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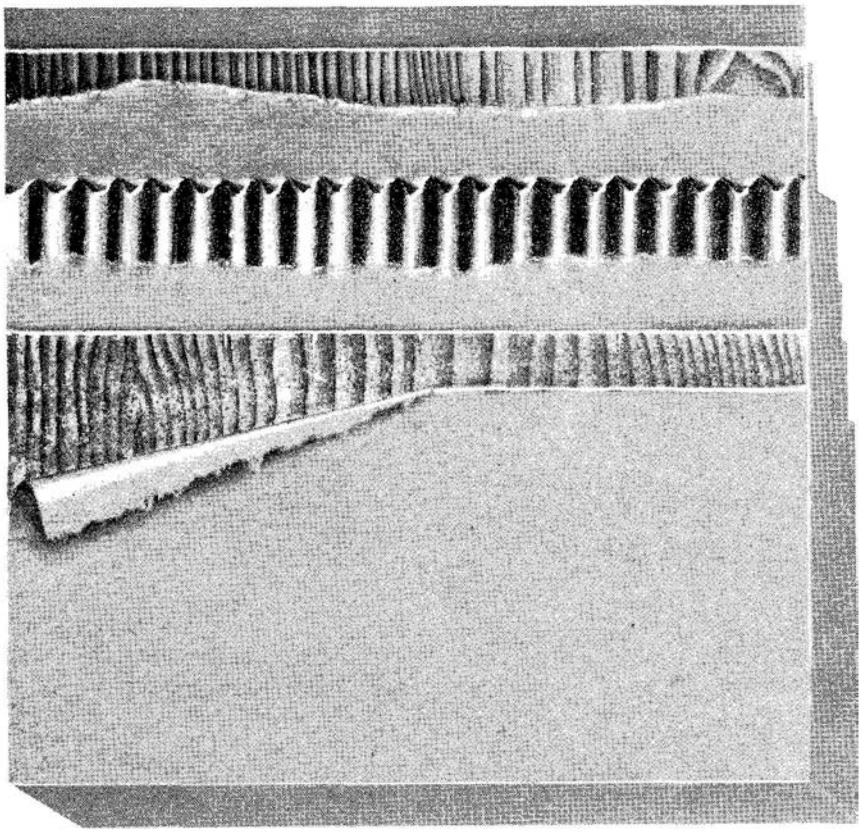
FIBERNEER



DEVELOPMENT, PRODUCTION AND EVALUATION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SUMMARY

Exploratory development and evaluation of a new packaging material called Fiberneer are discussed in this paper. The material is a combination of thin wood veneer and conventional paperboard corrugated box components.

Early trials to produce a double-wall material indicated its potential, but actual production resulted in crushed flutes. The use of thin veneer overlaid with paper and flexed, permitted a single-wall material to be produced on conventional corrugated combining equipment. The overlaid veneer was utilized as outer facings combined with a conventional semichemical corrugating medium

Evaluation of boxes and rectangular tubes produced from the material indicates that Fiberneer, either single–wall or double–wall, possesses certain compressive strength and performance characteristics desirable in a container material.

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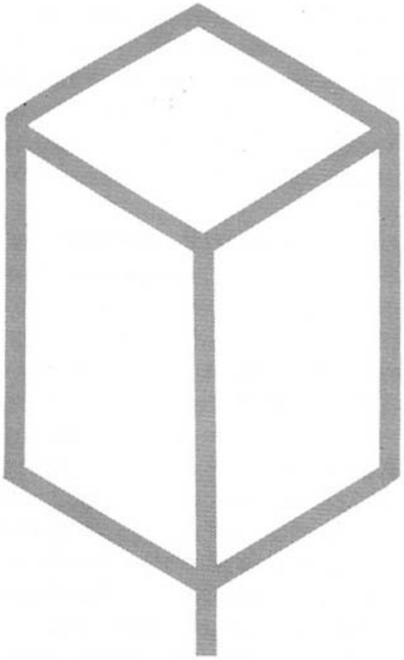

FIBERNEER

DEVELOPMENT, PRODUCTION, AND EVALUATION[1]

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INTRODUCTION

Competition within the packaging industry is extremely keen For example, the nailed wood box, once supreme in its field, has experienced heavy inroads from corrugated fiberboard, a wood-based product. Fiberboard moved into such strongholds of the wood container industry as textiles, foodstuffs, meat, furniture, fruit and vegetables, and even machinery, equipment, and hardware.

Some of the reasons for corrugated fiberboard's acceptance in these fields are quite obvious. It is lightweight, readily stored in hocked-down condition, presents smooth uniform aides and ends for printing, and is easily set up and closed without need for nailing machines.

On the other hand, the conventional wood box has its own advantages. Not only is it strong, but capable of retaining its strength and performance properties when subjected to high humidities and moisture. Also, wood containers can generally be designed to perform adequately with heavier loads than corrugated fiberboard,

Approximately 8 years ago, the Forest Products Laboratory contemplated a packaging material embodying the light weight, formability, and printability of corrugated fiberboard as well as the stacking strength capabilities of wood and its performance under high humidity. Was it possible to combine these two materials so that the resultant material would exhibit the desirable characteristics of both fiberboard and wood? If this could be done in a laboratory, would it be feasible to produce the material commercially, and how would such a material perform in a finished container? The answers to these and similar questions and the developments of a new combination packaging material are discussed in this paper.

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[1] The author and the Forest Products Laboratory acknowledge the assistance in this study of the U.S. Air Force Packaging Evaluation Agency, Mobile, Ala.; U.S. Air Force Logistics Command, Dayton, Ohio; and Green Bay Packaging, Inc., Green Bay, Wis.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

EXPLORATORY

In 1957, the Forest Products Laboratory began to develop a container or packaging material embodying the assets of corrugated fiberboard and wood. Exploratory in nature, this early work involved the use of handmade laboratory samples. These early samples were called “Fiberneer,” a word coined from fiberboard and veneer, the two materials initially used.

The first handmade samples were similar to conventional double-wall corrugated fiberboard. The difference was that the center facing was replaced with thin wood veneer. A piece of single-faced corrugated board was glued to both sides of the veneer. The grain of the veneer was placed at right angles to the flutes of the corrugated medium (fig. 1). This orientation of materials was similar to that in three-ply plywood--the grain direction of the center ply being at right angles to the grain direction of the face plies.

