THE TOP TO BOTTOM COMPRESSION RESISTANCE OF A FOLDING CARTON CONSIDERED AS A FUNCTION OF SIDEWALL SCORELINE ANGLE

Thesis for the Degree of M. S.

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DAVID LAWRENCE OLSSON
1960

The Top to Bottom Compression Resistance of a Folding Carton Considered as a Function of Sidewall Scoreline Angle

By

David Lawrence Olsson

An Abstract

Submitted to the College of Agriculture
Michigan State University of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Forest Products
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AN ABSTRACT

Compression resistance of folding cartons is of interest to the people in today's packaging industry because of present day high-speed packaging machinery, and the corresponding need for high-performance cartons. There is a trend towards the use of lightweight shipping containers; therefore it is desirable to have folding cartons with high compression resistance.

Cartons deform into any of several configurations under a compressive dead load because of size or product considerations. This study was conducted to investigate the loading characteristics of cartons deformed to have four equal angles other than 90 degrees along the vertical scorelines.

Also, it was known intuitively by people in the packaging industry that cartons with 90 degree corners were "best"; it was not known why. This paper was a basic study to show, in part, why folding cartons with square angles along the vertical scorelines have certain desirable characteristics.

Cartons of similar size were tested in order to reduce the number of variables studied. Loading characteristics vary because of folding carton size and type of board used in the construction of the carton. The loading characteristics of any given type and size of carton varied in positive correlation with the angle of the vertical scoreline. For larger angles along the vertical scoreline, the average compression resistance increased correspondingly. The range or distribution of individual failure points increased in positive correlation with the angle of the vertical scoreline.

Because of machine considerations that make it desirable to have a 90 degree angle along the vertical scorelines of folding cartons, and only a small, but statistically significant, increase in compression resistance due to deformed scorelines, it was concluded that use of 90 degree vertical scorelines in folding cartons be continued.

If, however, trends now operating continue strongly towards use of lighter weight secondary or tertiary containers, methods for efficient manufacture of what are presently termed "deformed" cartons will have to be investigated.

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To

Mrs. James L. Olsson

and in memory of

Mr. James L. Olsson

Acknowledgments

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D. L. O.

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INTRODUCTION

It was the intention of this study to show that square (90 degree) corners along the vertical scorelines of a folding paperboard carton are the optimum configuration in terms of top to bottom compression resistance of a folding paperboard carton.

In addition to the main purpose of this study was the intent to present formally what has been long known intuitively in the packaging industry. That is, people concerned with packaging have known, without being able to say why, that folding cartons with square vertical scorelines had good machine characteristics, and handled best at high speeds. In part, it was the intention of this study to show why 90 degree vertical scorelines are important for folding cartons in one respect -- machinability, while a different configuration is optimum in another respect -- compression resistance.

Since present day high-speed packaging machinery makes it necessary for a folding carton to set up squarely (four 90 degree corners along the vertical scorelines) to prevent improper forming of the carton or malfunction of the equipment, it is imperative to have folding cartons with square corners.

When a folding carton is manufactured properly, it becomes a free-standing entity. The carton may be supported by a bottle, but a tube cannot, by law, lend support to a folding carton. In the usual case, a primary container does not contact the sidewalls or the top of the folding carton. Therefore, when a folding carton is manufactured properly, it will set up with square corners along the various scorelines.

Present day trends, for reasons of economy, in part, are now

directed towards lighter weight shipping containers. Therefore, it is necessary that folding cartons, wherever possible, be self-supporting in a stack. That is, if a number of folding cartons have the compression resistance to withstand the weight of a stack of goods, very light shipping containers, to the point of a kraft overwrap, may be used for the shipment of a given product. The load that any individual carton will withstand is, in part, dependent upon the angle of the vertical scoreline. The angle of the vertical scoreline is critical in the performance of individual folding cartons under a compressive load, thus important in considering the stacking strength necessary for a shipping container for the folding cartons.

When a number of folding cartons are placed in a heavy corrugated container, there is relatively little stress applied to the folding cartons that would tend to deform them from their normal 90-degree scoreline configuration. If a lightweight corrugated container, or a kraft paper overwrap, were used to bundle a number of folding cartons, however, the weight of the stack would directly deform the cartons within the stack.

The cartons thus deformed may assume any of several configurations. This is due to the fact that air space is allowed around a primary container which may be placed in a folding carton. By use of a concept similar in nature to that of the Bristol-Lund formula,*

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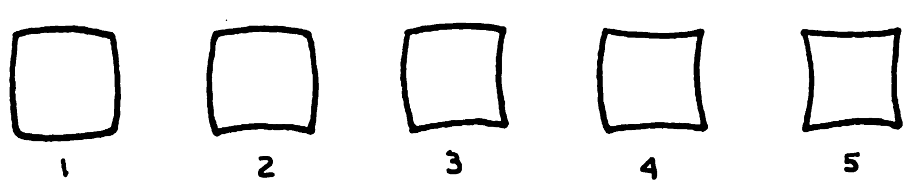
* The Bristol-Lund formula is used to determine proper dimensions of a folding carton for collapsible tubes. The formula is designed to allow sufficient free space around a tube in order to position the crimped end of the tube diagonally across the cross-section of a folding carton. The formula is approved by the federal Food and Drug Administration (sic) (1).

air space around a primary container may be as much as ¼ inch or more on any given side of the primary container. Also 1/8 inch or more may be allowed between the top of the primary container and the top of the folding carton.

For lightweight, free-flowing products such as cereals, soap chips, or powders, a folding carton under a compressive load receives support from the product. The product may, in fact, tend to deform a carton from a normal configuration. The sidewalls may bulge outward to form four greater than 90-degree angles at the vertical scorelines.

Concern for the angle of the vertical scoreline has universal interest for the packaging industry, regardless of what any given product packaged in a folding carton may be.

Under the free air space condition, a folding carton may deform into any of the following cross-sectional configurations:



Also, the folding carton may have one or more 90-degree angles along the vertical scorelines, with the other scorelines being deformed to some angle other than 90 degrees.

There is no way to determine in advance which way a folding carton may deform, so for purposes of this study the author considered only the configurations which had four equally deformed vertical scoreline angles (1 and 5 above). Under this consideration, the effect of deformation upon the compression resistance of folding cartons was determined.

BACKGROUND

As long ago as 1035 A.D. paper was used as a flexible material for overwrapping spices and hardware in Egypt. It was not until the early 1800's that paperboards were beginning to be used as a popular means of consumer packaging (2 and 3). And it was not until 1879 that an accident of production provided the key to successful mass production of folding paperboard cartons. Because of an error in printing press makeready, Robert Gair, a pioneer in the packaging field, was able to devise and develop the steel rule dies which are commonly used today in the mass production of folding cartons (4).

The folding carton has grown from an object of little more than curious interest to such a major, but common, type of packaging that intricacies of production are overlooked or taken for granted by today's consumer of packaged items.

