THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

A STUDY OF MACHINE-DIRECTION COLUMN TEST METHODOLOGY

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Preliminary Report

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SUMMARY

A study of three methods of evaluating the machine-direction edgewise compression of corrugated combined board has been carried out. These three methods used were: (1) Carbowax 4000 reinforced specimens, (2) Carbowax 4000 reinforced specimens tested using end-clamps, and (3) Epoxy resin reinforced specimens.

The results show that for best precision and accuracy, the machine-direction edgewise compression of combined board should be evaluated by means of Carbowax 4000 reinforced specimens tested using end-clamps.

INTRODUCTION

The machine-direction edgewise compression strength ($\underline{P}_{mx}$) of combined board is the apparent dominant physical property of the board in supporting end-load box compression.

A study of end-load compression on a sampling of commercial boxes resulted in an accuracy of about 8% using the following Equation (1) which was based largely on theoretical considerations (1):

$$P = 0.30P_{mx}\ d + 3.10P_{mx}^{0.787}(\sqrt{D_xD_y})^{0.213}(1 + W/L)^{0.512}\ W^{0.574} \qquad (1)$$

The short column strength, $\underline{P}_{mx}$, used in Equation (1) was obtained by testing columns which had their loading edges reinforced with Mobilwax D paraffin. Despite the reinforcement of loading edges with Mobilwax D considerable rolling and bending of the loading edges was observed. A study was undertaken (2) using harder formulations for edge reinforcement. On 52 samples tested, Carbowax 4000 (melting point approximately 200°F.) exhibited, on the average, about 23% higher machine-direction edgewise compression than the same samples reinforced with Mobilwax D (2). Formula (1) from Reference (1) was re-evaluated using the improved estimates of $\underline{P}_{mx}$ and resulted in Equation (2) from Reference (2):

$$P = 0.26P_{mx}\ d + 2.29P_{mx}^{0.785}(\sqrt{D_xD_y})^{0.214}(1 + W/L)^{0.754}\ W^{0.571} \qquad (2)$$

Equation (2) did not result in any major improvement in estimated *vs.* observed box loads as the average difference using Equation (2) was 8.2% in contrast to 8.6% for Equation (1) on the same box samples. Even with the improved methodology of testing machine-direction columns it was observed that with heavier weight boards some test specimens still exhibited edge roll failures. This indicates that perhaps the heavier weight boards are not yet adequately reinforced along the loading edges to enable these samples to support the equivalent loads they could carry in end-load box compression

Further study has been carried out to investigate the functional make-up of the formula (3). The results of a dimension study supported the structure of the end-load formula. From the work carried out in Reference (3), it was indicated another additive term, involving the machine-direction of combined board edgewise compression strength, should be incorporated into the end-load formula.

The present study was carried out to investigate ways of further improving the machine-direction column test. It is primarily important that the heavier weight boards can be tested in a manner which will eliminate edge-roll failures and thereby provide a more accurate evaluation of edgewise compression strength.

This report presents the results of testing machine-direction corrugated combined board columns by three different methods. One method used Carbowax 4000 reinforcement of loading edges without end clamps. A second method used Carbowax 4000 reinforcement of loading edges with end clamps. A third method used Epoxy reinforcement of loading edges without end clamps.

MATERIALS

Sixteen samples of combined board available from the commercial box study (4) were used for this study and are identified in Table I. Ten samples were used in comparing three test methods, two used only Epoxy resin, and Carbowax with end clamps, and the remaining four samples were tested with only Carbowax with end clamps because of insufficient material.

