

Compressive response of corrugated board

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ABSTRACT *An experimental technique that enables accurate measurement of the entire load-deformation curve up to failure in uniaxial compression of corrugated board is presented. The specimen is designed suitably to avoid end crushing, which is a common failure triggering mode in the edgewise compression test. With special side supports designed to avoid global buckling, it is possible to use long gauge lengths and a displacement gauge directly attached to the specimen. This technique has been employed to characterize the compressive response of corrugated board loaded in the cross-machine direction (CD).*

Comparison with the compression stress-strain curves for the components established by long-span compression tests shows that the compression load-strain curve of corrugated board closely represents the superposition of the load-strain curves of its components, provided that local buckling of the linerboards or fluting does not occur. Local buckling extends the deformation of the corrugated board and slightly reduces the compression strength. A simple scaling law, based on Weibull statistics, was developed to translate the short-span compression strength to long-span compression strength. This scaling law enables the straightforward prediction of the compression strength of corrugated board from short-span compression strength testing of the components.

KEYWORDS

Combined boards
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Corrugated boards
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Mechanical tests
Models
Packaging papers
Paperboard grades
Properties
Stress-strain properties
Tensile properties
Test methods

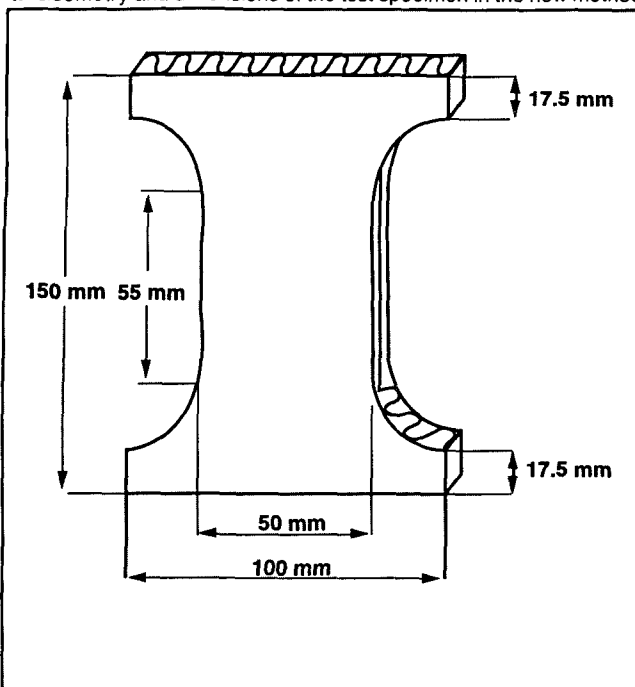
The compression strength of corrugated board is a key property in the design of board structures. It is desirable to develop a model that predicts combined board compression strength from properties of its constit-

uent linerboards and fluting in order to reduce manufacturing and testing costs and to simplify box design. Such a model would provide the corrugating industry a tool to specify mechanical properties of linerboard and

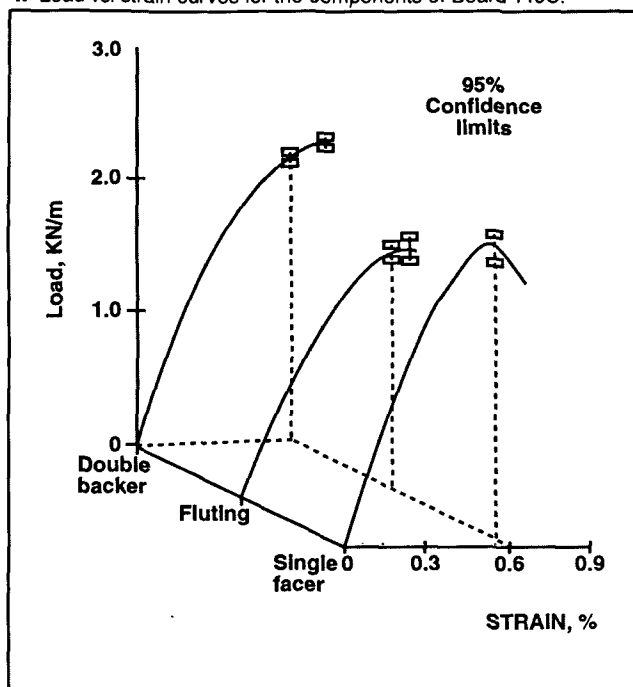
fluting to maximize the compression strength of combined board.

Our primary purpose in this study was to develop a test method to accurately measure the complete uniaxial stress-strain curve of corru-

1. Geometry and dimensions of the test specimen in the new method



4. Load vs. strain curves for the components of Board 140C.



gated board. Another objective was to examine the validity of the superposition principle in predicting board compression strength based on appropriate test methods. Finally, we used a simple scaling law based on Weibull statistics to calculate the compression strengths of paperboards from compression strength data obtained using a short span test.

