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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 ~~must~~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.

~~1.3Corrugated containers for packaging of hazardous materials for transportation must comply with federal regulations administered by the U.S. Department of Transportation (Code of Federal Regulations, CFR49~~

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

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[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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administered by the U.S. Department of Transportation (Code of Federal Regulations, CFR 49).

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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.

~~1.5The~~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.

~~1.6~~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
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[3]
T 803 Puncture Test of Corrugated Fiberboard[3]
T 808 Flat Crush Test of Corrugated Fiberboard-Flexible Beam Method[3]
T 810 Burst Test of Corrugated Fiberboard[3]
T 811 Edgewise Crush Test of Corrugated Fiberboard[3]
T 825 Flat Crush Test of Corrugated Fiberboard-Fixed Platen Method[3]

2.3 *Government Documents:*

CFR 49 Code of Federal Regulations, Title 49[4]

2.4 *Other Publications:*

Fibre *Box Handbook* [5]
~~Item 222National Motor Freight Classification~~
Edge Crush Test, Application and Reference Guide for Combined Corrugated Board, Fibre Box Association [5]
National Motor Freight Classification Item 222 [6]
~~Rule 41Uniform Freight Classification~~
Uniform Freight Classification Rule 41 [7]

3. Terminology

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

4. Significance and Use

~~4.1This 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.~~

[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] Available from Technical Association of the Pulp and Paper Industry (TAPPI), 15 Technology Parkway South, Norcross, GA 30092, http://www.tappi.org.
[4] 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.
[5] Available from the Fibre Box Association, 25 Northwest Point Blvd., Suite 510, Elk Grove Village, IL 60007.
~~[6] Available from American Trucking Association, Inc., 2200 Mill Rd., Alexandria, VA 22314-4677.~~
[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.

4.2The 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.

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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 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

7.1Corrugated 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.

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* *Construction*board —Singlewall board is used for lighter contents where some structural rigidity, compression strength, puncture resistance, resistance to puncture, and cushioning is needed. Doublewall board is used for heavier contents requiring a greater degree of structural rigidity, compression strength, and puncture resistance. *resistance to puncture. Triplewall is used for the heaviest contents where maximum structural rigidity, compression strength, and puncture 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 shipping containers. The following typical flute structures are provided as a reference: —*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:

Approximate Number

Approximate Flute Height

(not including thickness of facings)

	Flutes/ft Flutes/ Meter	(not includ- ing thick- ness of facings) Flutes/Foot
A-Flute	100 to 120	[30 to 36]
A-Flute	30 to 39	[30 to 36]
B-Flute	145 to 165	[44 to 50]
B-Flute	45 to 53	[44 to 50]
C-Flute	120 to 140	[36 to 42]
C-Flute	35 to 45	[36 to 42]
E-Flute	280 to 310	[86 to 94]
E-Flute	70 to 98	[86 to 94]

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 Strengthstrength 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 *Puncture Resistance*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.

7.3.1Puncture resistance is measured by the puncture test utilizing TAPPI Method T803.

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. Other versions Another widely used version of the McKee Formula utilize Formula, known as the modified version, utilizes the exponent values of box perimeter and board thickness instead of the square root function, or bending stiffness instead of board thickness, 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:

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

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, m [in.].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:

(3) $BCT = 5.874 \times ECT \times Caliper^{0.508} \times Perimeter^{0.492}$

where the terms are the same as for the simplified version (Caliper is another term for combined board thickness).

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

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 strengthBurst 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.[8]

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 linerboards (facings).

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

7.5.2

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 mustshall 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 the finished box compression, printing crush resistance, and quality of fabrication practice.

7.6.1Combined singlewall fiberboard should meet the following minimum flat crush requirements: —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/m² [26 lb/in²]:

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 *Printing Crush*—Excessive printing 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: crush deformations for singlewall boards due to feed rolls and printing:

Oil-Based Inks, mm [in.]	Water-Based Inks, mm [in.]
A-flute	0.38 [0.015]
B-flute	0.28 [0.011]
C-flute	0.33 [0.013]
A-flute	0.38 [0.015]
B-flute	0.28 [0.011]
C-flute	0.33 [0.013]

7.7.2 For doublewall boards useduse 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.] for water-based inks). 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

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

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 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.~~ 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 swivel 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 compression strength is less than the specified load.~~ 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 ~~F-factor~~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.].