TABLE I

SAMPLE IDENTIFICATION AND CHARACTERISTICS

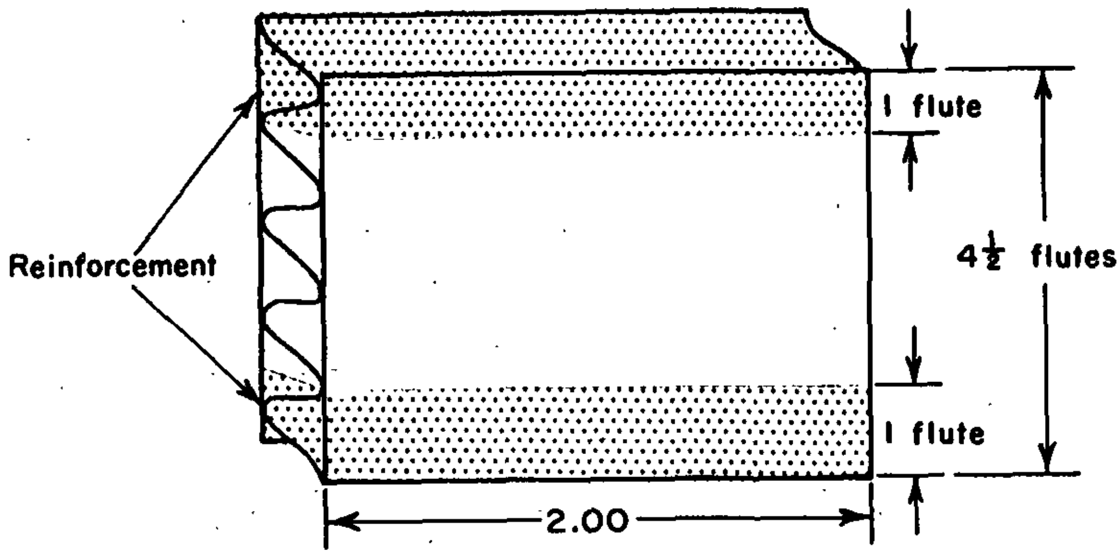
Sample No.	Flute Size	Series
1146	A	200
2373	A	275
2099	A	275
2159	A	275
2211	C	200
2215	C	200
2145	C	200
2398	C	200
2090	C	200
2369	C	275
2050	C	275
2349	B	175
2029	B	200
2240	B	275
2182	B	275
2248	B	275

TEST PROCEDURE

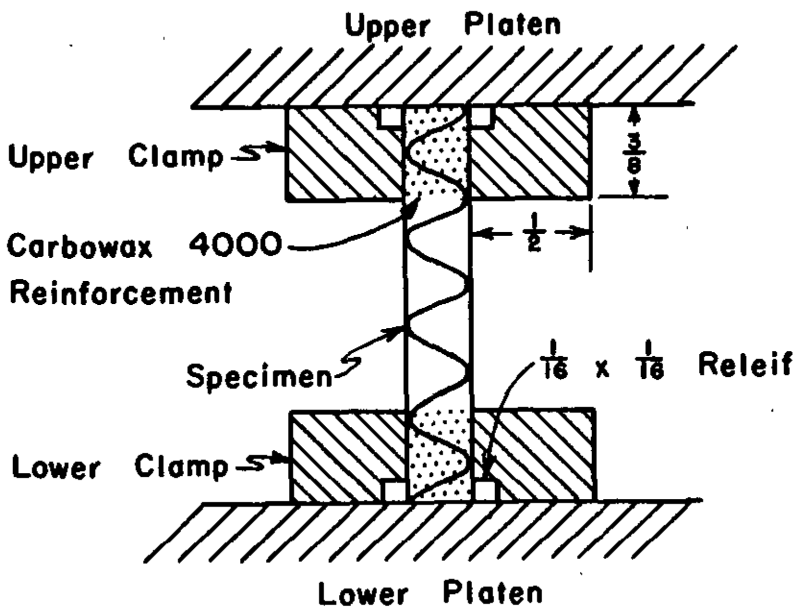
Two types of loading edge reinforcement, Carbowax 4000 and Epoxy resin, along with one type of edge support were used in this study. Fig. 1 diagrammatically shows the edge reinforcement of a machine-direction column (Fig. 1a) and a cross-sectional view of edge support (Fig. 1b).