Cartons were produced more rapidly than ever before on higher speed carton making machinery, and there was a corresponding expansion of interest by technical people in packaging who were concerned with how to make better scorelines in folding cartons. As of today, a considerable amount of research has been done to determine what is a good scoreline (5).

As preoccupation with what a good scoreline was became less dominant, a logical question to ask was, "Is making a 'good' scoreline necessary, or even desirable?" A good scoreline was thought by many to imply one which broke cleanly and easily along the line of the score, and one which would set up at a 90-degree angle along the length of the scoreline (6). Again, it was the intention of this study to prove that such an attempt was a worthwhile goal.

EXPERIMENTAL PROCEDURE

Cartons made of two different types of folding carton stock were tested for this study. All cartons were tested in a static dead-load recording device, and individual failure points in pounds were noted.

Sample Cartons

The size of the cartons tested was held constant at 2½ x 2½ x 5 inches. Constant dimensions were maintained in order to reduce variation in test results due to changing the perimeter of the test specimens, and in order to keep the number of variables studied as low as possible. It was assumed that cartons would fail at values in a normal distribution for a given material and perimeter, and that the distribution of failure points would vary for different materials and different perimeters.

The size carton selected for testing was a practical size in common use in the consumer market. The results of testing that size carton were logically inferred to apply to other size cartons. Dead-load failure points for cartons of a size other than tested in this study were construed to be different than the failure points observed in testing for this study. It was assumed that the manner in which average failure points increased through differing scoreline angles would vary in the same manner as observed during this series of tests.

The materials used for cartons in this study were 22-point (0.022 inch) white patent coated newsboard and 0.018 inch bleached manila board manufactured by The Lord Baltimore Press. The cartons

were preglued and ready for automatic machine setup.

Preparation--The sample cartons were stored for a minimum period of 72 hours in a controlled temperature and humidity room (73 degrees Fahrenheit and 50 per cent relative humidity). Conditioned air was allowed to circulate freely around the cartons to assure that the paperboard was at equilibrium at the time of testing (7 and 8).

The top and bottom flaps and tucks were folded into the normal closed position of the carton for individual tests.

The testing equipment for applying the dead load was in the same conditioned atmosphere, so variation in test results due to changes in the moisture content of the carton board was negligible.

The apparatus used during the dead load compression tests was the Baldwin-Emery SR4 Testing Machine (see Figure 1), used in conjunction with a sensitive load cell (Baldwin SR4 Load Cell, type U-1S), as shown in Figure 2.

To test by means of a dead loading device is consistent with the practical case. The cartons in a stack are under a compressive dead load. That means of test was the most common in use for testing compression resistance, i. e., by application of a static or dead load.

The machine settings used for the compression resistance tests were as follows:

Load range; 10,000 pounds

Load Cell; 500 pounds, maximum

Load Selector; 100 pounds

Platen speed; 100 of 300 equal divisions of scale for 0.012 to 1.2 inches per minute rate of loading

Upper Load Limit; 95 per cent

Lower Load Limit; -5 per cent

The samples were placed, in turn, between a wooden base resting on the lower platen, and a sheet of plywood inserted between the sensitive load cell platen and the carton (see Figure 2). The load was applied at one-third of the platen speed range of 0.012 to 1.2 inches per minute, or at 100 of 300 equal divisions of scale of the platen speed control rheostat.

The test of individual cartons was stopped when the carton failed to load further, and the failure point in tenths of a pound was recorded.

The tests for this study were run in two series. One series, testing white patent coated newsboard cartons, was conducted using three groups of 35 cartons with vertical scorelines formed at 86, 90, and 97 degree configurations. The second series of tests was conducted using four groups of 50 bleached manila board cartons with 86, 90, 94, or 97 degree configurations along the vertical scorelines.

Both sample sizes were large enough to make a significant statistical analysis.

Preparation of samples--The cartons tested were deformed to different sidewall scoreline angles by the following methods:

To obtain an 86-degree angle along the vertical scorelines, two small wooden blocks of appropriate size were placed in the center of each sidewall, and were held in place by rubber bands (see Figure 3). The variation from carton to carton in the angle thus induced was

