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CORRUGATED CONTAINERS

32.1 INTRODUCTION

Information on printing, paper used in corrugated boxes, paper production, paper testing, and other topics related to the manufacture of corrugated boxes can be found in the appropriate chapters of this book. Many of the same techniques described in other sections of the book apply to the manufacture of corrugated boxes including slitting, scoring, and crowning of press rolls.

Brief history

The production of corrugated paper was patented by Albert L. Jones in 1871 as a packaging material. It was used for protecting glass containers from each other during shipping. In 1874, Albert Long patented the use of corrugated paper glued to another piece of paper (single—faced corrugated board). The Shefton machine of 1895 could make single—face or double—face corrugated board and operated below 10 ft/min.

In the early part of this century, railroads had a virtual monopoly on long—distance transportation. Many of the railroads owned large areas of timber and had ownership in companies that manufactured wooden crates. The railroads, therefore, charged a tariff for products transported with fiber (solid paperboard) boxes and corrugated boxes. In 1914, the Pridham decision forced railroads to rescind this tariff. This marked the beginning of the large—scale use of fiber and corrugated boxes in transportation. The amount used (in billions of square feet) was 6.6 in 1923, 44.3 in 1943, and 251 in 1979.

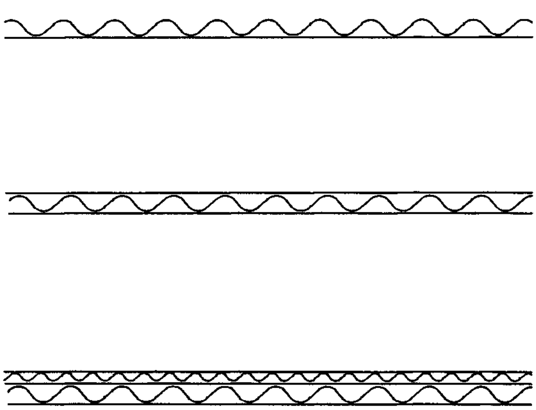


Fig. 32-1. Some examples of corrugated board including single—face (top), double—faced (middle), and double—walled.

Box types

Fig. 32-1 shows diagrams of several types of corrugated materials. Corrugated paper glued to one sheet on linerboard is called *single—face board.* It is used primarily as a spacer inside packages. If a second sheet of linerboard is glued to the other side the product is known as *double—face* board, and this product accounts for the largest percentage of corrugated board products.

Double—wall corrugated boxes are made with three layers of linerboard separated by two layers of corrugating medium. (A small amount of triple—wall corrugated boxes is produced.) Double—wall corrugated boxes usually use two different sizes of flutes, and the smaller flute is usually toward the outside of the box for several reasons. The smaller flute gives an even surface for the outer liner which provides a good printing surface; it also provides higher puncture resistance. (A common configuration for double—wall corrugated boxes is a B flute on top of a C flute.)

Flute types

The size of the flutes controls the properties of the final board. Small flutes increase the puncture resistance of boxes, while large flutes enhance the stacking strength of boxes. Page 162 gives the basic flute types, but the situation has increased in complexity. Flute C was originally 42 flutes per foot, but is now 39 flutes per foot. The C flute has replaced the A flute for most purposes since it requires less paper and gives similar properties to the A flute.

The E flute increased in use in the late 1980s in corrugated boxes designed to compete in the folding carton industry. The F flute was introduced in 1991 (about 0.03 in. high and about 150 flutes per inch) as a smaller alternative to the E flute and folding carton stock. Larger flutes are recent developments to allow double—face boxes to replace double—wall boxes. The K flute is 0.25 in. thick. The S flute is a jumbo flute.

32.2 MANUFACTURE

Introduction to the corrugator

The first part of the operation is accomplished by the *single—facer* section (Fig. 32-2). First the corrugating medium is unwound and conditioned to the proper moisture content and temperature with a preheater and steam shower. Preconditioning rolls, if used, are usually 12 to 18 in. in diameter. The corrugating medium must have enough water to make it flexible for proper flute formation. The adhesive usually has enough water to gelatinize the starch.