Carbowax 4000 (melting point approximately 200°F.) was melted in a suitable dip pan and with sufficient wax available to reinforce the loading edges of the machine-direction columns to a depth of one flute (see Fig. 1a). The loading edges of the columns were reinforced with the molten Carbowax in the conventional manner. In this study extra precaution was used in the blotting process to be certain that all excess wax was removed from the edges before allowing the wax to harden -- this was necessary to enable the use of clamps. After the edges were dipped and blotted the specimens were set in a conditioning tray and left to condition in the test atmosphere at least 12 hours before testing. The Carbowax reinforced samples were tested in two ways -- with and without end clamps.

One set of specimens for each sample had the loading edges reinforced with Carbowax and were supported along each loading edge with end clamps during testing. Fig. 1b shows a cross-sectional view of the loading edges of a machine-direction column supported in end clamps ready for testing. Fig. 2 is a photograph of the end clamps used for this study and shows one in position as placed on a specimen and the other with one face turned up to show the complete view of the end clamps. The small vertical slots seen in Fig. 2 are relief slots to accommodate the vertical edges of specimens which are either 1.75 in. or 2.00 in. wide, depending on flute size. The long notch across the face of the clamp is a relief to accommodate any



1(a) Edge Reinforcement



1(b) Clamp Support

Figure 1. A schematic Diagram of Edge Reinforcement and Edge Support.

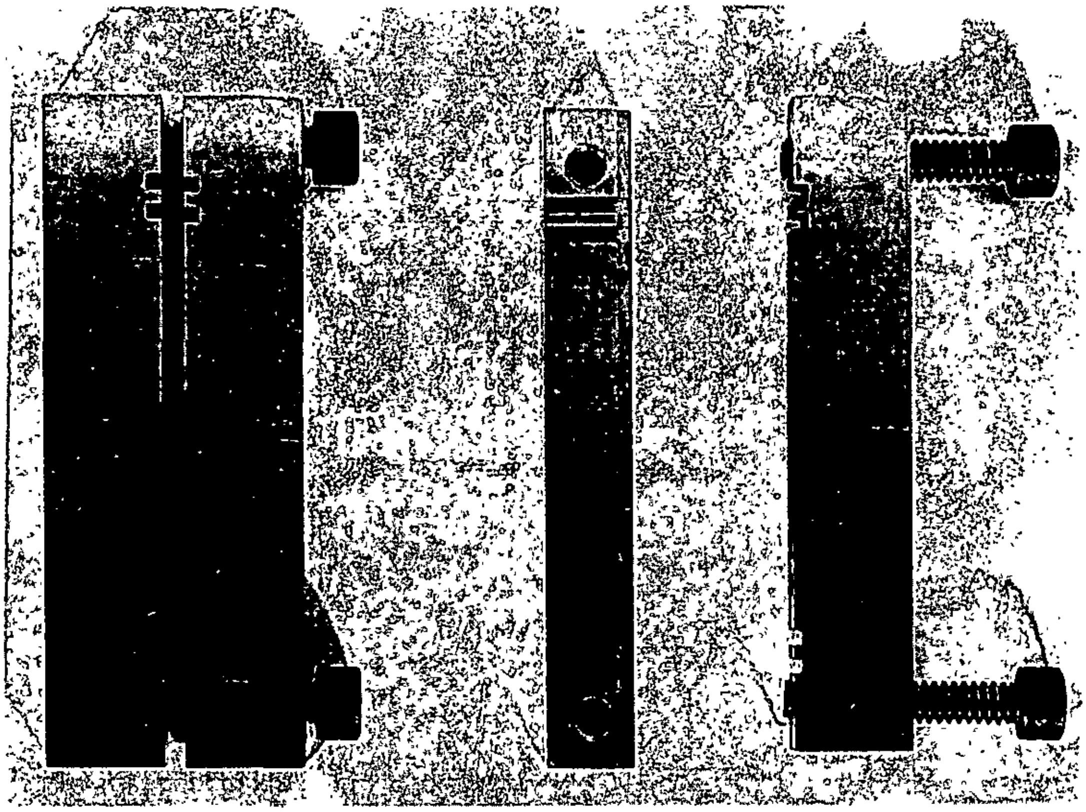


Figure 2. A Photograph of Clamps Used to Support the Loading Edges of Machine-Direction Short Columns.

