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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 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 D4169.

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 include detailed descriptions of the materials that may be used and style, closure, or other construction details of allowed shipping containers. These regulations 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 are not intended to provide for the distribution system beyond the transportation segment.

1.2.1 The attribute levels contained herein are based on US 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 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 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

[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.

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box compression values or performance protocols will help assure the lowest price for specific performance, regardless of the material used.

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).

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 and health practices and determine the applicability of regulatory limitations prior to use.*

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
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
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 Flat Crush Test of Corrugated Fiberboard-Flexible Beam Method[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]

2.3 *Government Documents:*

CFR 49 Code of Federal Regulations, Title 49[5]

2.4 *Other Publications:*

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[7]
Uniform Freight Classification Rule 41[8]

3. Terminology

3.1 *Definitions*—For general definitions of packaging and distribution environments, see Terminology D996.

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 for packing and distribution of goods. This practice describes several 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, 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 operations and distribution cycle(s). When using packaging regulations as a basis for developing specifications, the reason for the existence of the regulation and its function and importance should be understood. As previously stated, regulations may be exceeded and should be when the minimum specifications are inadequate for the full effects of the distribution cycle. 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. These minimum standards can be stated in the box drawing so as to ensure adherence to regulations If a Box Manufacturer's Certificate (BMC) is printed on the box, then

[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 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.

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

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

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

7.1 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. 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.

7.1.1 *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 for the heaviest contents where maximum structural rigidity, compression strength, and resistance to puncture are required.

7.1.2 *Flute Structure*—*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*. *C*-flute is the most common 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), states the following (paraphrased): *A*-flute has about 33 flutes/ft, *B*-flute has about 47 flutes/ft, *C*-flute has about 39 flutes/ft, and *E*-flute has about 90 flutes/ft." Please note the following table from Specification D4727/D4727M–07 provides only 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.

7.2.1 Burst strength is measured by the burst (Mullen) test utilizing TAPPI Method T 810 and is specified in the carrier regulations 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. These requirements may or may not be appropriate for the user's applications.

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 only for the various grades of triplewall 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.

7.4 *Edgewise Crush Resistance (ECT)*—This attribute of fiberboard relates directly to the finished box compression strength through the well-known simplified formula published in 1963 by the Institute of Paper Chemistry (now the Institute of Paper Science and Technology, or IPST) and commonly known as the McKee Formula. Another widely used version of the McKee Formula, known as the modified 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.

7.4.1 The simplified McKee Formula is:

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

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:

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

See Appendix X4 for example and limitations of formula use.

7.4.2 The exponent version of the McKee formula is:

$$BCT = 5.87 \times ECT \times T^{0.508} \times BP^{0.492} \quad (3)$$

where the terms are the same as for the simplified version. See Appendix Appendix X4 for an example of this formula in practice.

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

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 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.

7.4.5 Recent research calls into question the accuracy of performing edge crush testing on *E*-flute fiberboard.[9]

7.5 *Minimum Uncombined Flute Height*—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, *minimum* flute heights may be specified, *not* including any linerboard (facings).

7.5.1 To determine minimum flute heights, use the corrugated fiberboard manufacturer's target flute heights, *minus* 4 %.

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 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.

7.5.3 *Test Method*—First measure the thickness of the combined board structure 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.

7.6 *Flat Crush Resistance*—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^2 [26 lb/in^2]:

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

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 from feed rolls or excess printing impression will reduce compression strength of the finished box and adversely affect automatic packing equipment and warehouse stacking performance.

7.7.1 The following are suggested *maximum* crush deformations for singlewall 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.]

7.7.2 For doublewall boards use 75 % of the combination of flute structure allowances, for triplewall use 50 % (that is, *AAA*-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*) 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

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

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 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 also create different sequences of drop and orientations based on experience including multiple test specimens each tested differently in sequence and drop height.

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 contents from damage and maintaining stacks from toppling over due to crushing container walls.

8.3.1 Using Test Method D642, measure the resistance of corrugated boxes to stacking loads and provide an indication as to the amount of safe load it can withstand in normal stacking situations.