In this combination, the corrugated board provided a smooth exterior surface and also a certain degree of cushioning due to its inherent characteristics. Since the wood veneer was located near the neutral axis of the finished material, it was not expected to contribute significantly to the bending stiffness of the finished material (13).[3]

Kellicutt and Peters (14) describe the importance of the location of components in multi-wall structural materials as follows:

> “The stiffest board will result by placing the heaviest, thickest liners of the structure on the outside surfaces. In so doing, the greatest amount of material is kept as far as possible from the neutral axis of the structure. This results in the highest moment of inertia attainable for the combination and, in turn, the greatest stiffness for the board.”

It was believed, however, that the single-face corrugated material would offer some lateral restraint to the veneer and, thus, reduce the tendency for the veneer to buckle when loaded edgewise. This, in turn, might increase the

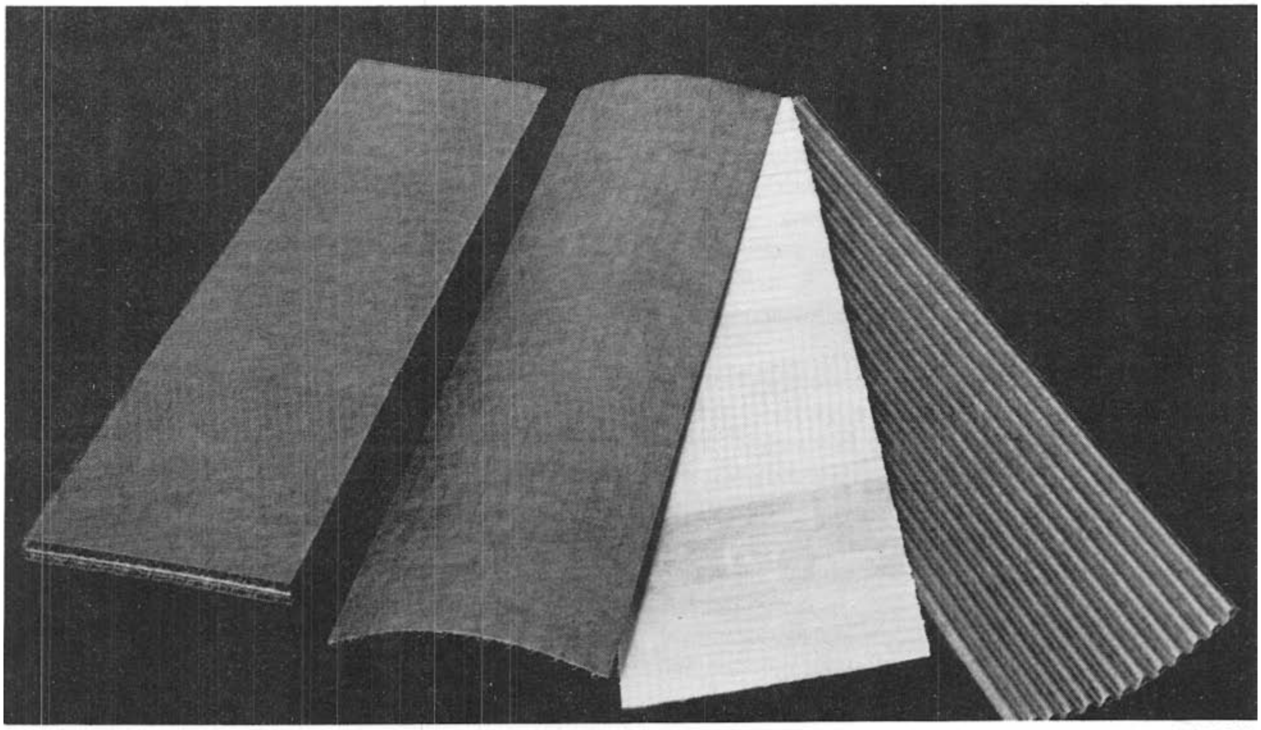
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Figure I.--Original concept of combining thin wood veneer and single-face fiberboard to make Fiberneer. The grain of the veneer is oriented perpendicular to direction of flutes.

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[3] Underlined numbers in parentheses refer to "Literature Cited" at the end of this report.

stacking strength by utilizing the high crushing resistance of wood as compared to paper.

Material

Any of the three generally available flute sizes used in corrugated fiberboard was considered suitable. A–flute, possessing the greatest flute height, would offer the most cushioning effect and also provide the maximum moment of inertia and, hence, greatest stiffness. It would also result in the thickest combined material.

B–flute, because of its greater number of corrugations to the foot, would offer the most lines of lateral restraint to the buckling of the veneer when loaded edgewise. Also, because the flute height is the smallest of the three flute sizes, its use would result in the thinnest combination.

C–flute, having flute height and number of flutes between A–flute and B–flute, appeared to he a compromise material. Thus, it was chosen for the initial laboratory exploration.

The material was handmade, from two components: (1) 1/32-inck-thick-rotary-cut Douglas-fir veneer, and (2) C–flute single–faced corrugated board, glued to each side of the veneer with silicate of soda.

The corrugations were oriented at right angles to the grain of and were adjacent. to the veneer. The C–flute single–face material was rated as a 175-pound test material with a corrugated medium of 26 pounds (basis weight, per 1,000 square feet) and a 90-pound facing.

The overall combined thickness of this handmade Fiberneer was approximately 0.35 inch.

Evaluation

Short–column tests (7) were made to determine the edgewise compressive strength (15) of the material. The compressive strength. in turn, should provide some idea of how a box fabricated from the material could resist stacking forces (16). These tests were made using 1- by 6–inch specimens. They were cut so that the flutes were either parallel to or perpendicular to the direction of the loading force.

Another well-recognized test for determining strength properties of corrugated boards is the static bending test (5, 6, 13). Relatively simple, it can be used for classifying or comparing combined boards according to their stiffness. The procedure used is described in the American Society for Testing and Materials (ASTM) Standard D 1098-61 (4). Specimens were made with the flutes parallel to and perpendicular to the span. Five replicates were used for each flute orientation.