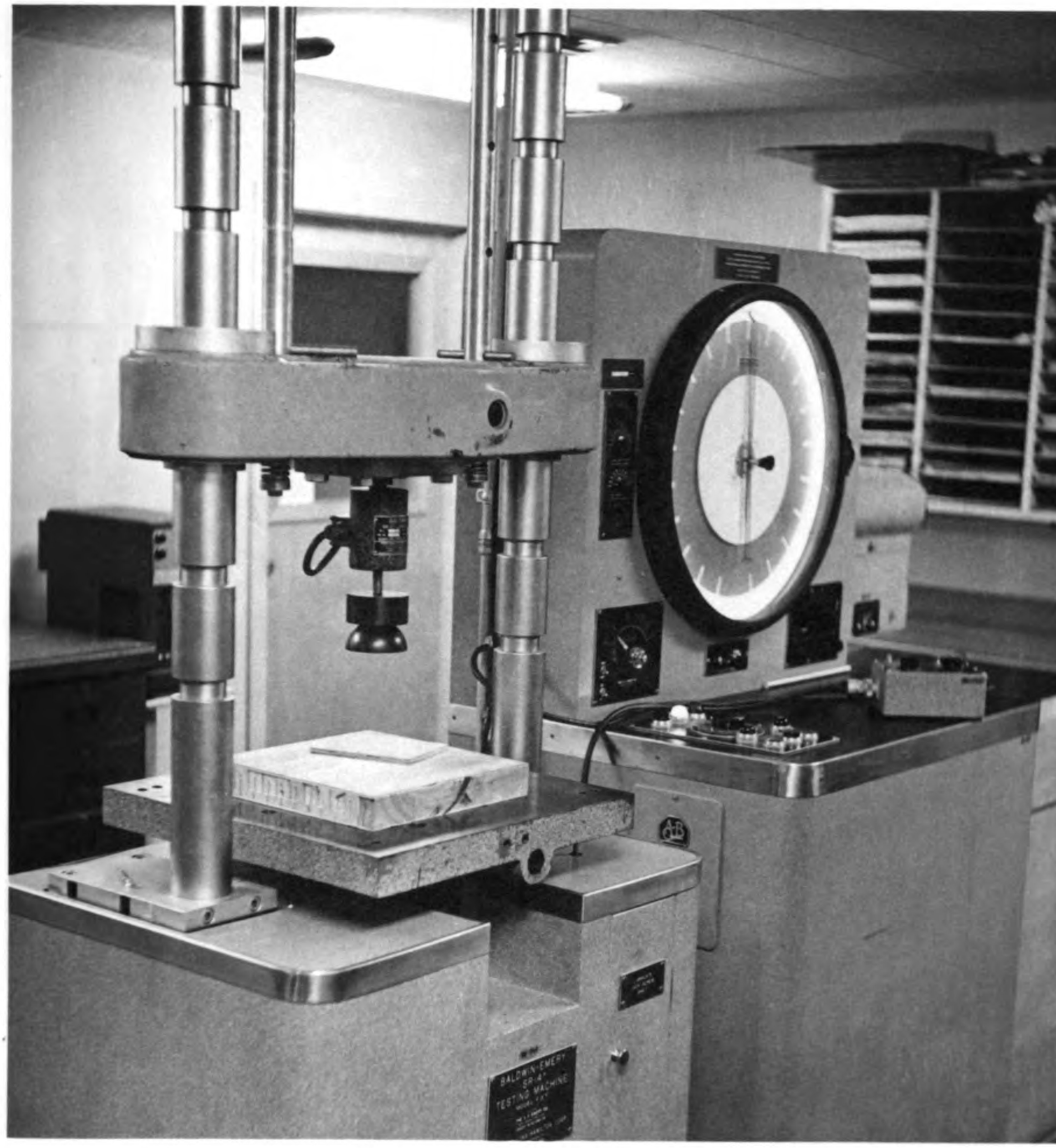


FIGURE 1

Showing Baldwin-Emery SR-4 Testing Machine Model FGT

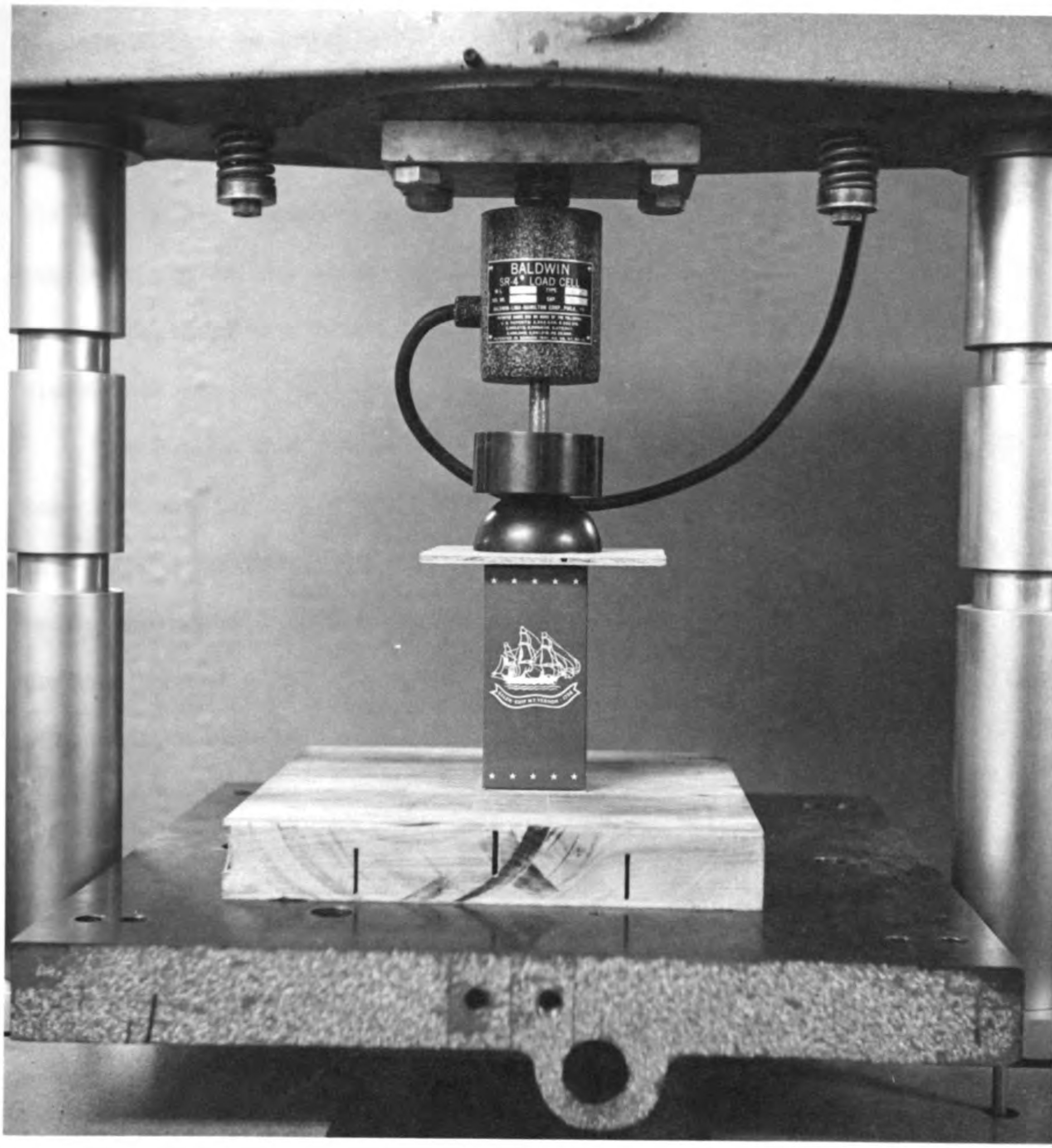


FIGURE 2

Showing sensitive load cell in place and carton in position for testing on Baldwin-Emery SR-4 Testing Machine Model FGT negligible as ascertained by a 20 to 30 per cent sample of cartons tested in each series group (see Figure 5).

To obtain an angle greater than 90 degrees along the vertical scorelines in the test specimens, a segment of bound hair cushioning material was inserted in the set up carton (see Figure 4). For example, a 3 x 3 x 1 inch segment of bound hair was used to form a 97-degree angle in the white patent coated newsboard cartons. Variation in the angle of the vertical scorelines thus induced in the test specimens was negligible (see Figure 6).

The blocks and cushions used to deform the side walls of the cartons did not interfere with the loading and failing characteristics of the cartons tested. The vertical scorelines were free to buckle at any point under the compressive load. Deflection of the cartons was not carried to the point where the blocks or cushions would have interfered with what otherwise would have been normal loading.

The dimensions across the cross-section of the cartons did not change appreciably when the side walls were deformed, because the top and bottom flap and tuck scorelines held the vertical scorelines fairly rigidly in the original position.