Background: models and theoretical approaches

Several models have been proposed to calculate the compression strength of combined board. The simplest model adds the compression strengths of the components while incorporating the takeup factor of the flute layer. For a single-wall corrugated board loaded in the cross-machine direction (CD), the compression strength can be expressed as:

$$X_c = X_{L,1} + X_{L,2} + \alpha X_F \quad (1)$$

where

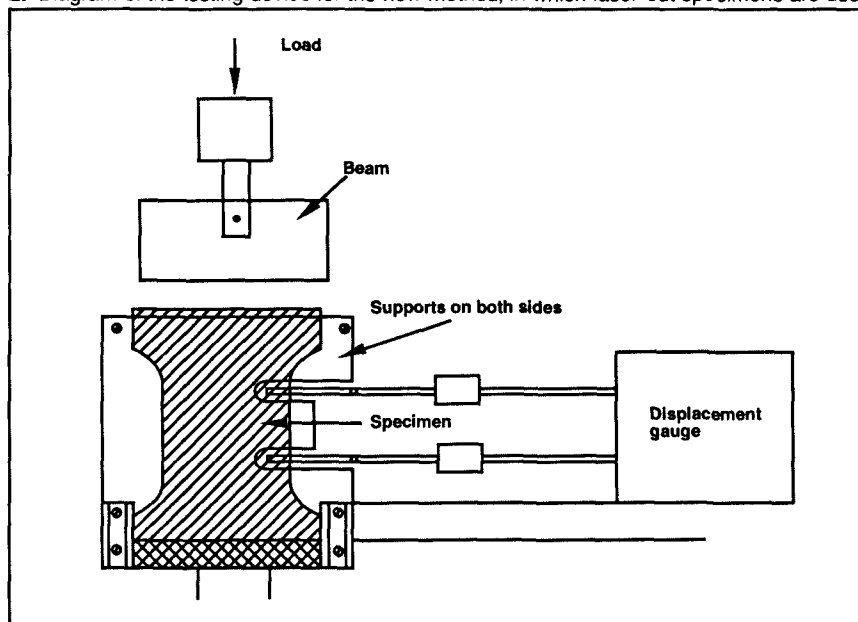
X_L = compression strengths of the Linerboards 1 and 2

X_F = compression strength of the fluting

α = takeup factor of the flute layer.

For double- or triple-wall corrugated boards, similar additive rules could be formulated.

2. Diagram of the testing device for the new method, in which laser-cut specimens are used

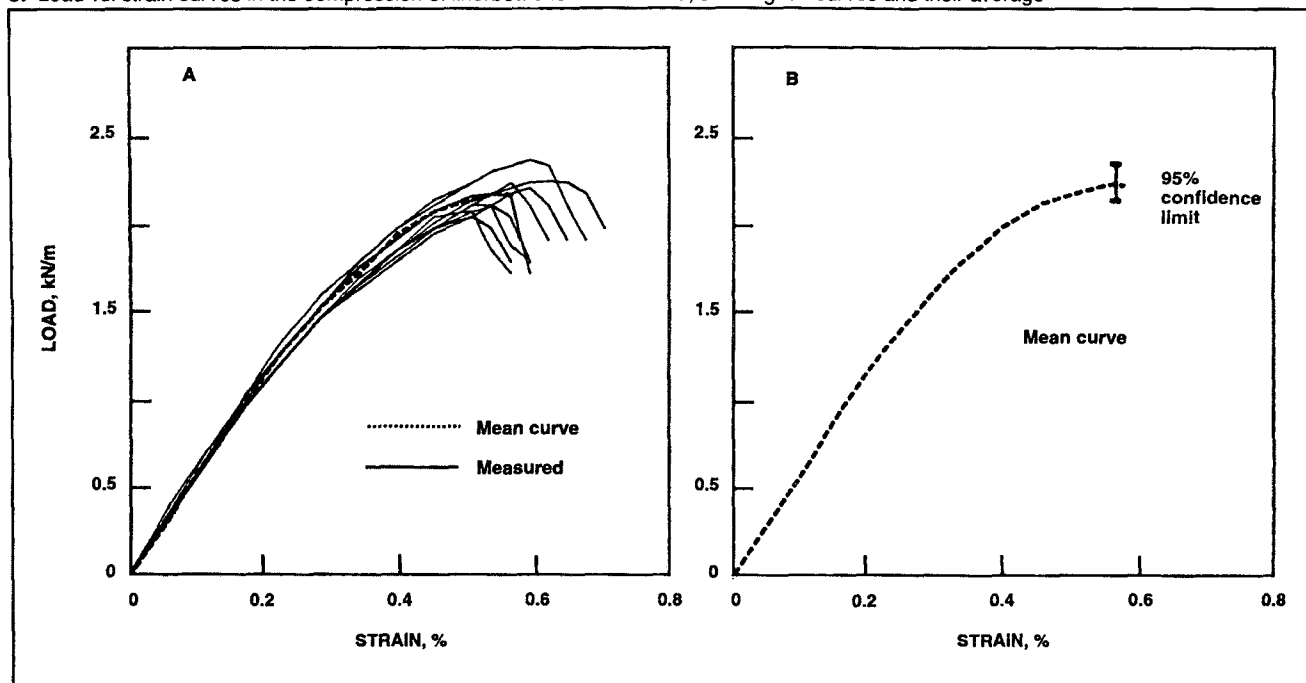


The agreement between experimental measurements of the compression strength of corrugated board (edgewise compression test values) (1) and predictions based on Eq. 1 has been found to be less than satisfactory (2). The discrepancy may be related to premature failures of the board at the loaded edges in the edgewise compression test, which reduces the apparent compression strength. The constituent facing and fluting compo-

nents of the combined board may fail in a local buckling mode, which also reduces the apparent strength. Determination of the compression strength of the components is also subject to errors arising from buckling prior to true compression failures or from clamping when short gauge lengths are used (3).