Load–deflection curves were made for each test. The information obtained from these curves was used to compute a measure of stiffness, as follows:

The deflection at the center of the span within the elastic limit of a simply supported beam with a concentrated load at the midpoint is given as

$$\Delta = \frac{P\ell^3}{48EI}$$

where P =load within the elastic limit (pounds)

Δ = deflection at load P (inches)

l = span (inches)

E = modulus of elasticity (pounds per square inch)

I = moment of inertia (inches^4)

The term EI is referred to by Carlson (5) and Kellicutt (13) as a stiffness factor or measure of stiffness of combined corrugated board. Treating the beam–deflection equation mathematically, it may be written

$$EI = \frac{P\ell^3}{48\Delta}$$

Since this was derived from the simple beam formula, the stiffness factor EI is for the particular beam being subjected to bending. The specimens used in this and other work involving fiberboard were rectangular in cross section. Since I, moment of inertia, of the rectangular section is influenced by the width of the test specimen, the stiffness factor EI is similarly influenced. Thus, comparisons may be made only when specimens of similar width are subjected to bending. To compensate for the influence of the width of the specimen, the stiffness factor EI may be reduced to a value per inch of width by dividing by the width of the specimen, Thus

$$D = \frac{EI}{b}$$

where D = flexural stiffness (pound-inches squared per inch of width)
b = width of specimen (inches)

Therefore

$$D = \frac{P\ell^3}{48\Delta b}$$

This material has a readily determined flexural stiffness with the corrugations either parallel or perpendicular to the span. Thus, a composite flexural stiffness value may be obtained by taking the square root of the product of the flexural stiffness in each of the two directions (15, 18).

$$D' = \sqrt{D_1 \cdot D_2}$$

where D' = composite flexural stiffness
D_1 = average stiffness for specimens with corrugations parallel to span
D_2 = average stiffness for specimens with corrugations perpendicular to span

Results and Discussion

The short-column test results of the experimental Fiberneer are given in the following tabulation:

Direction of corrugations	Number of specimens	Moisture content (Percent)	Average load per inch of length (Lb.)
Perpendicular	10	10.5	152
Parallel	10	11.1	184

Interestingly, rather uniform values were obtained regardless of flute direction. This was undoubtedly due to the veneer grain being perpendicular to the flutes. This same test procedure is also used with corrugated fiberboard, but the flutes are always oriented parallel to the height of the test specimen (parallel to the direction of applied load),

Kellicutt (7) reported short-column test values of 139 and 159 pounds per inch for triple-wall corrugated fiberboard and 50 to 88 pounds per inch for treated single-wall. McKinlay (16) recommends a minimum value of 130 pounds per inch for triple-wall board and 60 to 100 pounds per inch for double-wall construction, depending upon board quality.

The thickness of the triple-wall material was approximately 1/2 inch compared to 0.35 inch for Fiberneer.

The static bending tests and computations gave, in pound-inches squared per inch of width, the following average results for the experimental Fiberneer:

$D_1 = 502$

$D_2 = 560$

$D' = 530$

The composite value is not the highest stiffness the Laboratory has encountered in panel materials for packaging, but it is exceeded only by the thicker paper-overlaid veneers (18) and container-grade plywood.

Paper-overlaid veneer and single-wall corrugated fiberboard exhibit higher stiffness values when the grain of the veneer or flute direction are parallel to the span than when they are perpendicular to the span (15). The early exploratory work involving Fiberneer showed remarkably uniform stiffness values regardless of flute direction. Naturally, this was because the orientation of the grain of the thin veneer was at right angles to the flutes.

Samples of the material were subjected to rotary and bar scoring, Indications were that the material could be scored and slotted to permit some flexibility in forming boxes.

EFFECT OF COMPONENT VARIABLES

The exploratory work yielded promising results and substantiated the concept of combining thin veneer with corrugated components. Therefore, it was decided to further the research by investigating effects of certain variables such as veneer species, veneer thickness, flute size, and different qualities of corrugated components.

Materials

As in the exploratory work, the test material was handmade using materials available at the Laboratory. The veneer species were 1/64-inch thick ponderosa pine; Douglas-fir and yellow-poplar in 1/32-inch thickness; and birch in each of the following four thicknesses: 1/32, 1/48, 1/64, and 1/80 inch. Corrugated fiberboard components were:

(1) W6c (19) single-face B-flute corrugated.

(2) A-flute, 26-pound straw corrugated medium combined with 26-pound kraft facing.

(3) B-flute, 26-pound kraft corrugating medium combined with 26-pound kraft facing. Not all of the possible combinations of these variables were assembled for consideration. The combining was accomplished using a polyvinyl-acetate emulsion. In all instances, the grain of the veneer was perpendicular to the flutes.

Evaluation

As in the exploratory work, short-column tests were made on 1- by 6-inch specimens. cut so that the flutes were either parallel or perpendicular to the direction of the loading force.

Composite stiffness values were also computed from the bending test mentioned previously. Sufficient material in certain combinations was fabricated to provide for box blanks. These boxes had inside measurements of 18-3/8 by 12-3/8 by 7-1/8 inches and were to carry six No. 10 cans. Empty boxes were subjected to top-to-bottom compression tests, as described in ASTM Standard D 642-47 (2), Procedure A, The single-drop test procedure of ASTM Standard D775-61 (3) was used to evaluate the rough-handling performance capability of Fiberneer. For these tests, the boxes were loaded with six No. 10 cans filled with sand and sawdust so that the net weight of the box contents was 40 pounds. These boxes had a stapled manufacturer's joint and closure effected by gluing tup and bottom flaps. There was no reinforcement.

The Fiberneer, whether in specimen form or in boxes, was conditioned at 73° F. and 50 percent relative humidity (R.H.). Some specimens and boxes were also subjected to high moisture conditions--80° F. and 90 percent R.H.--until equilibrium moisture content was reached, and then subjected to the various tests.

Results

In general, the results of the short-column test did not exhibit extreme ranges between the high and low values in any one group. The summary of the average results is given in table 1.

The data are not extensive and do not coves all thicknesses nor species of commercial importance. Nonetheless. they do indicate that the stacking load characteristics of a box made from this combined material may be influenced by the orientation of the flutes and direction of the grain of the veneer. Further. although similar specimens with yellow-poplar and Douglas-fir are about equal in short-column performance, the use of birch veneer, a Group IV container wood (22), appears to improve the performance of the material.