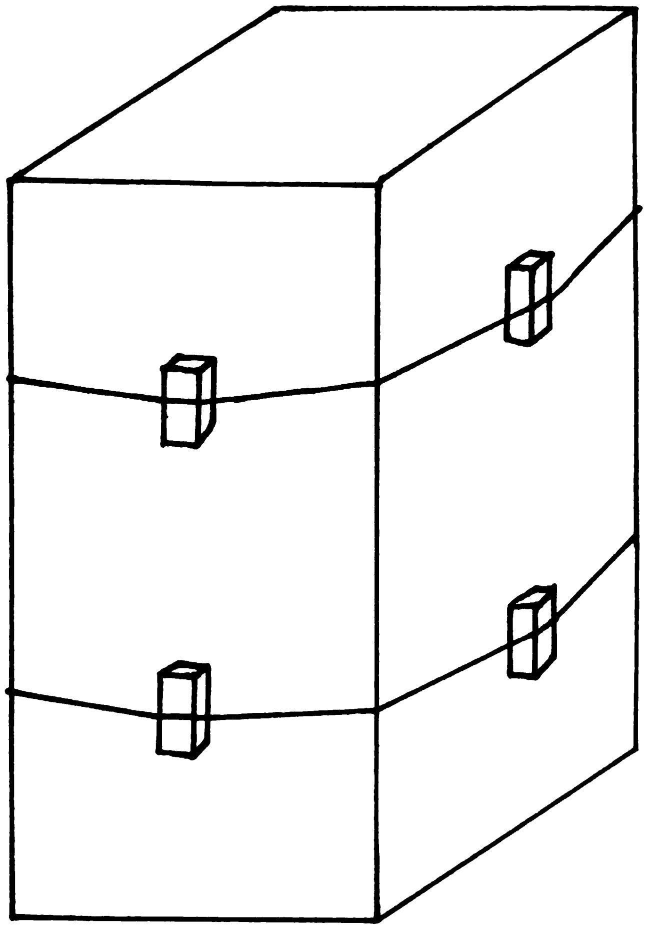


FIGURE 3

Showing placement of two rubber bands and eight wooden blocks around the carton to deform the carton sidewall panels to form less than 90 degree angles along the vertical scorelines

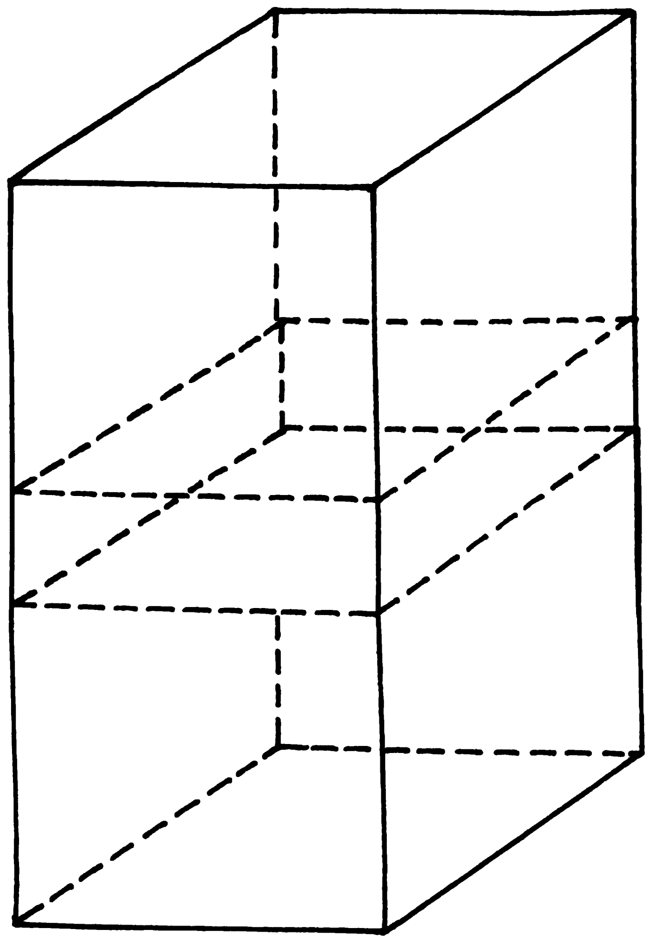
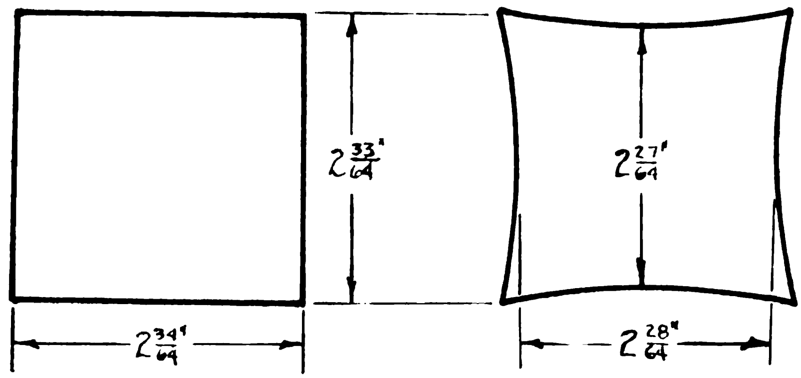
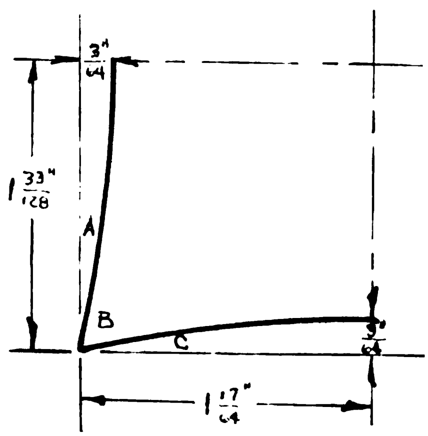


FIGURE 4

Showing placement of bound hair cushioning material within carton to deform the carton sidewall panels outward to form greater than 90 degree angles along vertical scorelines



Sketch showing cross-sectional dimensions of cartons before and after deformation to less than 90 degree angles along the vertical scorelines. Measurements were taken at the center of the side panels.



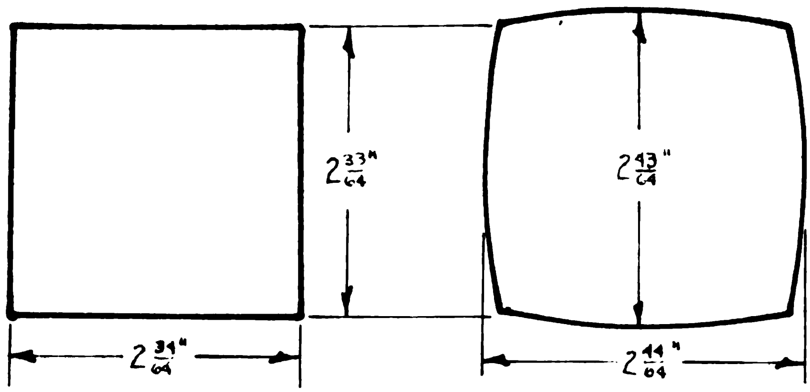
$$\tan \angle A = \frac{3/64}{1\ 33/128} = 0.03727 \qquad \angle A = 2°\ 8'$$

$$\tan \angle C = \frac{3/64}{1\ 17/64} = 0.03846 \qquad \angle C = 2°\ 12'$$

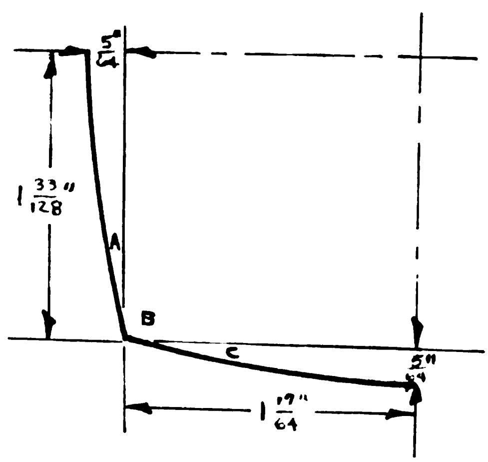
$$\angle B = 90° - \angle A - \angle C = 90° - 2°\ 8' - 2°\ 12' = 85°\ 40' \cong 86°$$

