The edge crush test

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The choice of ECT as the measure of strength in the new Alternate freight regulations provides a material standard much more closely related than burst to container performance.

The edge crush test (ECT) or short column test for corrugated board is in the limelight today for two reasons. First, this test has been adopted by the railroad and trucking classification committees as an alternate to bursting strength in determining the strength of corrugated board used in shipping containers—reason enough for a better understanding of the test. The second reason is that ECT is directly related to box compression strength and, in today's shipping environment, box compression is the most important factor affecting box performance. As we will discuss, we cannot ignore the fact that ECT is not the only factor affecting this performance. If we focus entirely on ECT we risk box failures. This could result in withdrawal of the permission to use the advantages of the Alternate regulations. There is further interest in edge crush because of the discussions in the international community toward finding an international standard test method.

Background

The edge crush test that is to be used in determining compliance with the new Alternate Rule 41/Item 222 is described by TAPPI Test Method T 811 (*1*). Briefly, this method prescribes a test specimen 2 in. wide with varying height, depending upon the flute construction. The loaded edges of the specimen are reinforced by impregnating with paraffin wax. The test is performed in a compression machine.

Edge reinforcement

The development of the method and the reasoning behind the various aspects of the technique have been described by Kroeschell (*2*). The first researcher speaking for the importance of the test was Kellicutt of the U.S. Forest Products Laboratory in Madison, WI (*3*). The basis for the T 811 test was the work of McKee and his associates at the Institute of Paper Chemistry (IPC)*, in Appleton, WI (*4*). One of the important features was preventing premature failure of the test specimen at one of the loaded edges. A classical expedient to eliminate edge failure is the use of a necked-down specimen shape such that the loaded edges are longer (e.g., 3x) than the narrow necked-down portion where failure almost always occurs. At the time of McKee's work, preparation of the necked-down shape was tedious. McKee had noted that reinforcement of the loaded edges of a rectangular specimen was also effective in eliminating premature failure at the loaded edge. It remained for Koning, also at the Forest Products Laboratory, to quantify the relationship and conclude that edge reinforcement of the rectangular specimen was preferred (*5*). Recently, however, Koning has devised a new means of cutting the necked-down specimen and he now prefers this technique (*6*).

Test preparation

Many researchers have identified the fact that the method of cutting the test specimen is critical, although with edge reinforcement this may not be as critical as was reported by the many who worked with unreinforced pieces. In a more recent study, Schrampfer and Whitsitt (*7*) in testing unreinforced specimens, also at the IPC, found that specimens cut with the circular saw with the sharp hollow-or taper-ground blade prescribed in T 811 gave the highest test results. However, the use of a double-bladed motorized cutter with sharp single-bevel blades yielded results so slightly lower that, with edge reinforcement, the differences may be insignificant. They have stated that this alternative procedure may be an acceptable substitute for the saw specified in T 811. The single-bevel blade operated with the bevel facing away from the test specimen appears to be critical in this alternative. It is also important that the test specimen be cut with the loading edges exactly perpendicular to the flutes (*8*).

Testing machine

The test originally proposed to the carriers for incorporation in the Alternate Rule 41/Item 222 was TAPPI T 823, which was identical to T 811 except that a rigid platen loaded-cell machine was used to measure the compression strength instead of the flexing-beam instrument. Subsequently, TAPPI included both instruments in T 811 and withdrew T 823. Whitsitt and Schrampfer compared several test machines and concluded that the differences are not significant. Fre-

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quent instrument calibration is essential, regardless of the machine used.

Because the rigid-platen testing machine is easier to maintain in the parallelism required, it will produce more reliable results day-in and day-out. It should be remembered that all of the test data used to determine the strength levels in the new Alternate Rules were determined on rigid-platen instruments operated in accordance with T 823, now T 811.

Alternate procedures

The use of alternate procedures has been the topic of wide discussion, and many literature references could be cited here. Major concern relates to the tedium in the edge reinforcement step. Australia has been strong in proposing that a method adopted by FEFCO (the European federation of corrugated box manufacturing associations) be an international standard (*9*). The U.S. concern with this widely used method is that in this test, failures almost always occur at the loaded edges and the results are consistently lower than those obtained by the T 811 procedure (about 12% on the average). We contend that the FEFCO method does not measure the intrinsic compression strength of the corrugated board. Another method has been developed by Schrampfer and Whitsitt using a test fixture devised for the Japanese standard (JIS) test method (*10*). Again, the test shows mostly loaded edge failure, but the results are equal to those obtained with T 811. It is felt by many that use of the fixture is also tedious. Many in the industry worldwide feel that they have alternate procedures that are simpler to use and highly correlated with T 811. The bottom line, however, is that the method prescribed in both the Rule 41 of the railroads or Item 222 of the trucks is TAPPI Official Test Method T 811. Other methods can be used with confidence since many of these are highly correlated with T 811, but for referee testing T 811 must be used.