Splicers for the corrugating medium and linerboards attach the end of one roll of paper to the beginning of the next roll so production can be continued without having to stop the machine. Automatic splicers are activated by the (small) diameter of the roll in use or by detection of the paper end. Modern splicers have an overlap of only a few inches, which causes little problem in the production process or the final product.

The corrugating medium is sent between a set of corrugating rolls (12 to 24 in. in diameter) to flute the medium. After the corrugating nip, adhesive is applied to the tips of the flutes on one side of the sheet. Linerboard (which is preheated, but not usually premoistened) is pressed against the corrugating medium by the pressure roll (with pressures of 300—500 pounds per linear inch) while it is still supported by one of the corrugating rolls; the pressure roll, or single—facer, is 16—18 in. in diameter and heated to 177°C (350°F). The initial bond that is formed is called the green bond. Control of the moisture content of the linerboard prevents curl of the board product during its production. In some (older) corrugators, thin metal plates called *fingers* hold the medium against the corrugating roll to maintain its shape while the liner is applied to the fluted corrugating medium. Most designs are now fingerless and use a vacuum or air positive pressure.

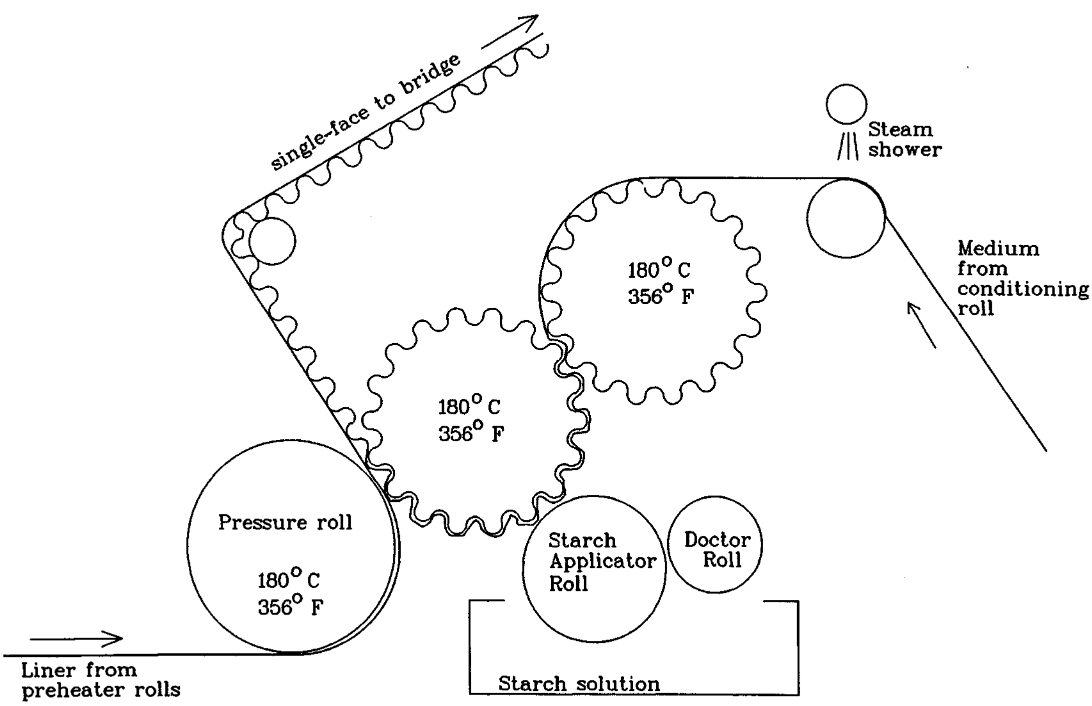


Fig. 32-2. Diagram of a single—facer.