As might be expected, the material and flute size in the single-face components also influence the short-column strength. Interestingly, these variations in single-face components have less influence on the performance of specimens subjected to high humidities than those at normal humidity conditions--particularly when the flutes are parallel to the load.

The short-column tests of combined specimens with birch veneer indicate that veneer thickness influences performance. Also, the 1/48- and 1/64-inch-thick veneers tend to give more uniform results in the short-column test, regardless of flute direction in relation to application of load.

When subjected to high humidity, the short-column performance decreases. In some instances, the combination material retained 50 percent or more of the short-column value when conditioned at 73° F. and 50 percent R.H. This is equal to and better than similar performance of some conventional corrugated fiberboards specifically treated to increase wet strength (7). Further, most of the combinations exceeded the values obtained for the treated corrugated material, except board No. 2. Some combinations outperformed this material. It should be noted that the combination material performs seasonably well regardless of flute orientation. However, conventional corrugated fiberboard is subjected to this test only with the flutes parallel to the direction of loading. This is because of corrugated fiberboard's poor short-column performance when the direction of loading is perpendicular to the flutes.

The bending stiffness results substantiate the general observations of the short-column test. Results of the bending stiffness are also given in table 1. It is evident that the paperboard

Table I.--Average results of laboratory-fabricated Fiberneer using different veneer species

Single-face components[1]			Type[2]	Veneer thickness	Pretest conditions		Short-column test			Bending stiffness			
Facing material	Corrugated				Temperature	Relative humidity	Moisture content	Flutes parallel to load	Flutes perpendicular to load	Moisture content	D_1[3]	D_2[4]	$\sqrt{D_1 D_2}$[5]
	Material	Flute											
				In.	°F.	Pct.	Pct.	Lb./in.	Lb./in.	Pct.	Lb.-in.^{2}/in. width		
						DOUGLAS-FIR							
Kraft	Kraft	B	D	1/32	73	50	9.9	95	143	9.7	104	151	125
		B	D	1/32	80	90	26.8	29	67	21.0	38	53	45
		B	W6c	1/32	73	50	7.2	77	108	7.6	114	161	135
		B	W6c	1/32	80	90	17.1	37	65	17.2	50	76	62
		A	D	1/32	73	50	8.1	65	67	8.6	197	199	198
		A	D	1/32	80	90	17.7	29	51	18.0	72	46	58
						PONDEROSA PINE							
Kraft	Kraft	B	D	1/64	73	50	11.0	86	74	11.4	108	129	118
		B	D	1/64	80	90	29.0	26	32	......	......	......	......
						YELLOW-POPLAR							
Kraft	Kraft	B	D	1/32	73	50	9.9	78	100	9.9	102	134	117
		B	D	1/32	80	90	28.9	24	45	24.7	34	52	42
		B	W6c	1/32	73	50	7.1	67	111	7.5	113	157	133
		B	W6c	1/32	80	90	17.9	37	81	17.2	51	74	61
		A	D	1/32	73	50	8.2	52	76	8.4	204	156	178
		A	D	1/32	80	90	18.0	29	54	19.0	68	127	93
						BIRCH							
Kraft	Kraft	B	W6c	1/32	73	50	6.8	83	156	6.9	118	149	132
		B	W6c	1/48	73	50	6.7	57	59	6.1	100	122	110
		B	W6c	1/64	73	50	6.7	55	44	6.4	......	117	......
		B	W6c	1/80	73	50	6.2	52	30	6.2	102	118	109
		A	D	1/48	73	50	6.6	51	38	6.9	185	141	162
		A	D	1/80	73	50	6.7	49	21	6.8	191	101	139

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[1] Both the facing and corrugated medium had a basis weight of 26 pounds per 1,000 square feet.
[2] Type of material: D - Domestic; W6c - Water-resistant--meets requirements of Federal Specification PPP-B-636.
[3] Average stiffness per inch of width, flutes parallel to span.
[4] Average stiffness per inch of width, flutes perpendicular to span.
[5] Composite flexural stiffness per inch of width.

component material, flute size, veneer species, veneer thickness, and pretest conditions all influence the performance of the composite material.

It can be seen that the performance of some combinations is influenced more by exposure to high humidity than other combinations. Some retain about 50 percent of their composite stiffness value at normal conditions when exposed to high humidities.

The results of the single-drop test are expressed as performance index values (table 2). Typical results of the single-drop test are shown in figure 2. Similar results for conventional corrugated cartons, carrying the same weight and type of load, and subjected to the same test procedure at 73° F. and 50 percent R.H., are given in the following tabulation (12):

Container description	Performance index value
175-pound test, A-flute	41.5
175-pound test, B-flute	48.0
200-pound test. A-flute	48.0
200-pound test, E-flute	36.0
350-pound test, B-flute	87.0
200-pound test, solid fiberboard	30.0

Comparing these results, it can be seen that Fiberneer boxes generally performed better than many grades of conventional. fiberboard boxes

Table 2.--Single-drop tests of laboratory-fabricated Fiberneer boxes

Single-face components[1]			Type[2]	Veneer		Pretest conditions		Number of tests	Performance index value[3]
Facing material	Corrugated			Species	Thickness	Temperature	Relative humidity		
	Material	Flute							
					In.	°F.	Percent		In.
Kraft	Kraft	B	D	Ponderosa pine	1/64	73	50	4	78
		B	D	Yellow-poplar	1/32	73	50	13	70.5
		B	D	Douglas-fir	1/32	73	50	13	66
	Straw	A	D	Yellow-poplar	1/32	73	50	7	91.5
		A	D	Douglas-fir	1/32	73	50	10	78
	Kraft	B	W6c	Yellow-poplar	1/32	73	50	7	82.5
		B	W6c	......do......	1/32	80	90	7	87
		B	W6c	Douglas-fir	1/32	73	50	7	82.5
		B	W6c	......do......	1/32	80	90	7	[4]112

[1] Both the facing and corrugated medium had a basis weight of 26 pounds per 1,000 square feet.

[2] Type of material: D - Domestic; W6c - Water-resistant--meets requirements of Federal Specification PPP-B-636.

[3] Performance index number is represented by an average of the lowest height of drop that caused failure in a single drop and the greatest height of drop that did not cause failure.