The importance of conditioning

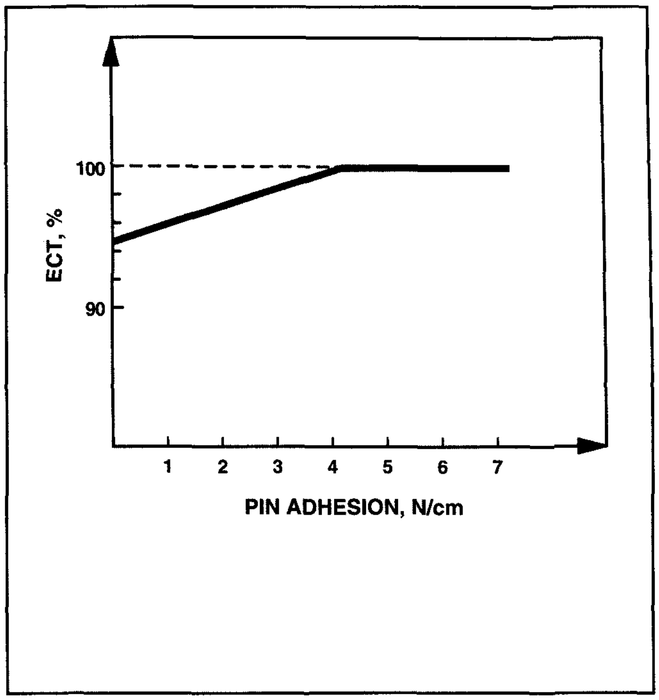
Edgewise compression is extremely sensitive to the atmosphere in which the test is performed. Again, good correlations may be achievable in the industrial atmosphere, but for referee purposes the procedures prescribed in T 811 (reference TAPPI T 402) for preconditioning, conditioning, and testing must be explicitly followed.

Corrugating variables

What are the variables that the boxmaker must control in order to assure optimum compliance with the edge crush test? Choice of raw materials is an obvious parameter and, indeed, as we will discuss later, it is the key variable. However, there are other factors under direct control in the box plant such as adhesion and absence of crushing that influence the test results.

The most comprehensive review of the effect of boxmaking variables on the edge crush test was given by Eriksson (*11*). He reported on the work of Langaard and Augustin, which indicated that a pin adhesion value of only 4 N/cm was required to reach an edge crush test independent of adhesion strength (**Fig. 1**). This equates to an adhesion strength of just slightly over 2 lb/in. or, for C-flute, only a little more than half of the generally recognized minimum pin adhesion strength specified for good operating practice. Thus, adhesion strength is of minimum importance in the edge crush test. This should not be surprising when it is realized that ECT is measured under the standard humidity of the laboratory. Only enough strength is needed to hold the component raw materials together.

1. The influence of pin adhesion values on ECT (*11*)

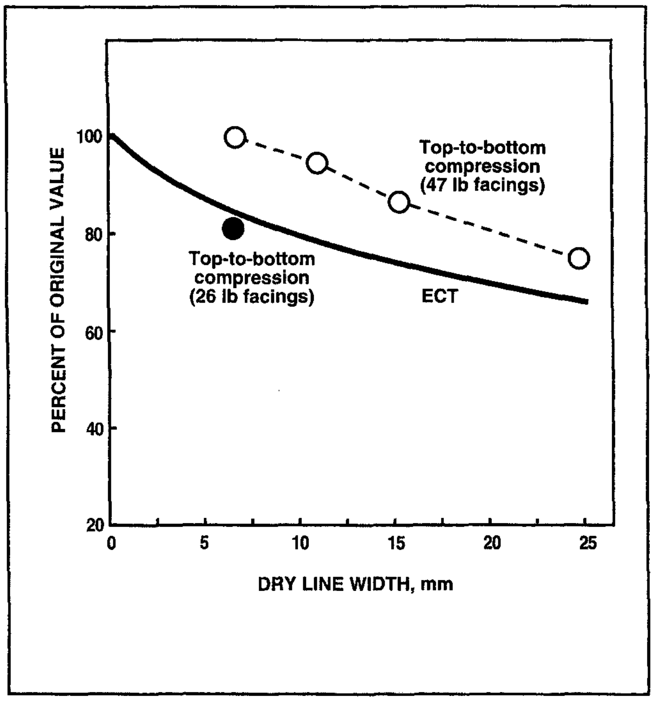


Glue skips are another factor. What should happen if a dry line from one of the slots of the single-facer applicator roll should occur in the test area? Eriksson reports a modest decline of ECT with increasing width of glue skip. A skip of 3 mm (1/8 in.) can reduce the ECT by 5% (**Fig. 2**). Despite this minimal effect, it would seem that glue skips should be prevented by proper setting of the clean-out prongs. Of course, the fingerless single-facer makes this discussion academic unless glue skips are induced by factors other than the slotted applicator roll.