FIGURE 5

SAMPLE CALCULATION



Sketch showing cross-sectional dimensions of cartons before and after deformation to greater than 90 degree angles along the vertical scorelines. Measurements were taken at the center of the sidewall panels.



$$\tan \angle A = \frac{5/64}{1\ 33/128} = 0.06215 \qquad \angle A = 3°\ 34'$$

$$\tan \angle C = \frac{5/64}{1\ 17/64} = 0.06172 \qquad \angle C = 3°\ 32'$$

$$\angle B = 90° + \angle A + \angle C = 90° + 3°\ 34' + 3°\ 32' = 97°\ 6' \cong 97°$$

FIGURE 6

TABLE I

33.4	39.0	41.6	44.0	46.5
34.4	39.2	41.8	44.1	46.6
35.9	40.8	42.2	44.8	46.7
36.0	40.9	42.6	44.9	47.1
36.9	41.0	43.2	45.2	47.9
37.9	41.0	43.9	46.3	48.4
38.0	41.2	44.0	46.3	50.8

Individual failure points, in pounds, for 0.022 inch white patent coated news folding cartons. Values are for 2½ x 2½ x 5½ inch cartons with 86-degree sidewall scoreline angles tested in 73 degree Fahrenheit, 50 per cent relative humidity atmosphere. Load applied at 100 of 300 equal divisions of scale for 0.012 to 1.2 inches per minute rate of loading.

$\bar{X}$ = Mean value of failure points = 42.4 pounds

$\Sigma X^2 = 63,568.13$

$\Sigma X = 1484.5$

$\Sigma x^2 = 604.12$

$n = 35$

TABLE II

39.4	44.5	46.4	47.8	48.9
40.9	44.8	46.6	48.2	49.0
41.9	44.9	46.7	48.2	49.5
43.0	45.4	46.8	48.3	50.3
43.1	45.6	47.0	48.5	52.3
43.5	45.7	47.0	48.5	53.0
44.4	46.2	47.5	48.8	62.7

Individual failure points, in pounds, for 0.022 inch white patent coated news folding cartons. Values are for 2½ x 2½ x 5½ inch cartons with 90-degree sidewall scoreline angles tested in 73 degree Fahrenheit and 50 per cent relative humidity atmosphere. Load applied at 100 of 300 equal divisions of scale for 0.012 to 1.2 inches per minute rate of loading.

$\bar{X}$ = Mean value of failure points = 47.0 pounds

$\Sigma X^2 = 77,870.84$

$\Sigma X = 1645.3$

$\Sigma x^2 = 527.64$

$n = 35$

TABLE III

29.8	45.3	48.5	51.2	58.0
34.5	46.2	49.1	52.5	60.4
36.4	46.9	49.4	54.5	61.0
40.8	47.1	49.7	55.4	62.1
43.8	47.2	49.9	55.9	62.3
44.0	48.2	50.6	56.3	62.7
44.9	48.3	50.9	57.1	62.8

Individual failure points, in pounds, for 0.022 inch white patent coated news folding cartons. Values are for 2½ x 2½ x 5½ inch cartons with 97-degree sidewall scoreline angles tested in a 73 degree Fahrenheit and 50 per cent relative humidity atmosphere. Load applied at 100 of 300 equal divisions of scale for 0.012 to 1.2 inches per minute rate of loading.

$\bar{X}$ = Mean value of failure points = 50.4 pounds

ΣX^2 = 91,059.55

ΣX = 1763.7

Σx^2 = 2,184.19

n = 35

TABLE IV

40.2	44.5	46.3	47.0	50.0
40.5	44.6	46.4	47.3	50.0
40.9	44.9	46.4	47.3	50.5
41.2	44.9	46.5	47.6	50.9
41.7	45.0	46.5	47.9	50.9
42.6	45.1	46.5	48.5	52.1
42.9	45.4	46.6	49.1	53.0
43.4	45.5	46.6	49.5	53.1
43.8	45.5	46.8	49.5	53.5
44.0	45.6	46.9	49.7	53.7

Individual failure points, in pounds, for 0.018 inch bleached manila board cartons. Values are for 2½ x 2½ x 5½ inch cartons with 86-degree sidewall scoreline angles tested in 73 degree Fahrenheit and 50 per cent relative humidity atmosphere. Load applied at 100 of 300 equal divisions of scale for 0.012 to 1.2 inches per minute rate of loading.

$\bar{X}$ = Mean value of failure points = 46.8 pounds

ΣX^2 = 109,958.65

ΣX = 2,338.7

Σx^2 = 568.30

n = 50

TABLE V

43.3	51.1	53.7	55.0	56.9
43.4	51.5	53.8	55.3	57.0
44.2	51.7	53.8	55.3	57.2
49.0	51.8	54.1	55.7	57.2
49.5	51.8	54.4	55.9	57.2
49.5	51.9	54.6	56.3	57.4
50.8	52.3	54.7	56.6	57.8
50.9	52.7	54.7	56.6	59.4
50.9	52.9	54.8	56.8	62.6
51.0	53.4	55.0	56.9	62.9

Individual failure points, in pounds, for 0.018 inch bleached manila board cartons. Values are for $2\frac{1}{2} \times 2\frac{1}{2} \times 5\frac{1}{2}$ inch cartons with vertical scorelines in their normal 90-degree configuration, tested in 73 degree Fahrenheit and 50 per cent relative humidity atmosphere. Load applied at 100 of 300 equal divisions of scale for 0.012 to 1.2 inches per minute rate of loading.

$\bar{X}$ = Mean value of failure points = 53.9 pounds

ΣX^2 = 145,838.36

ΣX = 2693.2

Σx^2 = 766.84

n = 50

TABLE VI

46.2	52.0	54.0	55.9	58.6
48.2	52.0	54.7	56.0	58.9
48.6	52.1	54.7	56.3	59.3
50.8	52.6	55.0	56.7	59.5
50.9	52.9	55.0	56.8	60.0
51.2	53.0	55.4	56.9	62.4
51.5	53.2	55.4	57.0	63.5
51.6	53.4	55.5	57.6	64.9
51.7	53.5	55.6	58.1	68.4
51.8	53.7	55.7	58.3	68.7

Individual failure points, in pounds, for 0.018 inch bleached manila board cartons. Values are for 2½ x 2½ x 5½ inch cartons with 94-degree sidewall scoreline angles tested in 73 degree Fahrenheit and 50 per cent relative humitidy atmosphere. Load applied at 100 of 300 equal divisions of scale for 0.012 to 1.2 inches per minute rate of loading.