The single—face product then goes to the *double—facer* (alias *double—backer*) section to apply a second layer of linerboard on the opposite side of the fluted corrugating medium. Starch adhesive is applied to the exposed tips of the fluted corrugating medium, the liner is put in contact with the medium, and the combination is placed under a belt that travels over steam chests; the nip at this point is extremely dangerous as it can drag a person's arm into it with severe consequences. (From here on out the board must be handled in a flat condition since wrapping it around rolls will cause permanent deformation.) The pressure applied in the *hot plate section* (or *double-backer*) cannot be so high as to crush the flutes. The product goes through the hot plate section for several seconds to allow the starch adhesive to set. It goes through a cooling section where it is pulled by the addition of a lower belt. The later section is often called the *traction section* because it pulls the web through as in the Langstron.

The adhesive application system had used tapered speed drives at one time, but developments in drive technology have changed this. For example, the speed of the adhesive applicator surface might be 20 ft/min slower than the paper speed regardless of the paper's speed in order to cause some wiping action; the more wiping action, the more adhesive transferred. When the machine is not moving, the applicator roll is separated from the paper. The distance between the starch applicator roll and the doctor blade is about 0.15 mm (0.006 in.).

Miscellaneous aspects of corrugators

Recent corrugators are 2500 mm (99 in.) wide and operate at 6 m/s (1000 ft/min). The corrugating medium may initially travel at 8 m/s if the take—up ratio is 1.33 (or 8 m/s divided by 6 m/s) as for a B flute. An 85" corrugator will use 4—5 tons of steam per hour requiring a minimal pressure of 175 psig.

Corrugating adhesive

Initially starch (one part in about 15 parts of water) was used as the adhesive, but it took a long time to set, which caused numerous problems for box makers. By 1920, sodium silicates (waterglass) were the principal adhesives used in boxmaking. This caustic material was strong but brittle and had some major problems in its use.

In 1936 J.V. Bauer patented the use of starch adhesive that was cooked on the box during assembly (which, of course, requires that the box be heated to set the starch adhesive). By 1960 starch regained its position as the principal adhesive for boxmaking. Corn is the most common source of the starch. The use of starch is just over 2 lb/1000 ft^2 of double—faced board.

In the Stein—Hall process, cooked starch (about 15—17% of the total starch) is used to make a suitable formulation for the uncooked starch. Sodium hydroxide is used in the formulation to lower the temperature at which the starch will gelatinize on the box; corn starch will gelatinize around 70°C, but NaOH lowers this to about 65°C for making corrugated boxes. Borax is used to increase the tackiness of the adhesive and act as a buffer for the NaOH. A preservative must be used to prevent microorganisms from attacking the starch because they can quickly alter the viscosity of the formulation. Other materials in addition to cooked starch can be used to make a suitable formulation with the uncooked starch, especially in water—resistant adhesives.

There must be adequate water in the starch formulation and sufficient heating of the formulation on the corrugator to get a suitable bond. The cooking of the starch and the formation of the bond take place within a few one—hundredths of a second on fast—moving single—facer machines (where high pressure between the corrugated sheet supported by the corrugator and the linerboard are possible). On double—backer machines, the time for cooking must be several seconds since much lower pressures are used, so a higher viscosity starch solution can be used.

A recent practice at some box plants is to use flexographic wash water as the water in the starch adhesive. One should know exactly what ink components are in this wash water and how they will affect the system. DiDominicis and Klein (1983) give much information on the starch—based adhesive used in corrugated boxes.

White boxes

White boxes can be made using a thin layer of white pulp on the top liner (applied with a second headbox) which gives a blotchy appearance. A second method is to use an entirely white linerboard, which is expensive. A third method is to coat the corrugated box.

Corrugator finishing operations

The continuous board must then be cut into *blanks* (individual sheets) that will each make an entire box. The continuous board first goes through the *slitter/scorer section*. Here, the board is cut and scored in the machine direction. A series of sheeter knives make cuts in the cross machine direction to produce the blanks.

Blanks to containers

The blanks go through a series of operations to become containers. They go through a printing operation. They must be scored in the cross machine direction. Slots must be formed by stamping out portions of the box to define the tabs for assembly.