To compensate for these deviations, Eq. 1 has been extended with two empirical parameters, a and b , which

3. Load vs. strain curves in the compression of linerboard for Board 140C, showing ten curves and their average



are determined by regression analysis for a given set of test methods for the compression strength of paperboards and combined board (2, 4-7):

$$X_c = a(X_{L1} + X_{L2} + \alpha X_F) + b \quad (2)$$

With this two-parameter empirical model, a reasonable estimate of the corrugated board compression strength can be made. However, the disadvantages of this empirical equation are that any inconsistencies in the test methods are hidden in the regression analysis and that the regression analysis has to be repeated for each combination of linerboards and fluting. Producers of linerboard and fluting would definitely benefit from a simpler and more accurate model for determining strength.

A more theoretical approach to the compression strength of combined board has been suggested by Moody (8). He divided the combined board structure into plate elements. The flute layer is approximated with straight and flat plate elements. The combined board is considered to fail when one of the elements, either facing or fluting, buckles.

Based on this hypothesis, assuming material to be isotropic and the stress-strain curves to be identical for linerboard and fluting, Moody derived a compression strength model using the theory of thin plates under

large deformation (8). This model was extended by Johnson *et al.* to predict the edgewise compression strength of combined board when local buckling occurs, allowing for elastic-plastic behavior, different elastic properties of the flute layer and the facings, and an arbitrary take-up factor (9).

Urbanik (10) and Ince *et al.* (11) applied this theory to evaluate the relative importance of the facings and core to the compression strength of the combined board. Bormett compared the model by Johnson *et al.* with experiments and showed that the model accurately predicts the compression strength of combined board if the compression stress-strain curves of the components are measured at long span and if strain rate differences in the testing methods for paperboard and combined board are taken into account (12).

Experimental procedures

Materials

Five grades of corrugated board were considered. The combined boards were produced at SCA Emballage in Gothenburg, Sweden. The boards were collected as corrugated board sheets and as paperboards from corresponding paper reels used in the production of the combined board. The corrugated board grades were

marked 140B, 140C, 160C, 530C, and 210BC. The characters B, C, and BC denote various standard flute geometries. The nominal grammages in g/m² of the linerboards and flutings in these boards were:

- 140B: 140-112-140
- 140C: 140-112-140
- 160C: 200-112-186
- 530C: 300-150-186
- 210BC: 140-112-112-112-140.

Mechanical testing

The apparent thickness, grammage, and short-span compression strength were measured according to standard test procedures for paper and paperboards. The paperboards were conditioned before testing in a controlled atmosphere of 23°C and 50% RH. Standard test procedures were also used to determine the grammage and thickness of the combined board. In all tests, except short-span compression strength, ten measurements were made on each board type, and average values and standard deviations were calculated. Twenty short-span compression strength measurements were made on each paperboard according to the Scandinavian pulp, paper, and board standard (SCAN P46).

To establish the stress-strain curve in compression, long gauge lengths are required. For this purpose, we

I. Mechanical properties of linerboard and fluting for the five different grades

Paperboard	Grammage, g/m ²	Thick- ness, μm	Long span compressive strength, kN/m		Compressive stiffness, kN/m	Ultimate strain, ^b %
			Ultimate ^a	Critical		
Board 140B						
Single facer	138±1.4	204±3	2.24±0.12	2.24±0.10	601±40	0.58±0.08
Fluting	112±1.4	205±4	1.70±0.29	1.68±0.25	474±30	0.59±0.10
Double backer	142±1.0	172±2	2.08±0.12	2.03±0.07	569±20	0.64±0.07
Board 140C						
Single facer	139±0.9	211±3	2.21±0.15	2.16±0.15	616±30	0.56±0.05
Fluting	110±0.9	185±4	1.81±0.12	1.79±0.07	459±30	0.62±0.08
Double backer	141±0.7	169±4	2.20±0.05	2.09±0.04	582±30	0.69±0.07
Board 160C						
Single facer	186±1.5	244±3	2.83±0.12	2.70±0.10	658±54	0.85±0.13
Fluting	109±2.1	217±7	1.55±0.14	1.54±0.14	404±23	0.68±0.10
Double backer	201±2.2	268±5	3.38±0.10	3.37±0.09	945±56	0.68±0.09
Board 530C						
Single facer	185±1.1	240±4	2.84±0.15	2.82±0.13	610±25	0.77±0.07
Fluting	147±2.6	283±6	2.10±0.11	2.09±0.09	492±25	0.78±0.07
Double backer	294±2.2	369±6	4.46±0.23	4.44±0.19	1055±32	0.74±0.10
Board 210BC						
Single facer	139±1.5	203±4	1.90±0.14	1.88±0.11	470±19	0.59±0.06
B fluting	110±1.3	206±7	1.60±0.15	1.55±0.14	395±17	0.67±0.10
Middle liner	111±1.3	210±6	1.39±0.16	1.38±0.09	382±20	0.63±0.10
C fluting	111±0.5	212±6	1.49±0.17	1.48±0.17	409±27	0.57±0.10
Double backer	140±0.7	173±4	2.05±0.10	1.98±0.06	580±20	0.68±0.08

Listed are mean values and standard deviations based on ten observations.

^aCD long-span compressive strength.