saw burr along the loading edges of the specimens. Clamping the specimens was achieved by keeping the loading edge of the specimen and the clamp face, which contacts the platens of the testing machine, against a flat surface and then tightening the clamp by turning in the clamp screws until they just became finger tight (both clamp screws were turned in together to avoid having the clamps introduce a scissors action on the specimen). After the first clamp was in position the specimen was inverted and the second clamp was placed on the remaining loading edge. After both clamps were in position the specimen was ready to be tested.

Epoxy resin was used to reinforce the loading edges of machine-direction columns to a depth of one flute (see Fig. 1a). Epoxy 907 adhesive, a product of the Miller-Stephenson Chemical Company, Inc., was used in this study. After mixing the two parts of adhesive, it was applied to the specimen liners (one flute deep along the loading edge) using a razor blade to trowel on as thin a coat as possible. After coating the liners the adhesive was used to fill the void between liner and medium of the last half-flute of the loading edge, and along the vertical edge to the same depth as applied to the liners. After one edge was treated as described, the specimen was positioned upright between two alignment blocks with the treated edge on a sheet of wax paper which was on a flat surface; a weight of one-half pound was placed on the upper (untreated) loading edge of the specimen and it was allowed to stand at least six hours in this fashion. After the initial hardening period the weight was taken off and the specimen was removed from the alignment blocks and the procedure listed above was carried out on the remaining loading edge. After the second loading edge was reinforced and allowed to dry the specimen was then placed in a conditioning tray and allowed to remain in the test atmosphere at least twelve hours prior to testing.

Prior to testing, all material was preconditioned at least 24 hours in an atmosphere of 73 ± 3.5°F. and not more than 35% R.H. After preconditioning the materials were conditioned in the test atmosphere of 50 ± 2% R.H. and 73 ± 3.5°F. for at least 48 hours, plus any additional conditioning times as listed above for various treatments of the loading edges, prior to testing.

All testing was carried out on a Baldwin-Southwark Universal testing machine at a strain rate of 0.025 in./in./min. Columns tested with only reinforced loading edges were vertically aligned in the test machine with alignment blocks which were removed when the specimen started to carry load (usually before a load of ten pounds was recorded). Columns tested with end clamp support along the loading edges required no vertical alignment and were placed in the tester with clamps on and the test load was then applied. All load readings of the clamped specimens had to include the weight of the upper clamps and all recorded Baldwin loads were increased to 0.28 lb. to account for the clamp load.

DISCUSSION OF RESULTS

It has been felt that while Carbowax reinforcement of loading edges results in a good failure pattern and load level for light weight boards (125-200-lb. series), it may not be appropriate for heavier weight boards (275-350-lb. series). For the latter weight boards the maximum load the machine-direction columns are capable of supporting may not be reached due to insufficient increase in the flexural stiffness of the wax-reinforced liner at the loading edge of the specimen (as indicated by edge roll failures observed in previous work (2)). Methods of improving the methodology of testing machine-direction columns were carried out in this investigation.

As previously mentioned, three methods of testing machine-direction columns were used in this study -- (a) Carbowax reinforced loading edges without end clamps, (b) Carbowax reinforced loading edges with end clamps, and (c) Epoxy resin reinforced loading edges without end clamps.