[4] Maximum obtainable height of drop.

when subjected to rough handling. Also of interest is that exposure to high humidities appears to improve the rough-handling performance of Fiberneer boxes. This is not surprising, since Kellicutt (12) reported optimum rough-handling resistance in corrugated cartons at a moisture content of 20 percent. Also table 1 indicates that exposure to 80° F. and 90 percent R.H. causes Fiberneer to approach a moisture content of 20 percent.

The single-drop results demonstrate that sough-handling performance may be influenced to some extent by species of veneer. However, flute size, and quality of paperboard components, apparently may influence rough-handling performance of Fiberneer to a greater degree.

The average results of the top-to-bottom compression test of empty Fiberneer boxes are given in table 3. It can be seen that when boxes are fabricated from Fiberneer, consisting of domestic-type corrugated components combined with veneer and exposed to high relative humidity, the containers may be expected to retain approximately 45 percent of the average crushing load at 73° F. and 50 percent R.H. If the corrugated components of the combination material are of the weather-resistant type, a higher percentage of the top-to-bottom compressive strength will be retained when evaluated after storage at 80° F. and 90 percent R.H. There is some evidence that the paperboard components, veneer thickness, and possibly species influence the top-to-bottom compressive strength.

Although some boxes failed due to buckling, many also failed due to crushing and rolling along the horizontal scores. Since these boxes were

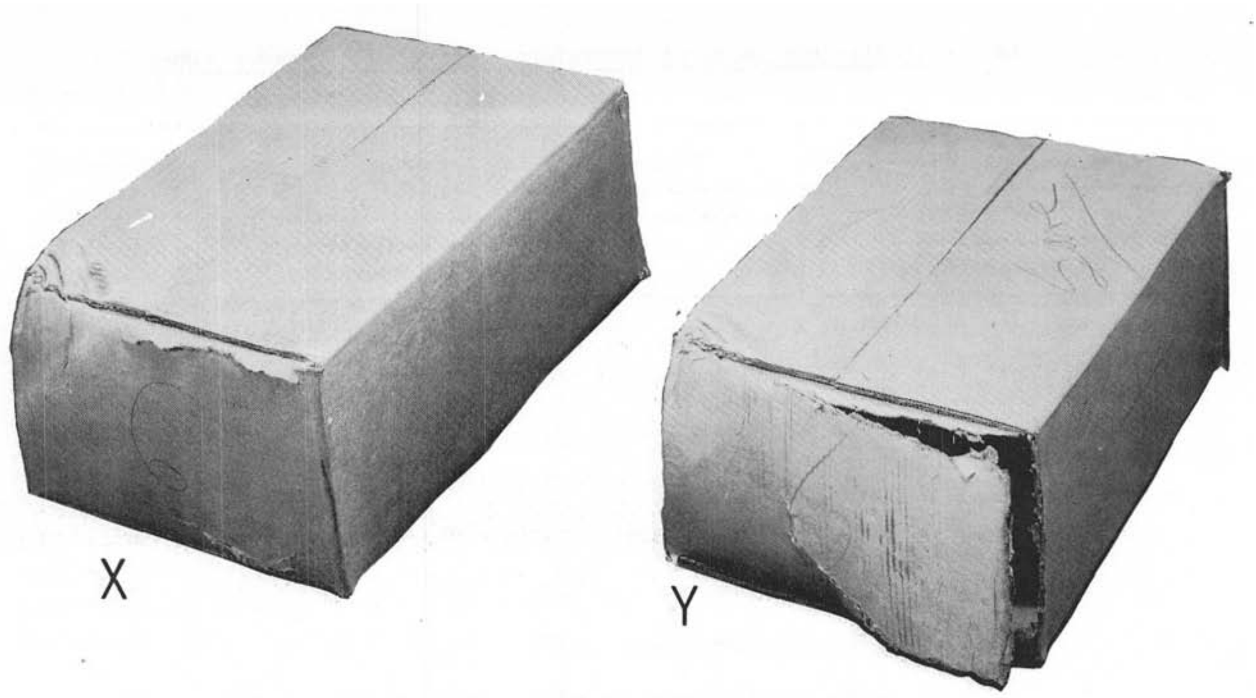

Figure 2.--Typical results of FPL handmade double-wall Fiberneer boxes subjected to the single-drop test. These boxes utilized 1/32-inch-thick yellow-poplar veneer and W6c single-face corrugated components. Box X did not fail when it was dropped 81 inches, but box Y failed when it was dropped 84 inches.

Table 3.--Results of top-to-bottom compression test of laboratory-fabricated Fiberneer boxes[1]

Single-face components[2]: Facing material	Single-face components[2]: Corrugated: Material	Single-face components[2]: Corrugated: Flute	Type[3]	Veneer: Species	Veneer: Thickness	Conditioned at 73° F. - 50 percent relative humidity: Moisture content	Conditioned at 73° F. - 50 percent relative humidity: Average load	Conditioned at 73° F. - 50 percent relative humidity: Average deflection	Conditioned at 80° F. - 90 percent relative humidity: Moisture content	Conditioned at 80° F. - 90 percent relative humidity: Average load	Conditioned at 80° F. - 90 percent relative humidity: Average deflection
					In.	Percent	Lb.	In.	Percent	Lb.	In.
Kraft	Straw	A	D	Douglas-fir	1/32	....	1,685	2.5	....	....	....
		A	D	Birch	1/48	6.8	1,160	1.0	17.7	580	1.0
		A	D	....do.....	1/80	6.3	1,150	1.8	16.6	505	1.0
	Kraft	B	W6c	....do.....	1/32	7.0	1,590	.7	18.9	735	.8
		B	W6c	....do.....	1/48	7.1	1,240	.7	18.6	645	.6
		B	W6c	....do.....	1/64	7.1	1,190	.6	18.2	645	.7
		B	W6c	....do.....	1/80	7.0	1,035	.6	17.4	670	.6

[1] Boxes for 6 No. 10 cans; inside measurements 18-3/8 inches long, 12-3/8 inches wide, and 7-1/8 inches deep.

[2] Both the facing and corrugated medium had a basis weight of 26 pounds per 1,000 square feet.

[3] Type of material: D - Domestic: W6c - Water-resistant--meets requirements of Federal Specification PPP-B-636.

about 8 inches high, this type of failure is similar to that described by Kellicutt (11) for triple-wall corrugated boxes.