$\bar{X}$ = Mean value of failure points = 55.5 pounds

ΣX^2 = 155,117.07

ΣX = 2775.7

Σx^2 = 1,026.86

n = 50

TABLE VII

47.5	55.2	58.8	62.6	67.1
49.8	55.9	58.9	62.7	67.4
49.9	56.0	59.0	62.8	68.0
52.5	56.3	59.6	63.4	68.4
52.8	56.5	60.2	63.5	68.6
52.9	56.7	60.3	64.0	70.0
53.2	56.8	60.9	64.2	71.4
53.9	57.2	60.9	66.1	76.4
54.7	58.6	60.9	66.5	77.1
54.8	58.7	61.6	67.0	77.4

Individual failure points, in pounds, for 0.018 inch bleached manila board cartons. Values are for 2½ x 2½ x 5½ inch cartons with 97-degree sidewall scoreline angles tested in 73 degree Fahrenheit and 50 per cent relative humidity atmosphere. Load applied at 100 of 300 equal divisions of scale for 0.012 to 1.2 inches per minute rate of loading.

$\bar{X}$ = Mean value of failure points = 60.9 pounds

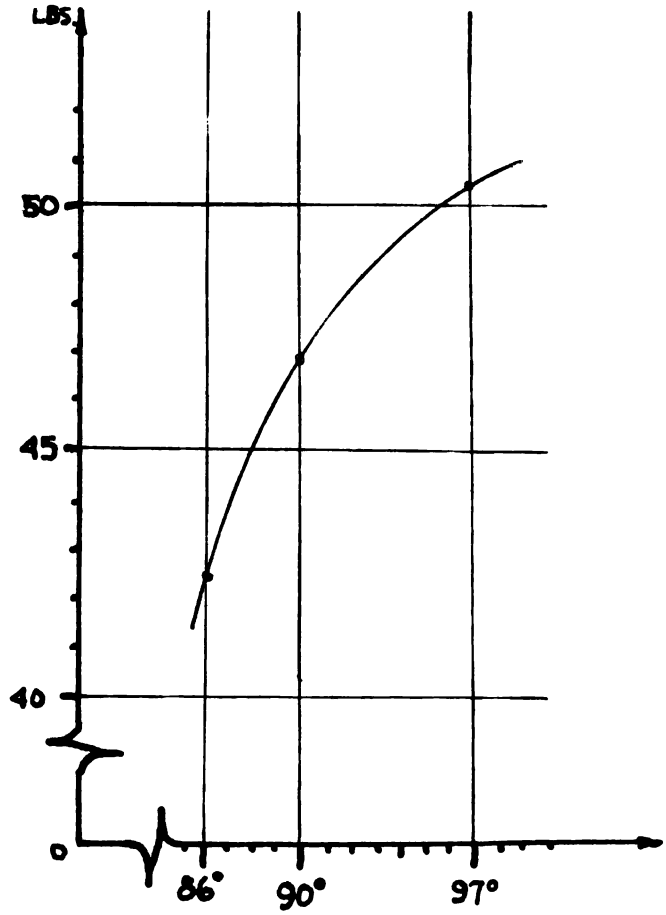
ΣX^2 = 183,448.05

ΣX = 2779.1

Σx^2 = 28,980.11

n = 50

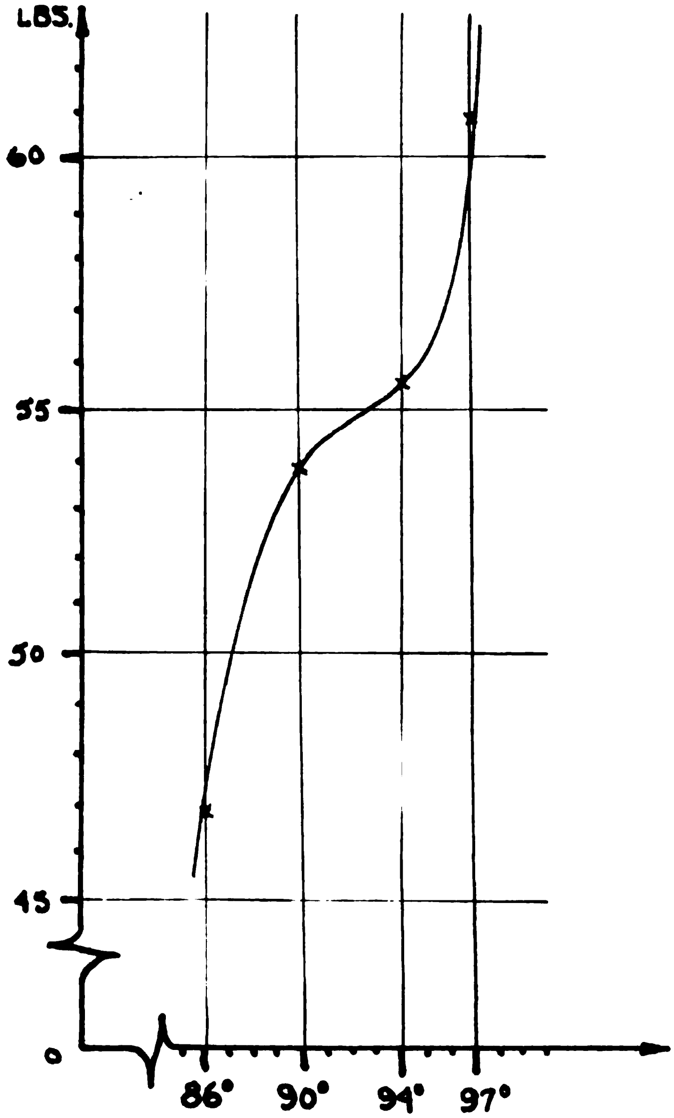
GRAPH 1



Showing relationship between mean load for test groups of 35 cartons made of 0.022 inch white patent coated newsboard versus the vertical sidewall scoreline angle.