Overall considerations

The cost of paper delivered to the box plant is usually 60—80% of the final cost of a box. Paper use (especially trim and other waste) must be minimized to stay competitive with other box plants. Boxes are constructed to meet requirements of the rail (especially Rule 41) or trucking industries (Rule 222 for common carriers). It takes about 60—70 tons of paper to produce 1 million square feet of corrugated board. A corrugator with a width of 97" and operating at 600 ft/min will use over 3500 tons of paper per month.

About 5—7% of the incoming paper will become scrap material. This is usually handled by a pneumatic system that goes to a cyclone separator. From the separator the waste paper goes to a baler, where it is apt to be sold to a pulp mill using waste paper.

Scheduling orders

A wide variety and number of orders may be processed in a relatively short time. These must be scheduled to meet deadlines, to obtain the maximum capacity of machines, to make the most efficient use of the machine width, and other factors. Also, the proper type and suitable amount of paper must be on hand (a 5—6 week inventory of paper is generally suitable). Scheduling orders efficiently, as is any scheduling operation, can be an extremely complex task using linear programming and other tools. Computer modeling of the scheduling process is extraordinarily complicated; thus, this position is of key importance to the smooth operation of the box plant.

Partial rolls of paper that remain after a job should be measured, recorded in inventory, and used in the next suitable job so one is not inundated with partial rolls (called butts) in inventory.

32.3 TEST METHODS

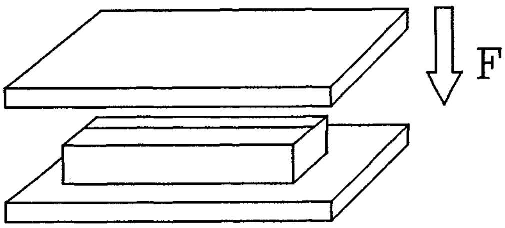
Testing of corrugated board

A variety of tests are used to test corrugated board, the two paper components of board, or assembled boxes. Some of these, depicted in Fig. 32-3, are performed between two flat platens. Various types of compression (or crush) tests are critical since most corrugated boxes fail in compression when stacked.

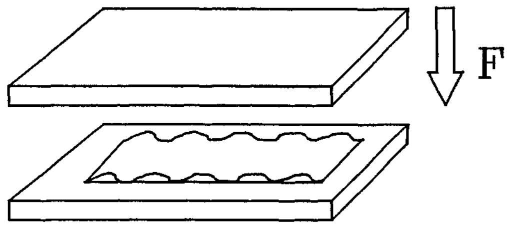
For routine quality control, sealed, empty boxes are tested on relatively large test devices with parallel platens (moving at 10—13 mm/min during the test) in the *box compression test*, BCT, (Tappi Standard T 804). A number of different box designs (flute types, liner types and weights, etc.) can be compared directly provided the boxes are all the same size. Inner packing may be used for testing design loads. This test best represents the performance of most corrugated boxes in service (i.e., where they are stacked on top of each other). In reality, however, loading will not be uniform, humidity conditions will vary, loading times will be much longer; loads substantially lower that of the test value can be used in service.

Testing of board components

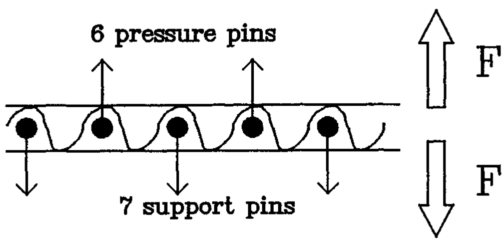
The remaining tests described here are done on small samples on a test device such as that shown in Fig. 7-16 on page 179. The *pin adhesion test* (T 821) tests the strength of the bond of the flute tips of the corrugating medium to one of the liner boards in a sample of corrugated board. The sample size is 2 in. by 6 in. for boards with A or C flutes and 1.25 in. by 4 in. for boards with B flutes. Low values for this test are caused by poor adhesive or poor adhesive application (if failure is at the glue line) or containerboard with a low internal bond strength (if failure occurs in the paper).