Further, table 3 indicates that after exposure to 80° F. and 90 percent R.H., these Fiberneer boxes retained 44 to 65 percent of their top-to-bottom compressive strength at normal conditions, 73° F. and 50 percent R.H. In other compression tests, V3c boxes retained 44 percent of their strength after storage at 80° F. and 90 percent R.H.; whereas cartons, treated by various means to retain their dry strength when wet, retained 45 to 60 percent of their strength.

INITIAL PILOT PRODUCTION

The exploratory and early work indicated that Fiberneer possessed desirable characteristics and might possibly emerge as a new lightweight packaging material capable of retaining 50 percent, or better, of its dry strength after exposure to high humidities. Therefore, it was planned to determine whether this double-wall material. combining wood veneer and paperboard components, could be economically produced on a commercial scale. Areas to be considered were: double-wall corrugated material with thin veneer center facing; two flute sizes. A and B; water-resistant adhesives; hardwood veneer thickness between 1/32 and 1/80 inch; and, if feasible, a single-face material consisting of a thin veneer face and a corrugating medium

Veneer Species

Investigation revealed that although many companies could produce veneer in the desired thickness range of 1/32 to 1/80 inch, only a few were doing so with low-grade veneers economically suitable for container applications. The biggest single objection of the veneer producers was the contemplated difficulty of drying thin veneers. The majority of the companies contacted had roller dryers and had experienced jamming of the dryers when running veneers less than 1/40 inch in thickness. Thus, to proceed with the pilot production, it was necessary to consider air drying for this phase of the work.

It was the opinion of all the producers contacted that only hardwoods should be considered. This might be due to the fact that veneer operations nearby had little experience in cutting, drying, and handling softwoods. Although several hardwoods could be considered soft maple was selected for this phase because of its availability, location, and price structure for small quantities.

Initial Production Trials

No. 1.--Combining the veneer and corrugated fiberboard was attempted using the bottom two openings of an eight-opening hot press, with a usable platen area of 52 by 102 inches. Veneer in sheet form and in thicknesses of 1/32 and 1/81) inch dried to 6 percent moisture content was combined as the center facing of double-wall board. The corrugated fiberboard components were single-face A-flute and B-flute en opposite sides of the veneer.

The single-face material used in sheet form consisted of 33-pound kraft corrugated medium combined with 90-pound weather-resistant facing; or 26-pound corrugated medium with 42-pound domestic facing. The various combinations were assembled by hand on aluminum cauls. The adhesive formulation applied to the flute tips consisted of 100 pounds liquid urea resin, 8 pounds catalyst, 100 pounds wheat flour, and 120 pounds water. There was no pressure applied except for the weight of the platens and cauls. estimated at 1-1/2 p.s.i. The press temperature ranged from 250° to 275° F. The cycle time was 2 to 2-1/2 minutes.

This resulted in visibly good adhesion, but the flutes were crushed, The actual average calipered thickness of the combined material was 64 to 85 percent of the calculated thickness.

No. 2.--In this series, precorrugated single-face material was used in roll form, while the veneer sheets were 1/64-inch-thick maple--dried to a moisture content of 9 percent. The combined material consisted of A-flute single-face and B-flute single-face combined with the veneer as the center facing. The corrugated medium was 33-pound kraft, while the facings were either 90-pound extensible kraft or 90-pound weather-resistant material. The adhesive was applied to the flute tips as the single face was unwound The formulation was 100 parts liquid urea resin glue, 8 parts catalyst, 50 parts wheat flour, and

40 parts water.

As in the first trial, the material was assembled by hand. The aluminum cauls used in the first run were eliminated since they were badly warped and appeared to be contributing to the severe flute crushing. Machined increment bars were used to support and space the platens, which were the only source of pressure. The press temperature was 240° F., with a cycle time of 2 minutes.

This second trial resulted in good adhesion and possibly acceptable board. In some sheets there was flute crushing. In others, it was necessary to use slip sheets to fill the space and hold the components in contact,

Conclusions.--Using increment bars with a conventional hot press and allowing for some flute crushing, it would be possible to produce a double-wall combination material with a thin veneer center facing. The practicality of this, however, is questionable for the following reasons:

(1) Normal inherent and acceptable variation in the materials being combined would create some flute crushing. This is because it would be necessary to use increment bars with thickness based on the lowest possible material thickness to avoid areas of no contact.

(2) The production rate would be rather slow because the single face acts as a heat insulator. Thus, to allow proper heat penetration, the cycle time needs to be increased over that required if just paper were being glued to the veneer.

(3) The liquid adhesive applied to the flute tips lowers their crushing resistance to such a point that suitable pressure cannot be applied to flatten the veneer, resulting in a wavy center facing.

USE OF CORRUGATOR

It was questionable whether combining could be accomplished with conventional corrugator equipment. Since dry veneer could not be wound into rolls, it was necessary to use green veneer. This presented storage problems because the rolled wet veneer developed mold in a relatively short time. The biggest difficulty was the inherent characteristic of the veneer to break while being fed from the roll, because in this operation the thin veneer was placed in tension perpendicular to the grain. In this direction, wood is relatively weak. Only a small amount of veneer was successfully fed into the drying section, but it was sufficient to indicate inadequate bonding. Subsequent drying caused severe warping, rendering the sheets unusable.

It was quite evident that unsupported veneer could not be run successfully on a conventional corrugator. An investigation was made into the possibility of developing a continuous traveling platen hot press to combine the material. Equipment manufacturers in this field believed that it would be possible to build such equipment, but that the problem of varying caliper material might render such equipment uneconomical.

Paper Overlaid Veneer as Facing

It was established that wood veneer. 1/64 inch thick, could be combined with fiberboard components using a hot-press operation; but unsupported veneer could not be run on present corrugated combining equipment. A somewhat different approach was suggested when handmade samples of thin veneer, overlaid with paper, showed improved bending characteristics of the veneer. When bending failure occurred across the veneer grain. the break was cleaner, and free of large splinters and slivers of veneer.