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 strongest point, while swivel platen machines cause failure at the 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 desired machine compression strength.

9. Workmanship

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

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.

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

X2. BURST STRENGTH

TABLE X2.1 Limits of Weight and Size Based on Burst Strength (based on Rule 41 and Item 222 of most recent issue of rail and truck classifications respectively)

Maximum Gross Weight, kg [lb]	Maximum Outside Dimensions (1 + w + d), m [in.]	Burst Strength, kPa [psi]	Construction SW (Singlewall) DW (Doublewall)
9 [20]	1.0 [40]	860 [125]	SW
16 [35]	1.3 [50]	1030 [150]	SW
23 [50]	1.5 [60]	1200 [175]	SW
29 [65]	1.9 [75]	1380 [200]	SW
36 [80]	2.2 [85]	1380 [200]	DW
36 [80]	2.2 [85]	1720 [250]	SW
43 [95]	2.4 [95]	1900 [275]	SW
45 [100]	2.4 [95]	1900 [275]	DW
54 [120]	2.7 [105]	2410 [350]	SW, DW
63 [140]	2.8 [110]	2760 [400]	DW
72 [160]	2.9 [115]	3440 [500]	DW
81 [180]	3.0 [120]	4140 [600]	DW

X2.1 Experience of shippers and carriers for many years has shown that the limits in Table X2.1 on gross weights and dimensions of corrugated boxes, as related to minimum burst requirements, will provide sufficient burst strength and containment strength for most products or contents, or both, when shipped by means of less-than-truckload (LTL), as well as air freight, truckload, and railcar. Shipments by small parcel carrier may require lower gross weight limits.

X3. PUNCTURE STRENGTH

TABLE X3.1 Limits of Weight and Size for Triplewall Boxes Based on Puncture Strength

NOTE 1—Based on most recent issue of carrier classifications, Rule 41 and Item 222.

Maximum Gross Weight, kg [lbs]	Maximum Outside Dimensions (1 + w + d), m [in.]	Minimum Puncture Strength, joules [in.-oz. per in. tear]
109 [240]	2.8 [110]	21 [700]
118 [260]	2.9 [115]	27 [900]
127 [280]	3.0 [120]	33 [1100]
136 [300]	3.2 [125]	39 [1300]

X3.1 Experience of shippers and carriers for many years has shown that the limits in Table X3.1 on gross weights and dimensions of triplewall corrugated boxes, as related to minimum puncture requirements, will provide sufficient puncture resistance, rigidity, and containment strength for most products or contents, or both, when shipped by means of LTL, as well as air freight, truckload, and railcar.

X4. EDGEWISE CRUSH TEST (ECT)

X4.1 The average top-to-bottom compression strength (BCT) of a finished RSC-style box can be estimated by using the simplified McKee formula with the ECT in conjunction with box perimeter and thickness of board:

$$BCT = 5.87 \times ECT \times \sqrt{\text{box perimeter} \times \text{thickness of board}} \quad (X4.1)$$

The thickness (caliper) of board in the formula includes linerboards as well as the flute height. Users should contact supplier(s) to obtain expected minimum combined board thickness (caliper).

X4.2 The formula is based only on a regular slotted-style (RSC) box with normal shape where all dimensions (*l, w, d*) do not vary by extreme amounts from each other. Specifically the depth shall not be less than 1⁄7 of the box perimeter and no one dimension more than double any other. When dimensions do vary extremely, the following adjustments are suggested:

Dimension Variations	Alter Calculated Strength
Depth < 2⁄3 of width	add 5 %
Depth > 1.5 width	subtract 8 %
Length > 2.5 width	subtract 8 %

NOTE X4.1—Extreme variations beyond the dimensions in this section preclude use of the formula. Individual experimentation will be required.