^bUltimate strain, or strain to failure, for each component, with the critical strain for the combined board highlighted in each case.

used a specially designed compression tester (3, 13). In this test, a specimen 15.5 mm wide and 80 mm long is clamped at a gauge length of approximately 40 mm. Specimen supports, which consist of four blocks, two on each side, prevent the specimen from buckling during compression loading. The specimen supports were adjusted with two micrometers to give a lateral clearance of approximately 10 μm in the sliding zone. A displacement gauge was attached to the specimen to measure the strain. The strain rate was approximately 0.001 s⁻¹.

Three techniques were used to measure the compression strength of combined board. The first technique was the standard edgewise compression test by FEFCO (1) that employs a rectangular CD specimen 25 mm high and 100 mm wide and a crosshead speed of 10 mm/min. The second method, the neck-down edge-

wise compression test, specifies specimens that are 50.8 mm high and 50.8 mm wide with a neck reducing the effective width to 25.4 mm (14). The neck was cut by a circular neck-down router. The crosshead speed was 10 mm/min.

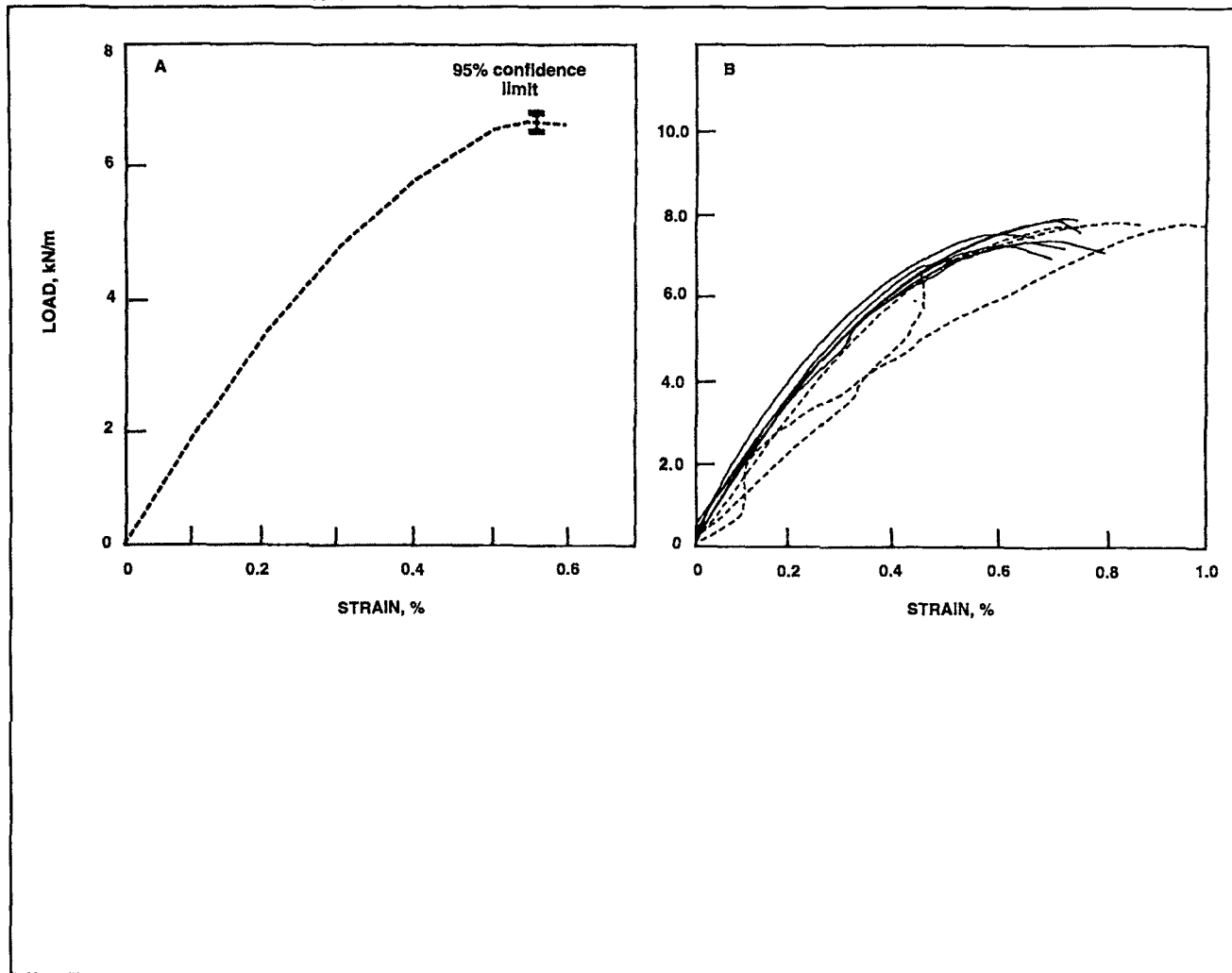
The third method was one we developed to measure the complete stress-strain curve of combined board in compression. It employs a specially designed test fixture fitted to a universal testing machine and laser-cut specimens. The geometry and dimensions of the specimen are shown in Fig. 1. The four intersections between the straight and curved regions were reinforced with an ordinary office glue to promote failure of the board in the region of constant width.

Figure 2 is an illustration of the testing device. An aluminium plate on the back and a transparent PMMA (polymethylmethacrylate) plate on

the front restrain the specimen from global buckling. The supports are adjustable to fit both single- and double-wall boards. By using a transparent front support, we were able to observe the specimen during testing to detect possible local buckling of the facings.