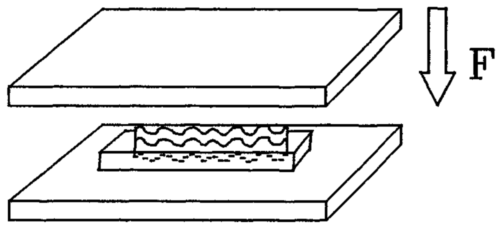
The box compression test (BCT) measures the resistance of an assembled box to compressive force.



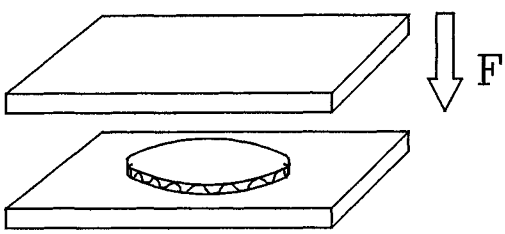
The concora medium test, CMT, measures the crushing resistance of a fluted sample of medium.



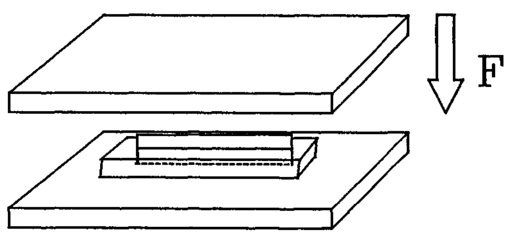
The pin adhesion test, PAT, measures the resistance of the flute tips to separation from the liner.



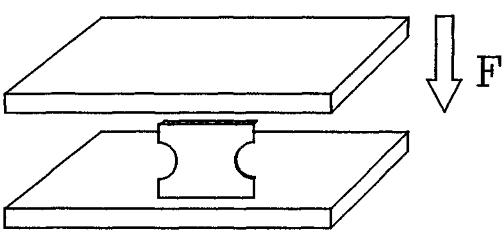
The corrugated crush test, CCT, is performed on medium (in a jig) fluted in the laboratory.



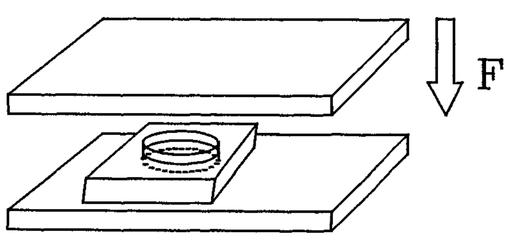
The flat crush test, FCT, measures the resistance of the flutes to a crushing force.



The concora liner test, CLT, measures the edgewise compression in a supported sample of liner.



The edge crush test, ECT, measures the compression strength as in boxes that are stacked.



The ring crush test, RCT, measures edgewise compression in a ring of liner supported by a jig.

Fig. 32-3. Some common tests performed on corrugating medium, linerboard, corrugated board, and completed boxes. One test machine is shown in Fig. 7-16 on page 179.

The *flat crush test* (T 808) measures the resistance of the flutes to crushing force from a sample cut from manufactured corrugated board. T 808 specifies a circular sample of 5 or 10 in.^{2} in area. Low values for this test might be due to medium of low strength, crushed flutes, or flutes that have not been well formed (such as leaning flutes). This test is not suitable for double— or triple—wall boards since the inner liner(s) are subject to lateral motion during the test, but would be much less so in products in use. This test does not simulate forces applied to boxes in use, so the correlation between this test and how a box will perform in service is not always high. The bending stiffness of the corrugated board should complement the FCT (Markström, 1992).

The *edge crush test* or *edgewise compression test*, ECT (T 811) also uses a sample cut from manufactured board. The shape may be rectangular or as that shown in the Fig. 32-3; the latter shape is designed to give a failure away from the edge. The force is applied parallel to the flutes, just as in a container in service. This test is a good indicator of the general performance of a box in transportation. ECT can be related to BCT by use of the McKee (1963) equation (Markström, 1992). There are many modifications to this test which are discussed and quantitatively compared by Markström (1992).