X4.2.1 Following is an example using the shape modifier:

X4.2.1.1 Given container is an RSC style, inside length (*L*) = 0.6 m, inside width (*W*) is 0.4 m, inside depth = 0.15 m, ECT = 6 kN/m, T = 0.004 m, and shape modifier = + 5 % (depth is less than 2⁄3 width):
Substituting these values in the McKee formula:

$$BCT = 5.87 \times ECT \times \sqrt{\text{perimeter, } 2L + 2W \times (T)} \quad (X4.2)$$

$$\times (\text{shape modifier})$$

$$= 5.87 \times 6 \times \sqrt{2.0 \times 0.004} \times (1 + 0.05)$$

$$= 3.31 \text{ kN } [744 \text{ lbf}]$$

X4.3 The McKee formula may be realigned to produce the following equation:

$$ECT = \frac{BCT}{5.87 \times \sqrt{BP \times T}} \quad (X4.3)$$

where:

ECT = estimated average edge crush test,
BCT = required top-to-bottom compression of the box,
BP = box inside perimeter (twice length + twice width), and
T = overall combined board thickness.

This will be of interest in determining a calculated ECT value based on known box compression strength requirement.

X4.3.1 *Example*—Referring to the example in X6.1.3, required box compression is 6.62 kN [1458 lbf]. If box perimeter is 1.5 m [60 in.] and thickness is 6.4 mm [0.250 in.], then the required average ECT can be estimated:

$$ECT = (6.62)/\left[(5.87) \times \sqrt{(1.5) \times (0.0064)}\right] = 11 \text{ kN/m} \quad (X4.4)$$

$$ECT = (1458)/\left[(5.87) \times \sqrt{(60) \times (0.250)}\right] = 64 \text{ lb/in.} \quad (X4.5)$$

NOTE X4.2—The FBA ECT Guide (ref 2.4) in addition to discussing ECT and BCT, provides an example of calculating the needed BCT from a given set of stacking conditions and includes the use of Environmental Factors (Safety Factors).

X4.3.2 The modified version of the McKee Formula, shown below, may also be used in the same way as that shown above for the simplified version.

$$BCT = 5.87 \times ECT \times T^{0.508} \times BP^{0.492} \quad (X4.6)$$

X4.4 Table X4.1 shows minimum requirements of fiberboard ECT strengths listed in carrier regulations (Rule 41 and Item 222). **Caution:** The user should determine maximum gross weights to be shipped in the box based primarily on the user's performance requirements, and secondarily on the carrier regulation maximum gross weight listings. Usually, if the user's performance requirements are met, the ECT values will be in compliance with carrier regulations. In general, carrier maximum weights and dimensions should never be exceeded unless the regulations do not apply for the shipment(s) and the user's performance requirements so indicate.

NOTE X4.3—The highest ECT grade of triple wall 27 kN/m [155 lb/in.] is based on Practice D5168.

TABLE X4.1 Edgewise Crush (ECT) Values

NOTE 1—Values for pounds/inch are extracted from most recent issues of carrier classifications, Rule 41 and Item 222. The SI units are not exact equivalents of the inch-pound units.

kN/m [lb/in.]	Construction
4.0 [23]	Singlewall
4.5 [26]	
5.1 [29]	
5.6 [32]	
7.0 [40]	
7.7 [44]	
9.6 [55]	
7.4 [42]	Doublewall
8.4 [48]	
8.9 [51]	
10.7 [61]	
12.4 [71]	
14.4 [82]	
11.7 [67]	Triplewall
14.0 [80]	
15.8 [90]	
19.6 [112]	
27.1 [155][A]	

[A]This specification does not appear in the carrier regulations.

X5. DROP TESTS TO MEASURE CONTAINMENT STRENGTH

X5.1 Utilizing Test Method D5276, Annex A2, select an appropriate procedure for drop testing, such as A.2.2.2, "Ten Drop Cycle." Drop the test specimen from the drop heights listed in Table X5.1 in the following sequence: a bottom corner, the three edges radiating from that corner, and six flat sides for a total of ten drops.

X5.2 A different drop test procedure may be selected than Test Method D5276, Annex A2, or one may also create different sequences of drop and orientations including multiple test specimens each tested differently in sequence and drop height. Creating new procedures should be based on extensive experience and information on packaged product performance in shipping and handling in one's distribution systems.