To investigate this approach further, so me paper-overlaid veneer was made as follows: (1) 1/64-inch-thick maple veneer was dried to 7 percent moisture content, and combined with 26-pound kraft paper using a phenolic resin adhesive; and (2) 1/48-inch-thick maple veneer was dried to 7 percent moisture content, and combined with 33-pound kraft paper using a phenolic resin adhesive. With both of these combinations, one-half of the material was made with the veneer grain perpendicular and one-half parallel to the machine direction of the paper. Although a phenolic-resin adhesive might not be economical for this particular application, it did permit combining the paper and veneer for experimental purposes.

Subsequently, attempts were made to combine these paper-overlaid veneer combinations with paperboard components on a corrugator to form an A-B double-wall material. The paper-overlaid veneer was combined with 33-pound corrugated medium to form B-flute single-face. This was combined with previously corrugated A-flute single-face having 33-pound corrugated medium and 90-pound weather-resistant facing. The outer facing used to complete the material was also 90-pound weather-resistant material. Weatherproof starch adhesive was used for all combining operations,

From this, the following were evident:

(1) Paper-overlaid 1/48-inch-thick veneer with the grain direction perpendicular to the flute direction split along the grain, requiring frequent rethreading. Further, the resulting single-face was too stiff to transfer to the bridge without manual assistance. Thus, 1/48-inch-thick paper-overlaid veneer was not runnable.

(2) Paper-overlaid 1/48-inch-thick veneer with the grain parallel to the flute direction did run on the single facer, but it too was stiff and could not be run at satisfactory speeds.

(3) Paper-overlaid 1/64-inch-thick veneer was run successfully without serious problems, regardless of the orientation of the veneer grain with the flute direction.

(4) In all instances, the paper-overlaid veneer acted as a heat insulator, thus preventing the formation of a satisfactory bond between the top single-face and center facing.

(5) To obtain proper adhesion elsewhere, it was beneficial to modify the weatherproof starch by increasing the amount of caustic and percent of solids.

These initial pilot production attempts resulted in sheets of various combinations of materials which were subjected to slatting, die cutting, and scoring operations as generally performed in a container plant. Table 4 gives the results of the combined materials when scored parallel to the flute direction and folded 180°.

For some of the combinations, there was sufficient sheet stock to make short-column tests and top-to-bottom compression tests of boxes and rectangular tubes[4] (figs. 3 and 4). Wherever possible, tests were made after conditioning at 73° F. and 50 percent R.H. or 80° F. and 90 percent R.H. Short-column tests were made similar to the previously described technique, using similar size specimens. Tubes and boxes were one of two sizes, 12 by 12 by 24 inches or 10 by 10 by 24 inches in length, width, and depth, respectively. The average results of the short-column test are given in table 4 and of the top-to-bottom compression tests in table 5.

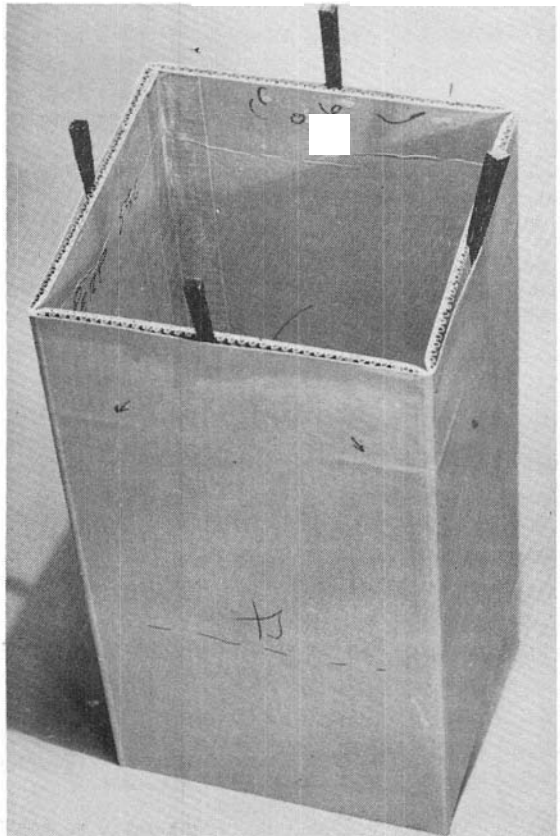
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Figure 3.--Typical tube of A-B flute double-wall Fiberneer, with weather-resistant outer facings and 1/64-inch-thick veneer center facing. The tube was subjected to top-to-bottom compression. Wedges at the top indicate areas of poor glue bond.

From table 4, it can be seen that the relationship of the grain direction of the veneer to the direction of the flutes influences the short-column performance, as does the direction of loading in respect to the grain of the veneer ox flutes. As might be expected, more uniform performance was obtained, regardless of direction of loading, when the veneer grain was at right angles to the flutes. Further, maximum performance was obtained when the flutes and veneer grain were parallel to the direction of loading.

A comparison of the short-column results in table 4 with those in table 1 indicates that the

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[4] A rectangular tube is essentially a box without top or bottom flaps. It is hereafter referred to as a tube.

Table 4.--Scoring characteristics and results of short-column tests on pilot-produced Fiberneer[1]

Facings		Veneer			Scored parallel to flute direction and folded 180°	Short-column tests					
Basis weight per 1,000 square feet	Material	Thickness	Overlaid with paper	Grain direction to flutes		Conditioned at 73° F. - 50 percent R.H.			Conditioned at 80° F. - 90 percent R.H.		
						Moisture content	Flutes parallel to load	Flutes perpendicular to load	Moisture content	Flutes parallel to load	Flutes perpendicular to load
Lb.		In.				Percent	Lb./in.	Lb./in.	Percent	Lb./in.	Lb./in.
90	Extensible kraft	1/64	No	Parallel	No fracture	7.7	229	56	23.9	87	17
		1/64	No	Perpendicular	.....do......	7.9	141	112	23.8	49	55
	Weather-Resistant	1/64	No	Parallel	.....do......	7.3	208	62	21.5	89	28
		1/64	No	Perpendicular	Fractured	7.3	143	117	22.4	53	49
		1/80	No	Parallel	No fracture						
		1/80	No	Perpendicular	.....do......						
		1/32	No	Parallel	Fractured						
		1/32	No	Perpendicular	.....do......						
42	Kraft	1/80	No	Parallel	No fracture						
		1/80	No	Perpendicular	.....do......						
		1/32	No	Parallel	Fractured						
		1/32	No	Perpendicular	.....do......						
90	Weather-Resistant	1/64	Yes	Parallel	No fracture	7.5	277	115	20.0	135	57
		1/64	Yes	Perpendicular	Fractured	7.3	198	154	19.7	88	67
		1/48	Yes	Parallel	.....do......	7.2	335	124	19.9	156	53

[1] All corrugated material was 33-pound kraft.

pilot production material was comparable to the handmade material. The pilot production stock retained 30 to 50 percent of its dry strength after exposure to 80° F. and 90 percent R.H. When paper-overlaid veneer was used the retention range, after exposure to the same conditions, was narrowed to 43 to 50 percent of the dry strength.