The results obtained on the sixteen samples evaluated in this study are tabulated in Table II along with the results reported in Reference (2). It may be seen from the results in Table II that when samples had Carbowax reinforced loading edges with end clamps, they exhibited higher results, on the average, for all samples tested than the corresponding samples with Carbowax reinforced loading edges without end clamps. Table III presents the differences between the various test methods and their

TABLE II

MACHINE-DIRECTION COLUMN COMPRESSION RESULTS OBTAINED USING TWO TYPES OF EDGE REINFORCEMENT AND ONE TYPE OF EDGE SUPPORT

Sample No.	Flute-Series	Column Compression Load, lb./in. Carbowax 4000 Original	New	Clamped[a]	Diff., %[b]	Epoxy Resin
				A-Flute		
1146[c]	A 200	22.5	--	23.7	+ 5.3	20.4
2373[d]	A 275	30.4	--	39.6	+30.3	--
2099	A 275	57.2	60.9	65.2	+14.0	61.0
2159[d]	A 275	60.2	--	49.7	-17.4	--
				C-Flute		
2211	C 200	20.0	19.0	20.8	+ 4.0	16.0
2215	C 200	25.9	26.6	29.1	+12.4	26.5
2145	C 200	30.8	28.0	28.3	- 8.1	27.4
2398[c]	C 200	34.7	--	36.3	+ 4.6	32.7
2090	C 200	26.5	22.8	27.4	+ 3.4	26.1
2369	C 275	51.0	52.2	55.4	+ 8.6	51.6
2050	C 275	56.3	53.7	56.3	0.0	61.3
				B-Flute		
2349	B 175	26.9	26.4	30.2	+12.3	28.9
2029[d]	B 200	37.6	--	41.9	+11.4	--
2240	B 275	64.6	66.1	69.1	+ 7.0	75.3
2182	B 275	59.2	57.4	64.2	+ 8.4	66.2
2248[d]	B 275	57.6	--	59.6	+ 3.5	--
				Av.	+ 6.2	

[a] Clamped specimens have loading edges reinforced with Carbowax 4000.

[b] Diff., %, based on original Carbowax 4000 values.

[c] Only enough material was available to prepare two sets of 10 specimens for these samples.

[d] Only enough material was available to prepare a single set of 10 specimens for these samples.

statistical significance as determined by the student 't' test. It may be seen from Table III that specimens with Carbowax reinforced loading edges with end clamps tested 8.9% higher than specimens with Carbowax reinforced loading edges without end clamps, on the average, ranging from 1.1 to 20.2% higher. Statistically, four out of ten comparisons were significantly higher -- two light weight and two heavy weight boards.

Comparisons of Epoxy resin reinforced loading edges without end clamps and Carbowax reinforced loading edges without end clamps in Tables II and III show that in six out of ten cases the Epoxy resin is higher, on the average, and three of these are significantly higher -- one light weight and two heavy weight boards. The four cases where the Epoxy resin is lower show one sample to be significantly lower, a 200-lb. series C-flute board. On the average, the samples with Epoxy resin reinforced loading edges without end clamps were 4.8% higher than the corresponding sample with Carbowax reinforced loading edges without end clamps.

Comparing the results obtained with Epoxy resin reinforced loading edges without end clamps and those obtained with Carbowax reinforced loading edges with end clamps shows that on the average the Epoxy resin-treated tested 5.0% lower than the Carbowax-treated with end clamps. All but three out of twelve samples show the Epoxy resin to be lower than the results obtained with Carbowax with end clamps. Of these nine cases, four were significantly lower although one of these is a borderline significance -- three of the materials showing significant differences were light weight boards and one was a heavy weight board. The three cases where the Epoxy resin-treated specimens were higher were with heavier weight boards; none of the differences was significant -- however, one instance is a borderline case.

TABLE III

PER CENT DIFFERENCES BETWEEN TEST METHODS AND THEIR SIGNIFICANCE DETERMINED BY THE STUDENT 'T' TEST FOR MACHINE DIRECTION COLUMN TEST RESULTS OBTAINED USING DIFFERENT EDGE REINFORCEMENT OR SUPPORT