TABLE X5.1 Suggested Drop Heights Based on Contents Weights

Contents Weight, kg[lb]			Drop Height, m [in.]
0	to 9.5	[0to20.9]	0.75 [30]
9.6	to18.6	[21to40.9]	0.60 [24]
18.7	to27.6	[41to60.9]	0.45 [18]
27.7	to45.4	[61to100.9]	0.30 [12]
45.4	to90.8	[101to200]	0.15 [6]

X6. COMPRESSION TEST REQUIREMENTS BASED ON STACKING LOADS

X6.1 Practice D4169, Section 11, covers how to calculate required compression test levels for warehouse stacking (Element C) and carrier vehicle stacking (Element D).

X6.1.1 A similar procedure may be used to determine the minimum compression strength to be specified for a corrugated box.

NOTE X6.1—The specification for a new box, untested in previous elements of a distribution cycle, should be somewhat higher than those of a sequential performance test procedure. Test shipments and storage trials should also be performed as a further check on calculated strengths.

X6.1.2 An example of a higher requirement for a new box is the following for a shipping unit construction Type 1, (see 11.2 of Practice D4169) where the design or F factor (see 8.3.3) for Assurance Level II is 4.5. A box specification based on the same method of calculation should utilize a design or F factor of 5 or 5.5. Otherwise the box may fail during a compression test element of a lengthy performance test sequence. Since Assurance Level II reflects an average distribution environment, the F factor for a box specification may be adjusted up or down depending on relative severity of the actual expected environment.

X6.1.3 Following is an example showing calculation of required box compression strength. The box construction is a *CB*-flute RSC style, normal shape, with exposure to an expected maximum warehouse stack height of 3 m for up to one year. The box and contents weigh 15 kg, and contents are non-load bearing so the box shall carry the entire stacking load. Box height is 0.3 m. Using the formula in Practice D4169:

$$L = M \times J \times [(H - h)/h] \times F \quad \text{(X6.1)}$$

where:

L = minimum required load, N [lbf],
M = mass of one package, kg [lb],
J = 9.8 m/s/s [1 lbf/lb] for gravity constant,

H = maximum height of stack, m [in.],
h = height of individual package, m [in.] and,
F = 5.0, as noted in X6.1.2 example.

Substituting:

$$L = (15) \times (9.8) \times [(3.0 - 0.3)/0.3] \times (5.0) \quad (X6.2)$$

$$= 6615 \text{ N or } 6.62 \text{ kN}$$

The minimum required compression strength of the box is equal to the minimum required load for stacking, or 6.62 kN [1458 lbf].

X6.1.4 An alternate method for calculating compression strength can be found in Appendix X4, providing an ECT value is specified for the fiberboard and box shape is within the formula parameters.

X7. EXAMPLES OF USING PRACTICE D5639 FOR SPECIFICATION DETERMINATIONS

X7.1 The first example is for a distribution environment that is similar to distribution cycle (DC) 6 of Practice D4169, unitized loads shipped by means of truckload, and with warehouse stacking as the first element of the cycle (DC 14 added). For this situation stacking strength is most important and rough handling potential is minimal.

X7.1.1 The attributes which should be considered for this example are as follows: Fiberboard-edgewise crush resistance, minimum flute height, printing crush limit; finished box-top to bottom compression strength.

X7.1.2 Parameters of the example are as follows: A shipper requires a corrugated container for a non-load bearing product and interior packaging. An RSC-style box is selected based on the product characteristics and method of packing. The weight of the packaged product is 15 kg [33 lb] and its dimensions are 0.5 × 0.3 × 0.25 m [20 × 12 × 10 in.]. The packages will be unitized 5 tiers per unit load and stored 2 unit loads high in warehouses for an average of one month and a maximum of one year. The handling and transportation environment is normal. The unit load base is a lightweight slipsheet, a flat sheet of material with a tab on one or more sides, used as a base for assembling, handling, storing, and transporting goods in unit load form.