To allow the displacement gauge to be attached to the specimen, two horizontal scores were machined in the vertical sides of each support. The arms of the displacement gauge were mechanically balanced in a horizontal position, and the ends of the arms were attached to the board specimen with a fork gap by two screws with sharp tips pointing toward each other. The displacement gauge was a Hottinger Baldwin Messertechnik Model D4. The analog force and displacement signals were collected by a personal computer at a sampling rate of 20 Hz. All tests were performed at a crosshead speed of 5 mm/min.

5. A theoretical load vs. strain curve (A) for the combined board and the curves determined from experimental data (B). The three curves in B drawn in dotted lines were discarded.



Failure criteria

In a compression test of combined board, all components are uniformly strained. When the strain in any of the components reaches its ultimate value, the critical strain has been reached: we first assume that the remaining constituents are not able to carry the load and that total failure occurs.

Based on this hypothesis, the compression strength of the combined board is the sum, at critical strain, of the loads per unit width for all of the components. As discussed, this definition is valid only if local buckling of either facing or core does not occur, because local buckling may reduce the load-carrying capability of a component.

If the compression measurements do not include strain recording, as in the short-span compression strength

test, the additive strength criterion (Eq. 1) based on the ultimate strengths of the components may be used as a second approach. Essential to such a criterion is the assumption that all components contribute with their ultimate load-carrying capabilities. This assumption may be justified if the ultimate strains are similar for all components and local buckling does not occur or, if it does occur, it does not severely reduce the load-bearing capability of a component.

Results and discussion

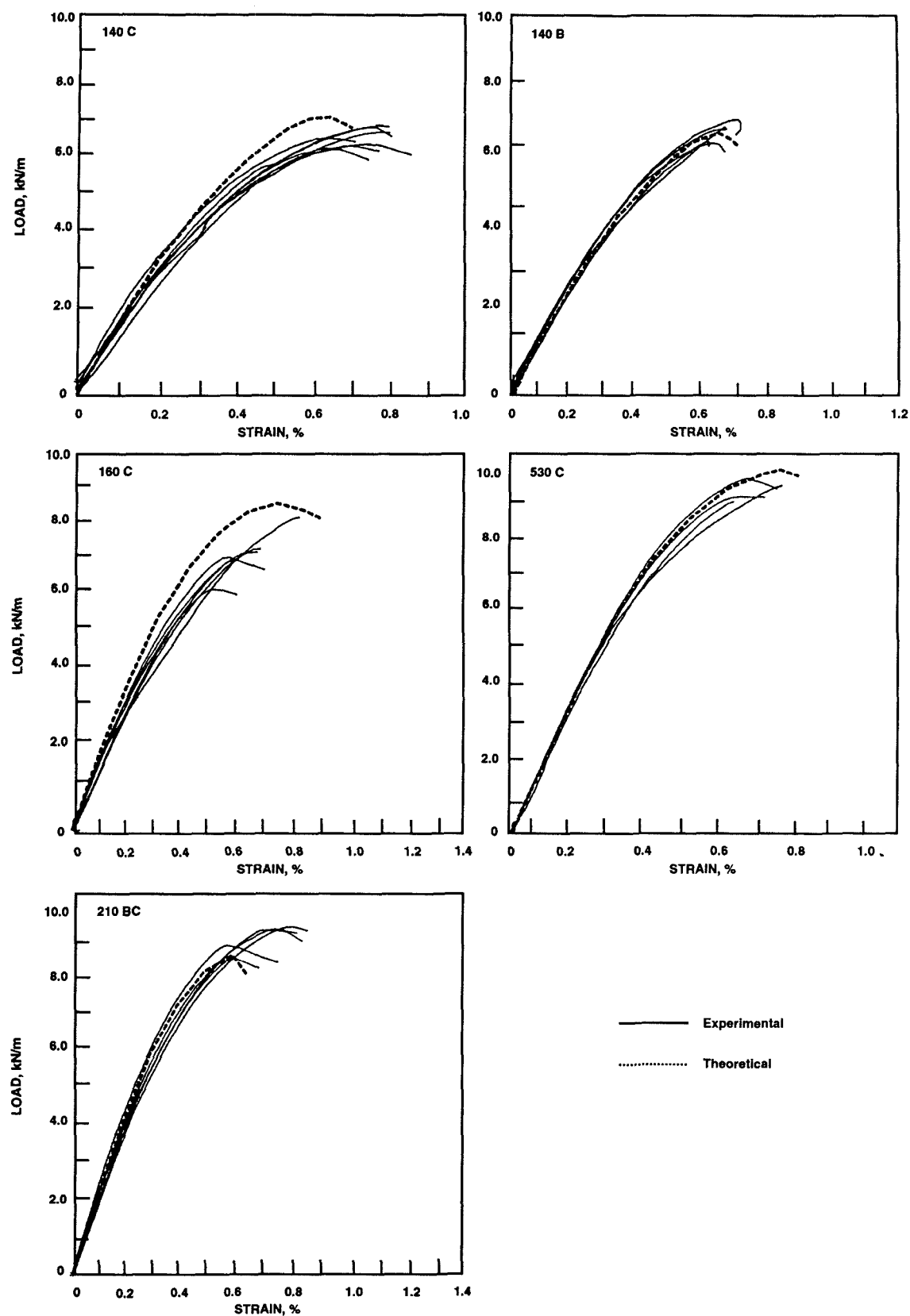
Stress-strain response

Figure 3 shows load vs. strain curves in compression for linerboard 140C. From a set of ten such curves in Fig. 3A, we constructed the curve average, which is plotted as a dotted line in Fig. 3A and is singled out in Fig. 3B. Figure 3B also includes a 95% confi-

dence limit for maximum strength. Mean compression curves were similarly obtained for all linerboards and flutings studied.