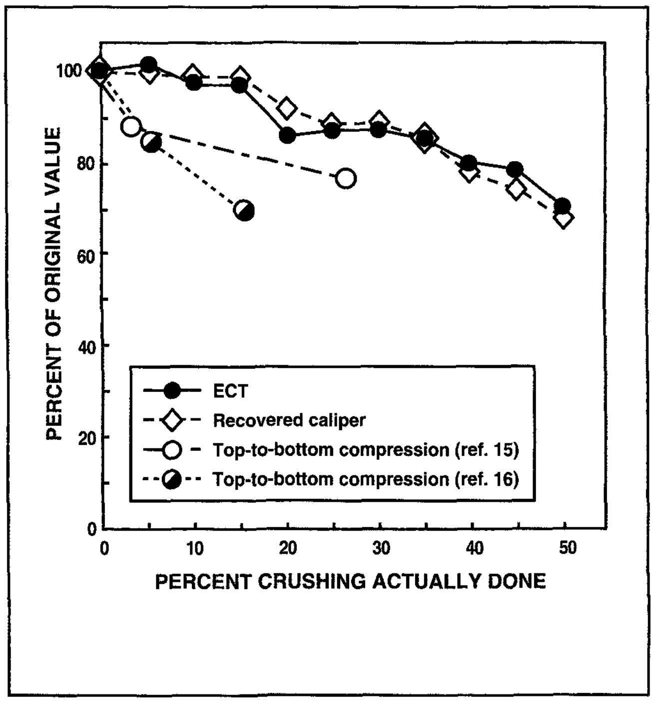
In unpublished work, McKee and his associates reported that corrugated board with fractured flutes had a 15% reduction in ECT.

What about crushing? Theoretically, crushing should also have a minimal effect on ECT. We should remember that the test heights in T 811 were chosen such that failure is in the true compression mode. There should be no flexural failures in the test. This resulted in the recommendation of a flute height of 38 mm for C-flute and 32 mm for B-flute. For example, if we were to crush the C-flute to the equivalent of B-flute, 28%, we could expect inducement of flexural failure and a significant reduction of ECT. At a series of seminars for boxmakers sponsored by The American Paper Institute and the Fibre Box Association in late 1984 and early 1985, Batelka presented data which showed that this approximately 30%

2. The relationship of ECT loss and box top-to-bottom compression strength to width of glue skips (*12, 17*)



3. Loss of ECT, combined board thickness, and box top-to-bottom compression strength as a function of crushing (*12, 15, 16*)



reduction in thickness resulted in a decrease of less than 15% in ECT (**Fig.** 3) (*12*). This was excessive crushing yet the effect on ECT was modest. Where crushing was less severe (less than 10%), ECT was virtually unchanged. Eriksson reports that less than 40% reduction in thickness reduced ECT (by the FEFCO method) by less than 5% and that complete crushing only lowered the ECT by 30%.

Linerboard and corrugating medium

Since all of these variables, adhesion, and combined board thickness have only minimal effect on ECT, this property must be largely determined by the strength of the component linerboard and corrugated medium; indeed, that is so. ECT is a material standard, but as we have said so very often in our pronouncements regarding the new Alternate Rules, ECT is a material property much more closely related to box strength than is bursting strength (Mullen), and it is a test that recognizes the contribution of the corrugated medium to box performance.