X7.1.3 Calculate the box specifications as follows:

X7.1.3.1 *Minimum Top to Bottom Box Compression (BCT) Strength*—Before calculating BCT, the design or F-factor shall be selected (see 8.3.3). A factor of 5.0 is chosen, based on the distribution environment and the discussion in X6.1.2. The BCT is then calculated using the formula from Practice D4169 as follows:

$$BCT = M \times J \times [(H - \text{h})/(\text{h})] \times F \quad (X7.1)$$

where:
M = 15 kg,
J = 9.8 m/m/s, gravity constant,
H = 5 tiers/unit load and 2 unit loads high or (5) × (0.25) × 2 = 2.5 m,
h = 0.25 m, and
F = 5.0.

Substituting:

$$BCT = 15 \times 9.8 \times [(2.5 - 0.25)/(0.25)] \times 5.0 \quad (X7.2)$$

$$= 6615 \text{ N or } 6.62 \text{ kN}$$

The minimum BCT to be specified therefore is 6.62 kN [1458 lbf].

X7.1.3.2 *Minimum Edgewise Crush (ECT)*—Using the simplified version of the McKee Formula (X4.3):

$$ECT = \frac{BCT}{5.87 \times \sqrt{\text{box perimeter} \times \text{board thickness}}} \quad (X7.3)$$

Assuming the box manufacturer has both *C* flute singlewall and *CB* doublewall available, calculate the minimum ECT needed based on both wall constructions to determine if both are feasible. For *C*-flute, assuming the manufacturer supplies a minimum of 4.1-mm overall caliper (thickness) for the heaviest fiberboards, calculate the ECT as follows:

$$ECT = \frac{6.62}{5.87 \times \sqrt{1.6 \times 0.0041}} = 13.9 \text{ kN/m } [80 \text{ lb/in.}] \quad (X7.4)$$

This ECT minimum value is higher than generally available in singlewall and therefore *C* flute singlewall is not applicable. For *CB* flute doublewall the manufacturer supplies a minimum of 6.9-mm caliper thickness for medium-strength boards and ECT is calculated as follows:

$$ECT = \frac{6.62}{5.87 \times \sqrt{1.6 \times 0.0069}} = 10.7 \text{ kN/m } [61 \text{ lb/in.}] \quad (X7.5)$$

This is in the medium range of doublewall strengths offered by the industry and therefore minimum specified ECT is 10.7 kN/m [61 lb/in.].

X7.1.3.3 *Minimum Flute Height (see 7.5)*—For *CB* flute doublewall, the manufacturer's target flute height (not including linerboards) is 5.7 mm. The minimum flute height to be specified is 4 % less, or 5.5 mm [0.217 in.].

X7.1.3.4 *Maximum Printing Crush (see 7.7)*—*CB*-Flute – 0.25 mm [0.010 in.].

X7.1.3.5 Carrier regulations should always be considered and calculated specifications checked against regulations to ensure compliance. In this example, the calculated specification of 61 lb/in. ECT far exceeds the minimum carrier requirements of 26 lb/in. ECT in Rule 41 and Item 222.

X7.2 The second example is for a distribution environment similar to distribution cycle (DC) 3 of Practice D4169, single package up to 45.4 kg [100 lb] by LTL truck shipment or small parcel carrier. For this situation, containment and protection in rough handling are most important with a secondary concern for stacking strength in carrier vehicles.

X7.2.1 The attributes which should be considered for this example are as follows: fiberboard—burst or puncture resistance; finished box—containment strength, top to bottom compression strength.

X7.2.2 Parameters of the example are: The shipper requires a corrugated container for a non-load-bearing product and interior packaging. An RSC-style box is selected based on manual method of packing and product characteristics. The weight of the packaged product is 30 kg [66 lb] and dimensions are 0.5 × 0.3 × 0.25 m [20 × 12 × 10 in.]. Although the packages are palletized, all storage is in racks, one pallet high, four tiers per pallet. The handling and transportation environment is normal.