The mechanical properties of the materials studied are given in Table I. Both mean values and standard deviations are given. Note that the *ultimate* load in compression, which is measured as long-span compression strength for each component, corresponds to the ultimate strain for each component. In other words, the values in the third column of values correspond directly with the values in the last column. On the other hand, the *critical* compression strength indicates the load-bearing capability of each component at the critical strain of the combined board. These values, in the fourth column of values, correspond to the critical strains highlighted in the last column (the lowest value in each group).

6. Curves based on theoretical predictions and on experimental data for the five different grades



Boards 140B, 140C, and 210BC are approximately symmetric, while Boards 160C and 530C are asymmetric. An unsymmetric board tends to bend under the influence of an axial load, but bending is prohibited by the supports in the test fixture used, and the board will strain uniformly across the thickness.

Figure 4 illustrates the superposition of the load vs. strain curves for Board 140C. The dotted line in the figure represents the critical strain for the board (0.56%, Table I) and corresponding loads for the components. The dotted line in Fig. 5A shows a theoretical load vs. strain curve for the combined board. This curve is calculated by superimposing the compression curves of the components and accounting for the takeup factor.

Before comparing theoretical and experimental curves for the combined boards, we should make some brief comments on the experimental curves. Figure 5B shows experimental load vs. strain curves obtained in the cross-machine direction for Board 140C. Three of the curves, drawn by dotted lines, were discarded from further evaluation. One of the curves was discarded for having an unreasonably low stiffness, and two were thrown out for having erratic shapes.

Failure of the combined board commonly occurred in the necked-down region between the two arms of the displacement gauge (Fig. 2). In the case of failure outside this region, the test was discarded from further evaluation. It is not likely that the behavior of the discarded curves is due to flaws in the corrugated board, such as glue skips or poor gluing. It is more likely that the erratic curves are due to imperfections in the experimental setup. The attachment of the two nipper arms of the displacement gauge is critical. A loose attachment of the arms may give rise to slippage, while an attachment that is too firm may damage the specimen. The alignment of the specimen under the horizontal load applicator beam might also influence the behavior under compression. If a specimen is off center, the load distribution will be skewed.

Measured vs. predicted values

Curves based on theoretical predictions and on experimental data for the

five combined board grades are shown in Fig. 6. The agreement between superimposed curves of the components for combined board and experimental curves for combined board is excellent for Board 140B, good for Board 140C, 530C, and 210BC, and reasonable for Board 160C. The experimental curves for 140C and 160C are lower than theoretically expected, while they are higher for 210BC. Furthermore, for 140C and 210BC, the combined board strains to failure are larger than the critical strains obtained from measurements on the components, while the critical strains are lower than those for the components for 160C and 530C.

Tables II and III offer a quantitative comparison between measured and predicted stiffness and strength properties. In Table II, the measured board stiffness generally is in close agreement with predictions, although the measured values are somewhat lower than those predicted. In this context, the compression measurements of the components have been taken prior to corrugation. Obviously, properties of the combined board are measured after corrugation. In the superposition analysis, the component properties are assumed to remain unaffected by the corrugating process. However, the corrugated process reportedly damages the fluting and reduces the short-span compression strength of the fluting in the cross-machine direction by about 15-20% and perhaps by even more in the machine direction (15). This damage might explain in part why the measured values of combined board stiffness are lower than the calculated values (Table II).

The combined board strength is in better agreement with experimental values than is the stiffness (Table III). In contrast to the B-flute boards, the C-flute corrugated boards do not utilize the inherent compression strength of the components. Notice that only Board 140C possesses non-overlapping 95% confidence intervals for strength and strain to failure (Table III).

For Board 140C, the measured combined board strain to failure, $0.66 \pm 0.05\%$, is slightly larger than the critical strain of its components, $0.56 \pm 0.04\%$. The most likely explanation is that local buckling slightly reduces the compression strength of

these combined boards. Local buckling of the linerboards can be observed visually during compression testing of combined board. However, more precise studies are required to establish the exact point on the stress-strain curve where local buckling occurs. In light of the possible influence of local buckling of the fluting or linerboards on the compression strength of the combined board, the close agreements between theoretical and experimental strengths indicate that this influence is small and insignificant. The fact that the measured compression strength for double wall board 210BC is slightly larger than the calculated value may possibly be explained by the reinforcing effect of the starch adhesive in the combined board.

The relationship between short-span and long-span compression strengths

The compression strength of paperboards obtained at short span can be transformed to the compression strength obtained at long span. This conversion is of practical utility since compression testers employing a long span are not commonly used. Short-span compression testers are widely used because they are simple to operate.

The compression strength of paperboard using the short-span compression strength method with a short span of 0.7 mm is generally 15-30% higher than the strength determined by test methods employing a long span (16). Reasons for the increased strength are (a) that the strain rate is an order of magnitude higher in the short-span compression strength test and (b) that there is a higher probability that defects will initiate failure in a longer specimen (16).