o - Mean Failure Point, in Pounds, for Test Group

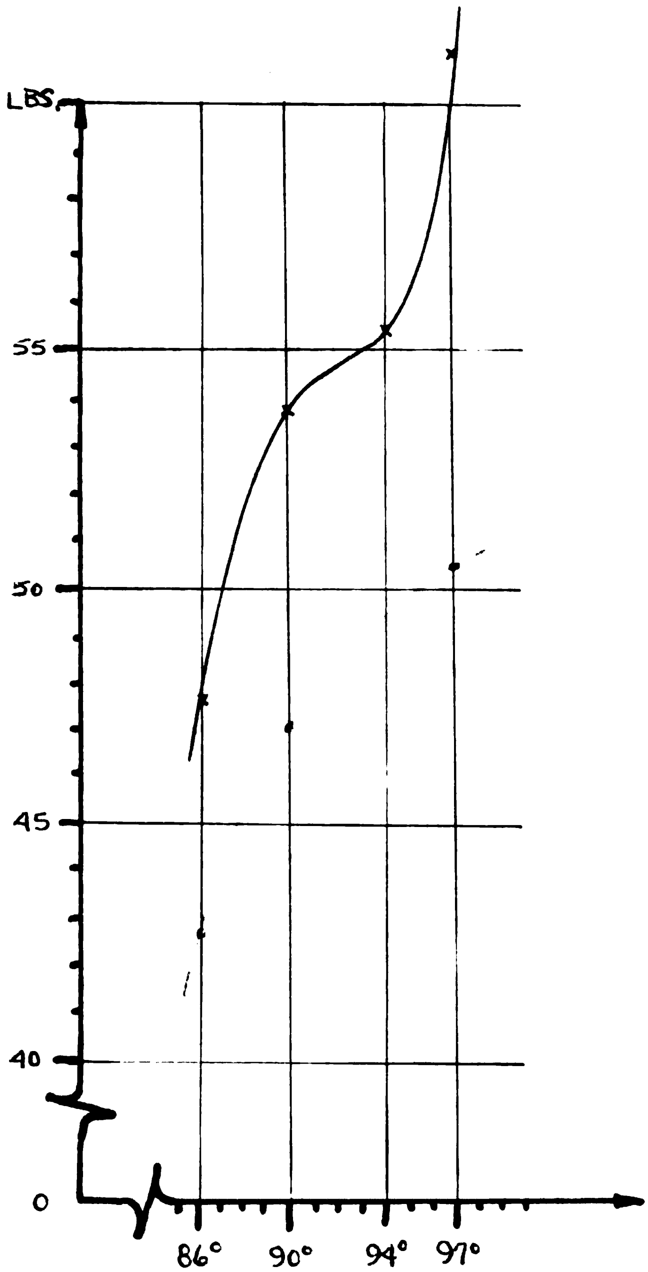
GRAPH 2



Showing relationship between mean load for test groups of 50 cartons made of 0.018 inch bleached manila versus the vertical sidewall scoreline angle.

x - Mean Failure Point, in Pounds, for Test Group

GRAPH 3



Showing relationship between mean load for test groups of 35 cartons made of 0.022 inch white patent coated newsboard versus the vertical sidewall scoreline angle compared with mean load for test groups of 50 cartons made of 0.018 inch bleached manila versus the vertical sidewall scoreline angle.

o - Mean Failure Point, in Pounds, for 35 Cartons
x - Mean Failure Point, in Pounds, for 50 Cartons

ANALYSIS OF DATA

Test Results

Tables I - VII show the failure points for the individual cartons tested in the two series of tests. The failure points are arranged from lowest value to highest value in each table, and not necessarily in the order in which they were obtained. In fact, the results of individual tests varied quite randomly; the data are presented here in ordered form so to be more easily read and interpreted.

Tables I - III are for 0.022 inch white patent coated newsboard cartons of dimensions $2\frac{1}{2}$ x $2\frac{1}{2}$ x $5\frac{1}{2}$ inches.

Tables IV - VII are for 0.018 inch bleached manila board cartons of dimensions $2\frac{1}{2}$ x $2\frac{1}{2}$ x $5\frac{1}{2}$ inches.

Graphs I and II show the average failure points for a given type of carton board versus the sidewall scoreline angle for the two types of board described above.

Graph III gives a composite illustration of how the average load sustained by the two types of cartons varied as a function of the sidewall scoreline angle.

The compression resistance of the folding cartons tested varied directly with the angle of the vertical scoreline. As the angle along the vertical scorelines increased, the mean compression resistance of the folding carton also increased. By inspection, the relationship was not proportionate or arithmatic, but was positively correlated with the scoreline angle. This case may not hold indefinitely, but for the range tested the variance of compression resistance was positively related.

The 0.022 inch white patent coated newsboard cartons with sidewalls deformed to 86 degrees along the vertical scorelines withstood a mean dead load of 42.4 pounds. The range of failure points was 17 pounds for the 35 specimens tested.

The 0.022 inch white patent coated newsboard cartons with the sidewalls forming a normal 90 degree configuration along the vertical scorelines loaded to a mean of 47.0 pounds before failure. The range of failure points was 23.3 pounds for the 35 specimens tested.

The 0.022 inch white patent coated newsboard cartons with sidewalls deformed to 97 degrees along the vertical scorelines withstood a mean dead load of 50.4 pounds. The range of failure points was 33 pounds for the 35 specimens tested.

The 0.018 inch bleached manila board cartons with the sidewalls deformed to 86 degrees along the vertical scorelines loaded to a mean dead load of 46.8 pounds. The range of failure points was 13.5 pounds for the 50 specimens tested.

The 0.018 inch bleached manila board cartons with the sidewalls formed in the normal 90 degree configuration loaded to a mean deadload of 53.9 pounds. The range of failure points was 19.6 pounds for the 50 specimens tested.

The 0.018 inch bleached manila cartons with the sidewalls deformed to 94 degrees along the vertical scorelines withstood a mean dead load of 55.5 pounds. The range of failure points was 22.5 pounds for the 50 specimens tested.

The 0.018 inch bleached manila board cartons with the sidewalls deformed to 97 degrees along the vertical scorelines loaded to a mean

TABLE VIII

		86°	90°	94°	97°
0.022 inch white patent coated newsboard	Range	17.0	23.2		33.0
	Mean	42.6	47.0		50.4
0.018 inch bleached	Range	13.5	19.6	22.5	29.9
manila board	Mean	46.8	53.9	55.5	60.9

"Degrees" above the vertical columns indicates vertical scoreline angles.

"Range" indicates distribution, in pounds, of the individual failure points.

"Mean" indicates the average value of failure points, in pounds, for each group of data.

deadload of 60.9 pounds. The range of failure points was 29.9 pounds for the 50 specimens tested.

The range of failure points was smallest for the cartons with the side panels deformed inwards to form 86 degree angles along the vertical scorelines. The cartons with the sidewalls in their normal 90 degree configuration had the next wider range or variation of failure points. The cartons with the 94 degree angle along the vertical scorelines had the third widest range of failure points, and the cartons with the 97 degree angle along the vertical scorelines had the broadest range or distribution of failure points.

There was a direct relationship between the angle of the vertical scoreline and the range of failure points for both types of board; the more acute the angle along the vertical scoreline, the narrower the range of failure points. Although the average load sustained by the cartons was less than for other groups of cartons tested, the range of failure points was narrowest for the 86-degree-angled cartons. This fact indicated that the cartons became more stable in the dead load they would support as the angle along the vertical scoreline became more acute.

Statistical Analysis

The angles of deformation compared with the normal configuration of the carton for the average load sustained by the cartons tested were statistically significant as shown by a t-test (9 and 10).