X7.2.3 Calculate the box specifications as follows:

X7.2.3.1 *Minimum Fiberboard Burst Strength*—Using the carrier classification for burst strength (see Table X2.1), for a 30-kg [66-lb] weight of box and contents, the minimum burst strength value to be specified is 1720 kPa [250 psi] for singlewall construction.

X7.2.3.2 *Minimum Box Containment Strength(see X5)*—Conduct ten drop tests from 0.3 m [12 in.] height with results to meet acceptance criteria. The dropping mass may be a dummy load weighing 30 kg.

X7.2.3.3 *Minimum Top to Bottom Compression (BCT) Strength (see Practice)D4169*—The maximum stack height one might encounter is in LTL trucks or small parcel vehicles. Assuming a maximum stacking height in carrier vehicles is 2.74 m [108 in.], an average density of miscellaneous freight is 160 kg/m^3 [10 lb/ft^3] and a design factor of 7.0 for corrugated without loadbearing contents, calculate the required compression strength as follows using the formula of Practice D4169:

$$BCT = M \times J \times ((L \times W \times D)/K) \times ((H - h)/(h)) \times F \quad (X7.6)$$

where:

BCT	=	minimum required load, N [lbf],
M	=	average shipping density factor, kg/m^3 [lb/ft^3],
J	=	constant for gravity, m/s/s,
L	=	inside length of the box, m [in.],
W	=	inside width of the box, m [in.],
D	=	inside depth of the box, m [in.],
K	=	1 m^3/m^3 [1728 in.^{3}/ft ^{3}],
H	=	height of the stack in the trailer, m [in.],
h	=	outside height of the box, m [in.], and
F	=	7.0.

Substituting:

$$BCT = 160 \times 9.8 \times [(0.5 \times 0.3 \times 0.25)/1] \quad (X7.7)$$

$$\times [(2.74 - 0.25)/(0.25)] \times 7.0 = 4100 \text{ N or } 4.1 \text{ kN}$$

The minimum BCT to be specified is 4.1 kN [920 lbf].

X7.2.3.4 *Determination of Fiberboard Strength and Flute Configuration*—The next step is to determine what fiberboard strength and flute configuration is required to provide the calculated BCT of 4.1 N [920 lbf]. Using the transformed simplified version of the McKee formula shown in equation Eq X7.3 and checking to determine if the minimum fiberboard strength calculated in X7.2.3.1 will be sufficient for the compressive load of 4.1 N [920 lbf], it is determined by substituting alternate ECT for burst strength that singlewall 1720 kPa [250 psi] burst and 7.0 kN/m [40 lb/in.] ECT is too low in compressive strength. The required ECT value for a CB flute doublewall construction is then calculated as follows:

$$ECT = \frac{BCT}{5.87 \times \sqrt{\text{box perimeter} \times \text{board thickness}}} = 4.1/\left[(5.87)\right.$$

$$\left. \times \sqrt{(1.6 \times 0.0069)}\right] = 6.65 \text{ kN/m } (37.9 \text{ lb/in.}) \quad (X7.8)$$

Comparing the required ECT above with the values of standard strengths in Table X4.1, the lowest grade of doublewall is sufficient in compressive strength with an ECT minimum value of 7.4 kN [42 lb/in.]. The alternate to 7.4 kN is 1380 kPa [200 psi] and it has an approved gross weight limit of 36 kg [80 lb.] according to Table X2.1 and therefore meets the LTL trucking requirements.

Summarizing, the recommended specification of fiberboard strength and flute configuration for the application described in X7.2 is 1380 kPa [200 psi] burst, *CB* doublewall.

X7.2.3.5 The modified version of the McKee Formula as shown in Eq X4.6 may also be used in the same way as the simplified version to develop a recommended specification of fiberboard strength and flute configuration.

X7.2.4 Carrier regulations should be considered where applicable and calculated specifications checked against regulations to ensure compliance. Since the burst strength, maximum gross weight and maximum outside dimensions for this example are taken from carrier regulations in the listing of Table X2.1, they will be in compliance.

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