What do we know about the relation of ECT to properties of the linerboard and medium? Koning reported long ago that ECT was strongly related to the sum of the ring crush values of the component facings and the medium with allowances for the additional length of medium in a unit length of combined board (the strength of the medium multiplied by its take-up factor), with a constant multiplier to reflect the different unit lengths in the two tests (*5*). There is some deviation of this relationship in the extremes because the ring crush test was being used to measure materials beyond its scope. However, the relationship has good correlation and this has been confirmed by a number of published and many more unpublished studies. Most recently Seth (*13*), at the Pulp and Paper Research Institute of Canada, made an extensive study of the relationship, in this instance using the short span compression test (TAPPI T 826) to characterize the edgewise compression strength of the components. This has the advantage that the scope of the test was not exceeded for any of the materials used. The study included 57 lots of commercially manufactured boards of both B- and C-flute construction from three corrugated box plants. Using the sum of the short span compression strength, again adjusted by the take-up factor, correlation coefficients with ECT ranged from 0.942 to 0.978. Seth concluded that, "In spite of the various factors that affect the strength of corrugated combined board and its measurement, this study has demonstrated that the edgewise compressive strength of combined board is proportional to, and can be predicted with considerable accuracy from, the intrinsic edgewise compressive strengths measured on corresponding component paperboards." In fact, when we discussed the various test methods for ECT with the Europeans, some Swedes asked, "Why test ECT at all? Merely test the component materials and calculate ECT."

If the variables under control by the boxmaker other than proper selection of the component paperboards have so little influence on ECT, and that is the criterion for strength in the new Alternate Rules, should we be concerned at all with crushing, glue skips, and inadequate adhesion? The answer is "YES," of course! While ECT is the single most important property of corrugated board in determining box compression strength, it is not the only factor by any means. The second important property is the board's flexural rigidity, and this is determined by the board's thickness (*14*).

The effect of crush on box compression

In 1974, in a cooperative research project for the American

Paper Institute, Whitsitt and McKee, at the Institute of Paper Chemistry, subjected commercially manufactured boxes to flat crushing loads to determine the effect on box compression (*15*). Two sizes of boxes were fabricated from standard linerboards and mediums of varying flat crush strength. Top-load and end-load compression tests were made. Since varying flat crush boards were made and two crushing loads were chosen, the crush varied from 30% to 93% of the boards' flat crush strength. Under this range of loading the caliper was reduced by up to 1.16 mm (0.046 in.) or 29% of its original thickness. Top-to-bottom compression strength was decreased by 18–22%. These may seem to be modest reductions when related to the degree of crushing, but it should be noted that these maximum reductions occurred even at 25% reduction in caliper with loads only about 60% of the boards' flat crush. End-to-end loading was more severely affected. Compression strength losses were as high as 41%.

Perhaps of even greater significance was the loss of compression strength of the uncrushed boxes. Compression strength was significantly lower than expected from theoretical consideration of the ECT of the board. It was then noted that all boxes showed two relatively narrow crushed streaks running vertically on each box, presumably from improperly adjusted pull-rolls on the folder-gluer. There was insufficient material to rerun the test. Only when the lowest caliper of these two streaks was used in the box compression prediction formula was there any agreement with the actual compression measured. In other words, the maximum degree of crushing determines the box's ultimate compression strength. This underscores the importance of eliminating crushing. Crushing in a narrow streak is just as damaging as an overall crush.

Bick (*16*) has expressed these kinds of losses in terms of the cost of replacing the components with heavier materials to achieve the same compression strength had there been minimal crushing. He shows an increase of fibrous raw material cost in excess of 20% if the board is crushed by just 0.5 mm (0.020 in.). He says, "...savings from the elimination of as little as 0.002" of crush can result in savings approaching US$ 100,000 per year." The damaging effect of crushing will not make much of a mark on ECT and will therefore not affect the box's acceptance by the freight regulations, but it can have a significant effect on performance, as illustrated in Fig. 2. There is compelling reason for the boxmaker to inspect every place in his operation where crushing can occur and take corrective action when necessary, from the rider-roll on the glue machine to the pull-rolls in the counter/ejector.

The importance of adhesion on box performance

Earlier we discussed the need for only minimum adhesion to comply with the ECT under standard humidity. It should be remembered that much research and practical experience has shown that the stronger adhesion provided by water-resistant bonding has significantly improved the compression strength and stacking performance of corrugated shipping containers in the real environment.

Koning and Moody made an extensive study of the effect of glue skips on the compression performance of corrugated boxes (see Fig. 2) (*17*). They found that while the effect of narrow glue skips was negligible on boxes made with heavy (229 g/m^2) (47 lb/1000 ft^2) facings, on boxes made with 127 g/m^2(26 lb/1000 ft^2)facings, a glue skip 6 mm (0.24 in.) in width caused an 18% reduction in compression strength.

Summary

The choice of ECT as the measure of strength in the new Alternate freight regulations is wise, for now we have a material standard much more closely related than burst to container performance. However, we must also be aware that some fabrication variables may not strongly influence ECT while they can have a very significant effect on performance. Ignoring these principles will produce box failures in shipping, handling, and warehousing. Too many such failures could lead to cancellation of the Alternate Rules. □

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