railcar-load shipments.

8.2.2.1 The test method recommended for measurement of containment strength of corrugated boxes is a free fall drop of loaded containers in accordance with Test Method D5276. See Appendix X5 for drop sequence and suggested drop heights. A different drop test procedure may be selected from Test Method D5276, Annex A2; or one may create different sequences of drop and orientations based on experience including multiple test specimens each tested differently in sequence and drop height. Practice D7386 shows how to calculate required BCT for boxes in drop testing, based on single parcel density of 190 kg/m^3 [12 lb/ft^3].

8.2.2.2 For the dropping mass, use the actual product (or a dummy load of similar shape, size, weight, and dynamic characteristics) with the same interior packaging as generally used.

8.2.2.3 The container fails if it does not meet acceptance criteria previously determined. The required condition of the container at receipt by the ultimate customer should be the primary test criteria.

~~8.2.2 For the dropping mass, use the actual product (or a dummy load of similar shape, size, weight, and dynamic characteristics) with the same interior packaging as generally used.~~

~~8.2.3 The container fails if it does not meet acceptance criteria previously determined. This criteria should consider the required condition of the container at receipt by the ultimate customer.~~

8.3 *Top to Bottom Stacking Strength*—A major function of the corrugated container is to provide sufficient stacking strength in storage and transportation for ~~the dual purpose of protecting the~~ boxes where the box itself provides most or all of the required compression strength. This both protects the contents from damage and ~~maintaining~~maintains stacks from toppling over due to crushing container walls. Minimum box compression strength (BCT) as measured by Test Method D642 is often the key value in box specification. Buyers should obtain BCT information from the manufacturer and include that information in the box specifications.

8.3.1 ~~Using Test Method~~ An ~~D642, measure the resistance of corrugated boxes to stacking loads and provide an indication as to the amount of safe load it~~ indication of the safe load that a box can withstand in ~~normal stacking situations.~~stacking can be determined by BCT using the appropriate safety factor. The estimated target BCT can be calculated by multiplying the weight on the bottom box in a stack times the safety factor.

8.3.1.1 The range of normal F factors used by industry are:

Rapid use, normal humidity, mild abuse or misaligned stacks F range = 3–5
Use within a 100 days, slightly elevated humidity, cross stacking F range = 5–7
Storage over 100 days, humidity to 80 %, and cross stacking F range = 8–10
Storage over 100 days, humidity 85–90 %, cross stacking with over-hang F = 12+

8.3.1.2 The range of normal F factors specified in Practice D4169, 11.2, for type 1 boxes:

Minimum (Assurance Level III) F range = 3-5
Mid-Range (Assurance Level II) F range = 4.5-7
Highest (Assurance Level I) F range = 8-10

8.3.1.3 Safety, F, factors can be calculated using the subfactors and process shown in Table X6.1.

8.3.2 Test Method D642 permits either fixed or floating platens. Since fixed platen machines generally cause failure to occur at the ~~specimen's~~specimen's strongest point, while swivel platen machines cause failure at the ~~specimen's~~specimen's weakest point, only one of these two methods should be specified by the user. Failure is considered to occur if the maximum compression strength attained is less than the specified load, or the specified load has not been reached before a critical defined deformation, for example, 19 mm [0.75 in.] deflection for top loaded RSC style containers.

8.3.3 Specified load will depend on the stacking load expected in storage or transportation. A method of determining compression test requirements based on specified stacking loads is described in Appendix X6. Calculation of specified load includes the use of a design factor (often called a Safety Factor or an Environmental Factor) to account for the loss of strength in a corrugated box due to distribution hazards such as long-term storage, high humidity, stacking and palletizing irregularities, and rough handling. The factor is multiplied by the known stacking load to determine the desired ~~machine compression strength.~~initial compression strength required by the box.

8.3.3.1 This initial box compression requirement is the strength required to support the anticipated load on the bottom box in a stack considering the conditions used to calculate the safety factor, F.

8.3.3.2 This initial, target, strength is based merely on load and anticipated hazards not pre-knowledge of the materials required or the box design to be used.

8.3.3.3 This target strength can be used to evaluate materials of construction and box structure in the box design process.

8.3.3.4 Sample boxes made with the selected materials and design can be tested to confirm compliance with this minimum strength using Test Method D642 at standard conditions (Practice D685).

8.3.3.5 All proposed box constructions need to be confirmed for suitability by means of trial shipments, see 1.3.4.

9. Workmanship (see also Practice D5118/D5118M)

9.1 Corrugated fiberboard should show no continuous visual surface break (checking) of the outer component ply nor any facing completely split through at the score line (fracture). Commercially accepted fiberboard is normally free of tears, punctures, wrinkles, blisters, washboarding, splices, and scuff marks or any other types of physical damage.

9.2 Edges of fiberboard should be properly aligned so that the distance between the edges of any two components should not exceed 6 mm [¼ in.].

9.3 The amount of warp upon delivery to the customer should not exceed 20 mm/m [¼ in./ft].

9.4 Corrugated fiberboard should be free of excessive dirt or oil spots or any other deposit which will detract from the appearance of the fiberboard.

9.5 The edges or ends of the fiberboard sheet should not be delaminated for a distance of more than 6 mm [¼ in.].

10. Precision and Bias

10.1 The precision and bias of this practice are dependent on those of the various test methods used, and cannot be expressly determined.

11. Keywords

11.1 box; containment; corrugated; fiberboard; performance; rough handling; stacking

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLE OF SAMPLING PLAN BASED ON PRACTICE D585

TABLE X1.1 Acceptance/Rejection Based on Various Lot Sizes

NOTE 1—n = sample size for first try and n_t = total sample size, that is sum of test units in first and second tries (if a second sample is required), and where Ac_t and Re_t are the acceptance and rejection numbers for double samples.

Lot Size	Sample Size		Acceptance and Rejection Numbers			
	n	n_t	Ac	Re	Ac_t	Re_t
151 to 1200	5	...	0	1	...	...
1201 to 35 000	8	16	0	2	1	2
35 001 and over	13	26	0	3	2	3

X1.1 Table X2.2 in Practice D585 lists the acceptance/rejection based on various lot sizes. (Table X1.1 is excerpted from Table X2.2 in Practice D585.)

X1.2 The following is an example based on an order for 5000 corrugated containers.

X1.2.1 In accordance with Table X1.1, a sample size of 8 is used for the lot size of 5000 (within the range from 1201 to 35 000). Eight test units are selected at random and are tested for each attribute specified. For each attribute, *no* test unit may be below the minimum specified. If not more than one test unit fails, a second series of eight may be retested but no further failures are allowed. In this example the acceptance of the double sample lot is 15 of 16.