Tests of edgewise compression strength of combined board show an increase in compression strength of approximately 7.5% due to a tenfold increase in strain rate (12, 17). Moreover, the short clamped length in the short-span compression strength method will restrict strain in directions perpendicular to the applied compression load. This restraint will create a biaxial stress, or "plane strain," condition rather than a uniaxial stress condition such as that in a long-span compression strength test.

At short spans, the material will act as if it were stiffer and possibly stronger as a result of the biaxial directions of the stress.

The increased chance of failure initiation in test specimens having long gauge length is referred to as the "volume effect." Donner (18) considered the influence of plane strain and size and proposed a relatively complex method to shift short-span compression strength values to longer gauge lengths (18). Donner's approach is based on a classical three-parameter Weibull probability density function and minimum-value statistics. The purpose here is to present a simpler approach, based on Weibull statistics, to relate short-span compression strength values to long-span compression strength values.

Weibull postulated a two-parameter strength distribution function of the form of Eq. 3 (19):

$$F(s/s_0) = 1 - e^{-V(s/s_0)^m} \quad (3)$$

where

- s_0 = a reference strength level
- m = a shape parameter related to the scatter in strength
- V = the material volume, which is subjected to the constant stress level s .

If the material strength is described by Eq. 3, then the ratio of the mean strengths of two volumes V_1 and V_2 is given by Eq. 4.

$$\bar{s}_2/\bar{s}_1 = (V_1/V_2)^{1/m} \quad (4)$$

The Weibull shape parameter can be approximated from the coefficient of variation, c , according to (19):

$$m \approx 1.2/c \quad (5)$$

Equations 4 and 5 and the volume ratio between short-span and long-span compression strength specimens (59.05) give

$$LCS \approx SCS (1/59.05)^{(c/1.2)} \quad (6)$$

where

- LCS = long-span compression strength
- SCS = short-span compression strength.

Table IV lists the measured average short-span compression strength

II. Mechanical properties of combined boards for the five different grades

Combined board	Grammage, ^a g/m ²	Thick- ness, ^a mm	CD compressive stiffness, MN/m		No. of observa- tions, <i>n</i>
			Measured ^b	Calculated ^a	
140B	435±2.8	2.87±0.01	1.54±0.04	1.81±0.06	5
140C	448±3.5	3.91±0.02	1.63±0.13	1.86±0.06	7
160C	556±4.7	4.02±0.03	1.83±0.13	2.18±0.08	6
530C	689±5.0	4.21±0.02	2.27±0.06	2.37±0.05	4
210BC	702±5.2	6.52±0.03	2.34±0.09	2.55±0.06	5

^aBased on ten observations. ^bValues for measured compression stiffness are based on *n* number of observations.

III. Compression strengths and strains of combined boards based on critical strains

Combined board	Compressive strength, kN/m		Strain to failure, %	
	Measured	Predicted	Measured	Predicted
140B	6.52±0.30	6.54±0.26	0.60±0.04	0.58±0.06
140C	6.36±0.21	6.83±0.13	0.66±0.05	0.56±0.04
160C	7.02±0.60	8.28±0.17	0.60±0.11	0.68±0.06
530C	9.57±0.61	10.27±0.19	0.67±0.07	0.74±0.07
210BC	9.91±0.49	9.47±0.24	0.70±0.13	0.57±0.07

Mean values and 95% confidence intervals are listed.

values and standard deviations in the machine and cross-machine directions for the various boards. These values are shifted according to Eq. 6 to give values that correspond to long-span compression strengths.

Figure 7 shows raw data and vertically shifted data for short-span compression strength plotted against long-span compression strength. Note the one-to-one correlation between shifted short-span compression strength and long-span compression strength. The line in the figure denotes a perfect correlation.

Table V lists the compression strength values of the five combined board grades obtained by three measuring techniques on combined board and three analytical methods based on measurements of the components. The compression strength

based on the critical strain of the combined board gives a slightly lower value than do methods based on the ultimate compression strengths of each component.

The difference between the critical compression strength of the combined board and the sum of the ultimate compression strengths of the components is small and not significant, which might be a consequence of the fact that the failure strains are similar for kraft linerboard and semichemical fluting (Table I). A larger difference might occur if, for instance, two linerboards with dissimilar failure strains were used in the combined board.

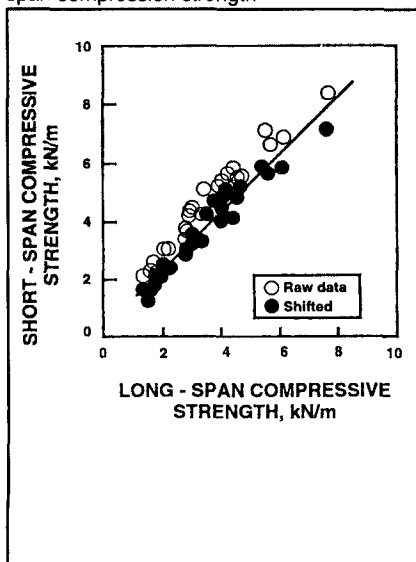
Table V shows that values for edge-wise compression test taken according to the FEFCO method are lower than the compression strengths measured