The remaining tests described here are designed to test the properties of the medium or liner, i.e., they are quality control tests of the raw materials. The sum of the compression strengths of the liner and medium layers correlates well with the compression strength of the corrugated board.

The *short—span compression test*, SCT, has been described on page 177. T 826 specifies a sample 15 mm wide. This test provides similar information to other compression tests except sample geometry does not enter into the results. Geometry is an issue for at least two reasons: slender samples, such as a straw in the lengthwise direction, fail by buckling long before the material fails by compression; samples that fail at the edge give lower strength results than are truly representative. For this reason it is replacing other, older compression tests such as those described below (Markström, 1992).

The *concora medium test*, CMT, or *flat crush test* [T 809 specifies a sample 0.5 × 6.0 in. (12.7 × 152.4 mm)] measures the crushing resistance of a single—face sample prepared in the laboratory. It tests the medium's resistance to crushing.

The *corrugated crush test*, CCT, or *fluted edge crush* measures the edgewise compression strength of a piece of corrugated medium. This provides a measure of the corrugating medium's contribution to the compression strength of a corrugated box. It is an alternative to the ring crush test (T 818). T 824 calls for a sample 0.5 in. by 6 in. with the longer dimension in the machine direction. The sample is held in a specimen holder during the test. The *concora liner test*, CLT, is very similar to the CCT, except the sample is not corrugated.

The *ring crush test*, RCT, measures the edgewise compression in a ring of liner or medium that is supported in the groove of a jig. Two variations of the test are T 818 (flexing beam) and T 822 (rigid platen).

32.4 ANNOTATED BIBLIOGRAPHY

Corrugated containers—thermal resistance, misc.

1. Bormett, D.W., Overall effective thermal resistance of corrugated fiberboard containers, USDA For. Ser. Res. Pap. FPL 406 (1981), 12 p. The effective thermal resistance of corrugated fiberboard containers was determined versus air velocity (0—5.4 m/s) and board thickness. Differences were noted for heating versus cooling for boards less than 20 mm thick. This information is useful for consideration of how produce and frozen foods will behave during shipping. The effective thermal resistance of a corrugated fiberboard package was found to be about 0.18 K·m^2/W (although the outer boundary air and box—product interface may effectively double or triple this value) for a kraft linerboard package (0.33 mm thick) to 1.10 for a corrugated fiberboard box having walls 51 mm thick as shown in Table 32-1.

2. TAPPI Technical Information Sheets (TIS) with numbers 0303 to 0305, and several 0306

to 0309 cover various aspects of corrugating medium and starch adhesive preparation.

3. DiDominicis, A.J. and G.H. Klein, Corrugating, in *Pulp and Paper Chemistry and Chemical Technology*, 3rd ed., J.R. Casey, Ed., 1983, Wiley, New York, pp 2373-2398.

4. Markström, H., *Testing Methods and Instruments for Corrugated Board*, 3rd ed., Lorentzen & Wettre, Stockholm, 1992, 77p. While promoting the publisher's test instruments, it is a useful, relatively unbiased source for the theory of the test methods. It is usually available on a complimentary basis.

5. McKee, R.C., J.W. Gander, and J.R. Wachuta, Compressive strength formula for corrugated boxes, *Paperboard Packaging* 48:19, 149-159(1963).

Table 32-1. Overall effective thermal resistance (values listed are R or K·m²/W) of a cubical corrugated container. From USDA For. Ser. Res. Paper FPL 406 (1981).

Board caliper, mm	Air velocity, m/s		
	0.0	1.8	5.4
0.00	0.33	0.14	0.13
0.33	0.42	0.19	0.18
4.23	0.45	0.31	0.28
12.7	0.61	0.50	0.50
25.4	0.80	0.73	0.70
50.8	1.10	1.04	1.04