Sample Calculation:

For 0.022 inch white patent coated newsboard cartons at 86-

and 90-degree scoreline angle cross-sectional configurations:

$$t = (\bar{X}_1 - \bar{X}_2)\sqrt{\frac{n\ (n-1)}{\Sigma\ x_1^2 + \Sigma\ x_2^2}} \qquad (1)$$

where

$\bar{X}_1$ = average load for cartons with 90 degree vertical scorelines

$\bar{X}_2$ = average load for cartons with 86 degree vertical scorelines

n = number of specimens tested

$$\Sigma x_1 = \Sigma X_1^2 - \frac{(\Sigma X_1)^2}{n} \quad \text{(for 86 degrees)}$$

and $$\Sigma x_2 = \Sigma X_2^2 - \frac{(\Sigma X_2)^2}{n} \quad \text{(for 90 degrees)}$$

For 86 degree vertical scorelines, then:

$$\Sigma x_1^2 = \Sigma X_1^2 - \frac{(\Sigma X_1)^2}{n}$$

n = 35

ΣX_1 = 1484.5

ΣX_1^2 = 63,568.13

$$\Sigma x_1^2 = 63{,}568.13 - \frac{(1484.5)^2}{35}$$

$$\Sigma x_1^2 = 63{,}568.13 - 62{,}964.01$$

$$\Sigma x_1^2 = 604.12$$

For 90 degrees:

$$\Sigma x_2^2 = 527.64$$

then, per formula (1):

$$t = (47.01 - 42.39)\sqrt{\frac{1190}{604.12 + 527.64}}$$

$$t = (4.62)(1.0257)$$

$$t = 4.739$$

For 35 degrees of freedom, and probability = 0.05, t is 2.03. Therefore, for 86 degrees versus 90 degrees for 0.022 inch white patent coated newsboard cartons, the t value of 4.739 was significant. The deformation of the cartons to 86 degree vertical scorelines did affect the compression resistance of the folding cartons tested.

For 0.022 inch white patent coated newsboard cartons with 97 degree vertical scorelines versus 90 degree vertical scorelines t = 2.241. Therefore, using the same t-table value as before, the t value of 2.241 is statistically significant. The deformation of the cartons to 97 degrees along the vertical scoreline did affect the compression resistance of the folding cartons tested.

For 0.018 inch bleached manila board cartons tested, the t value for 50 degrees of freedom and probability = 0.05 is 2.01.

For cartons deformed to 86 degrees along the vertical scorelines versus cartons with 90 degree angles along the vertical scorelines, t was 9.61.

For 90 degrees versus 94 degrees, t was 1.93.

For 90 degrees versus 97 degrees, t was 6.40.

The t-test showed that deforming the 0.018 inch bleached manila board cartons to 86 degrees along the vertical scorelines was statistically significant, as was deforming the cartons to 97 degrees along the vertical scorelines. Deforming the cartons to 94 degrees along the vertical scorelines did not produce a statistically significant change in the compression resistance of the cartons tested, as compared with the normal 90 degree configuration as a standard.

The t-test indicated that the deformation of folding cartons to 86 degrees along the vertical scorelines induced a significant

lowering of the average compression resistance of a folding carton. Also, the t-test indicated that the deformation of cartons to 97 degrees along the vertical scorelines induced a significant increase in the compression resistance of a folding carton.

Observations

The cartons failed at some indefinite point greater than 1/8 inch or more deflection. In some cases of normal usage, a bottle or other type of primary container would take up the applied load. The problem discussed in this study, however, was not the load a carton would withstand at some particular deflection, but rather what happened to the total loading capacity (compression resistance) of the carton at various scoreline deformations. The data do have direct practical application, where no direct support is given by a product to the carton.

The very broad distribution of failure points experienced by cartons deformed to 97 degree configurations may be due to two causes. One, the experimental method; i.e., placing a segment of bound hair cushioning material into a carton, may induce a wide fluctuation of test values because of small variations in vertical scoreline angles allowed by the deforming material. Two, there may have been an inherent mechanical weakness induced in the cartons by deforming the sidewalls from the normal 90 degree configuration.

The type of board used for the cartons tested in this study affected the compression resistance of the carton. The thinner manila board cartons consistently loaded to higher mean compression resistance values than did the heavier white patent coated newsboard

cartons. Caliper of the board alone, then, was not necessarily a determining factor of compression resistance.

The distribution of failure points for manila board cartons was consistently narrower than the range or distribution of individual failure points for white patent coated newsboard cartons. This indicated that a difference in composition in various boards affected the distribution of failure points. Longer fiber length of bleached manila fibers, as compared to the relatively short and broken fibers of white patent coated newsboard, was one of the determining factors.

CONCLUSIONS

The analysis of data presented in this study logically indicated the following conclusions:

The compression resistance of folding cartons varied as a function of the type of board tested through the angles of deformation tested.

Deformation of the sidewalls of a folding carton inward to 86 degrees along the vertical scorelines lowered the compression resistance of the cartons by a statistically significant value. It was concluded that it would not be of practical value to develop a carton that had the sidewalls bowed inward. And, that cartons presently in use that become deformed in that manner significantly lower the compression resistance of a number of cartons in a stack.

Inducing a 97 degree angle along the vertical scoreline did result in a higher mean compression resistance value for folding cartons. Folding cartons may be deformed to take advantage of that fact, for example, by placing an oversized primary container within the carton. However, lateral shock protection provided for the primary container by virtue of the carton being oversize is largely lost.

Redesign of the structure of folding cartons to units having slightly bowed sidewalls and vertical scoreline angles of approximately 97 degrees, would produce cartons capable of taking advantage of higher compression resistance.

It is difficult, however, with present handling methods, to package a group of semi-cylindrical containers (such as cartons with 97 degree vertical scorelines) in a bundle wrap.

Free-flowing products which do not support the carton, but tend to deform it outwards, naturally induce a higher compression resistance in the folding carton.

Machine considerations for today's high-speed packaging machinery require that a folding carton have 90 degree vertical scorelines. Machinery will be jammed, or efficiency will otherwise be lowered by use of cartons which are malformed with vertical scoreline angles in configurations of other than 90 degrees.

There is no way at present to manufacture a carton with vertical scorelines formed to a particular angle greater than approximately 95 degrees--the point, by inspection, where increased angles induce a statistically significant increased compression resistance.

There is no automatic cartoning machinery at present to handle folding cartons with vertical scorelines of configurations other than 90 degrees.

In light of the above considerations and analysis of data of this study, it was concluded that the 90 degree vertical scoreline induces optimum performance features in the folding carton.

If, however, the present trend towards lighter weight shipping containers continues, new style cartons will have to be designed, or machinery to set up folding cartons will have to be redesigned, or both, to take advantage of the higher compression resistance induced by greater than (about) 95 degree vertical scorelines.

If the use of conventional machinery and cartons is continued, board that is more resistant to compressive forces will have to be developed to allow the trend towards lighter weight shipping containers to continue.

RECOMMENDATIONS FOR FURTHER STUDY

Because there was a comparatively broad distribution of failure points for cartons deformed to 97 degree configurations along the vertical scorelines, it is recommended that further study be done to determine the cause of the wide range of values.

Because cartons may deform into several different configurations with angles greater or less than 90 degrees, it is recommended that further study be made to determine the results of compressing a number of deformed cartons at one time. Compression resistance values for a number of deformed cartons may be determined and compared to the compression resistance value for the same number of cartons, all with 90 degree vertical scorelines.

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