IV. A comparison between short-span, shifted short-span, and long-span compressive strengths

Paper-board	Short-span compressive strength, kN/m		Shifted short-span compressive strength, kN/m		Long-span compressive strength, kN/m	
	MD	CD	MD	CD	MD	CD
Board 140B						
Single facer	5.68±0.28	2.85±0.21	4.80	2.22	4.29±0.20	2.24±0.12
Fluting	4.38±0.39	2.52±0.30	3.24	1.68	3.12±0.21	1.70±0.29
Double backer	5.56±0.31	2.75±0.15	4.60	2.28	4.54±0.11	2.08±0.12
Board 140C						
Single facer	5.87±0.28	3.00±0.22	4.99	2.34	4.45±0.19	2.21±0.15
Fluting	4.98±0.30	2.47±0.17	4.06	1.95	3.65±0.15	1.81±0.12
Double backer	5.50±0.27	2.74±0.14	4.65	2.30	4.57±0.20	2.20±0.05
Board 160C						
Single facer	7.10±0.42	4.20±0.33	5.81	3.22	5.57±0.16	3.38±0.10
Fluting	3.74±0.35	1.95±0.27	2.72	1.22	2.81±0.16	1.55±0.14
Double backer	6.66±0.31	3.33±0.15	5.69	2.86	5.72±0.11	2.83±0.12
Board 530C						
Single facer	8.42±0.40	5.15±0.38	7.16	4.01	7.73±0.36	4.46±0.23
Fluting	5.36±0.48	2.98±0.28	3.95	2.17	4.08±0.25	2.10±0.11
Double backer	6.90±0.38	3.61±0.20	5.72	2.99	6.19±0.17	2.84±0.15
Board 210BC						
Single facer	5.16±0.26	2.46±0.19	4.35	1.89	3.99±0.30	2.05±0.10
B-fluting	4.21±0.24	2.10±0.15	3.47	1.65	3.06±0.31	1.49±0.17
Middle liner	4.01±0.29	2.03±0.16	3.14	1.55	3.04±0.20	1.39±0.16
C-fluting	4.23±0.28	2.21±0.21	3.38	1.60	3.10±0.20	1.60±0.15
Double backer	5.43±0.28	2.66±0.18	4.56	2.11	4.20±0.31	1.90±0.14

Mean values and standard deviations for short-span compressive strengths are based on 20 observations. Mean values and standard deviations for long-span compressive strengths are based on 10 observations.

7. Raw and shifted data for short-span compression strength plotted against long-span compression strength



on supported and laser-cut specimens. Values obtained by the neck-down edgewise compression test are higher than those obtained on supported specimens. The lower value obtained by the FEFCO method is explained by edge crushing, which can be observed on the tested specimens. The higher value for edgewise compression test for the necked-down specimens compared to the supported specimens might be explained by the small failure zone in a neck-down edgewise compression test, which, statistically, leads to increased strength.

Conclusions

The curve for compression load vs. strain of corrugated board can be obtained by superimposing long-span compression curves of the constituent

linerboards and flutings. Deviations between predicted and measured response curves are attributed to the corrugation process, adhesive reinforcement, and possibly local buckling of the components.

Local buckling of the components may occur at or close to failure of the combined board. In comparing measured and calculated compression strengths, we recognize that the combined boards 140B and 210BC utilize the inherent compression strength of the components and fail in pure compression rather than in a local buckling failure mode. This behavior is probably due to the shorter wavelength in the B-flute than in the C-flute, which makes the facings more resistant to washboarding and local buckling.

The compression tests on combined

V. Measured and calculated compression strengths of combined board

Combined board	Measured edgewise compression strength, kN/m			Calculated compression strength, kN/m		
	New method	FEFCO	Neck-down	Long span ^a	Long span ^b	Short span, shifted
140B	6.52±0.24	6.12±0.28	7.07±0.35	6.54±0.36	6.62±0.43	6.77
140C	6.36±0.22	5.87±0.21	6.89±0.87	6.83±0.19	7.02±0.23	7.46
160C	7.02±0.57	6.53±0.19	7.23±0.59	8.28±0.24	8.44±0.28	7.83
530C	9.57±0.49	8.27±0.23	8.91±0.64	10.27±0.26	10.32±0.32	10.12
210BC	9.91±0.39	9.25±0.34	10.47±0.48	9.47±0.34	9.66±0.39	10.09

^aSum of the compression strengths of the components at critical strain.
^bSum of the ultimate compression strengths of the components.
Mean values and standard deviations are based on ten observations except for compression strength measured by the new method, which is based on *n* observations as listed in Table II.

board specimens and its components show that the compression strength of combined board can be estimated from short-span compression strength measurements if the short-span compression strength value is shifted using Weibull statistics, provided that the failure strains of the components are similar.

We found that the FEFCO edge-wise compression test method provides strength data that are quite conservative as a result of edge damage, while the small failure volume of the neck-down edgewise compression test specimen produced data that are not considered conservative. The newly developed test method presented here should be more appropriate for an element of a box in the sense that a reasonable test section is utilized and edge damage is inhibited.

Although this new edgewise compression test can produce highly relevant data, a simple, yet accurate, prediction of the edgewise compression test value of the combined board may be obtained by the Weibull shifting method in combination with the simple strength superposition criterion. With this procedure, the time-consuming tasks of making and testing the combined board by the edgewise compression test are eliminated. Of course, this conclusion should be verified by testing more board types at various relative humidities.□

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