		Clamped vs. Carbowax 4000			Epoxy Resin vs. Carbowax 4000			Epoxy Resin vs. Clamped		
Sample No.	Flute-Series	Diff., %[a]	Calculated 't' Test Value	Significant Difference[c]	Diff., %[a]	Calculated 't' Test Value	Significant Difference[c]	Diff., %[b]	Calculated 't' Test Value	Significant Difference[c]
					A-Flute					
1146	A 200							- 13.9	3.031	Yes
2099	A 275	+ 7.1	2.380	Yes	+ 0.2	0.050	No	- 6.4	2.148	Yes
					C-Flute					
2211	C 200	+ 9.5	1.465	No	- 15.8	2.661	Yes	- 23.1	3.463	Yes
2215	C 200	+ 9.4	1.525	No	- 0.4	0.073	No	- 8.9	1.752	No
2145	C 200	+ 1.1	0.203	No	- 2.1	0.492	No	- 3.2	0.621	No
2398	C 200							- 9.9	2.234	Yes
2090	C 200	+ 20.2	3.201	Yes	+ 14.5	2.406	Yes	- 4.7	1.184	No
2369	C 275	+ 6.1	1.659	No	- 1.1	0.132	No	- 6.9	0.989	No
2050	C 275	+ 4.8	0.687	No	+ 14.2	1.679	No	+ 8.9	1.282	No
					B-Flute					
2349	B 175	+ 14.4	2.477	Yes	+ 9.5	1.553	No	- 4.3	0.911	No
2240	B 275	+ 4.5	0.960	No	+ 13.9	3.333	Yes	+ 9.0	2.081	No
2182	B 275	+ 11.8	2.949	Yes	+ 15.3	2.476	Yes	+ 3.1	0.590	No
Av.		+ 8.9			+ 4.8			- 5.0		

[a] Diff., %, based on values obtained with Carbowax 4000 reinforced loading edges.

[b] Diff., %, based on values obtained with clamped loading edges.

[c] Significant difference is at 5% level comparing calculated 't' test values to a tabular 't' test value of 2.10 for two samples of size 10, i.e., 18 degrees of freedom.

All three test methods showed favorable types of failure, with one exception, the type of failure was either an interflute buckling of liners or compression failure of liners, the latter being more prevalent with heavier weight boards. The one exception was Sample 2050, where in three of the specimens reinforced with Carbowax 4000 and tested without end clamps failed by bowing. No incidences of edge roll failures were recorded.

The coefficients of variation obtained for the three different test methods are tabulated in Table IV. It may be observed that the coefficient of variation for samples reinforced with Carbowax 4000 and tested without end clamps, reinforced Carbowax 4000 and tested with end clamps, and reinforced with Epoxy resin, were 12.19, 9.78, and 13.46%, respectively.

Referring again to Table II, the results obtained for all sixteen samples by testing with Carbowax reinforced loading edges with end clamps along with test data for these same samples from Reference (2) may be observed. A column of per cent differences is also shown comparing the results obtained in this study using Carbowax reinforcement with end clamps with the data from Reference (2) where the test method used only Carbowax reinforcement and did not include the use of end clamps. The results obtained for these sixteen samples show the Carbowax reinforcement with end clamps to be higher in fourteen cases, the composite average difference being 6.2%.

The foregoing results indicate that for best accuracy and precision the machine-direction edgewise compression of combined board should be evaluated by means of Carbowax 4000 reinforced specimens tested using end clamps.

TABLE IV

COEFFICIENTS OF VARIATION OBTAINED TESTING MACHINE-DIRECTION COLUMNS USING DIFFERENT EDGE REINFORCEMENT OR SUPPORT

Sample No.	Flute-Series	Coefficient of Variation, %		
		Carbowax 4000	Clamped	Epoxy Resin
		A-Flute		
1146	A 200		7.59	14.31
2099	A 275	6.85	6.04	7.87
		C-Flute		
2211	C 200	10.59	15.26	19.11
2215	C 200	15.53	10.66	13.44
2145	C 200	10.54	13.80	11.62
2398	C 200	--	7.65	13.41
2090	C 200	15.89	9.82	8.69
2369	C 275	9.64	6.71	22.47
2050	C 275	18.46	11.89	16.46
		B-Flute		
2349	B 175	14.41	10.26	11.84
2240	B 275	9.80	10.73	7.77
2182	B 275	10.18	6.93	14.57
Av.		12.19	9.78	13.46

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