As mentioned previously, some difficulty was encountered in obtaining an adequate adhesive bond between the corrugated medium and plain veneer, The use of paper-overlaid veneer improved the quality of the glue bond. This may explain why the retention percentage was smaller for that material using paper-overlaid veneer.

Table 5 shows that the average deflection was relatively uniform for all boxes or tubes, regardless of dry or wet conditioning. Average deflections for boxes ranged from 0.66 to 0.79 inch, and for tubes from 0.07 to 0.20 inch, The boxes retained 34 to 42 percent of their dry compressive strength after exposure to 80° F. and 90 percent R.H. The performance of the tubes was somewhat more erratic, since their retention range was 27 to 48 percent. The tubes had a taped manufacturer's joint reported to be water resistant. However, it was of poor quality and varied widely in performance, the tape sometimes separating from the Fiberneer.

Table 5 also indicates that the average compressive strength of Fiberneer boxes ranges between 68 to 90 percent of tube values. Generally, a box will attain a maximum top-to-bottom compressive strength approximately 70 percent of that attained by its tube counterpart (8). Thus, although there were some indications that scoring, particularly across the grain of the veneer, might cause some problem, the compression tests of boxes and tubes seem to indicate that satisfactory scores can be made. Also, in four instances, table 5 indicates that the boxes outperformed the corresponding tubes. Each of these instances occurred after exposure to 80°F. and 90 percent R.H., and was probably caused by the erratic behavior of the water-resistant tape used in the tube joint,

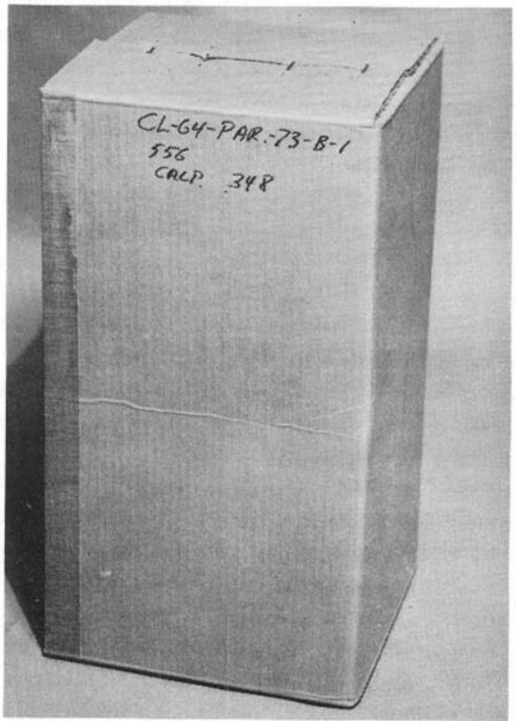

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Figure 4.--Typical box made from A-B double-wall Fiberneer, including extensible kraft outer facings with 1/64-inch-thick veneer center facing. Box was subjected to top-to-bottom compression.

From this pilot production, it was evident that Fiberneer--consisting of a sheet of thin veneer and various paperboard components--could be produced and satisfactorily combined to form a container material. Further, it could be concluded that:

(1) Material thus produced can be formed into boxes and tubes.

(2) Such material, as well as boxes made from it, retains a sufficient amount of its dry-strength characteristics and performance after exposure to 80° F. and 90 percent R.H., to warrant further consideration.

(3) Veneer thickness should probably not exceed 1/64 inch for combining purposes as well as

Table 5.--Average results of top-to-bottom-compression tests on Fiberneer[1] from initial pilot production

Facings		Veneer			Top to bottom compression											
Basis weight: per 1,000 square feet	Material	Thickness	Overlaid with paper	Grain direction to flutes	Box results						Tube results					
					73° F. - 50 percent R.H.			80° F. - 90 percent R.H.			73° F. - 50 percent R.H.			80° F. - 90 percent R.H.		
					Moisture content	Maximum load	Deflection at maximum load	Moisture content	Maximum load	Deflection at maximum load	Moisture content	Maximum load	Deflection at maximum load	Moisture content	Maximum load	Deflection at maximum load
Lb.		In.			Pct.	Lb.	In.	Pct.	Lb.	In.	Pct.	Lb.	In.	Pct.	Lb.	In.
90	Extensible kraft	1/64	No[2]	Parallel	7.5	4,270	0.66	21.5	1,770	0.74	7.4	5,270	0.11	22.4	1,630	0.10
		1/64	No[2]	Perpendicular	7.4	3,270	.72	22.6	1,150	.72	7.7	3,780	.12	22.1	1,050	.20
	Weather-Resistant	1/64	No[2]	Parallel	7.3	4,700	.68	22.0	1,800	.76	7.4	6,160	.12	23.8	1,680	.11
		1/64	No[2]	Perpendicular	7.8	3,730	.77	22.0	1,490	.71	7.6	4,520	.15	22.8	1,410	.15
		1/64	Yes[3]	Parallel	7.7	5,310	.70	19.2	1,780	.79	7.9	5,880	.13	19.6	2,100	.07
		1/64	Yes[3]	Perpendicular	8.0	3,720	.69	18.8	1,540	.77	7.8	4,720	.14	19.2	2,260	.13

[1] All corrugated material was 33-pound kraft.

[2] Box and tube size was 12 by 12 by 24 inches.

[3] Box and tube size was 10 by 10 by 24 inches.

being able to be handled by present scoring and slotting equipment.

(4) The use of paper-overlaid veneer improved the glue bond at the fluke tips and also permitted running and combining the material on a conventional corrugator.

(5) The use of paper-overlaid thin veneer may permit the production of single-wall Fiberneer, but this product would also entail further scoring problems.

PILOT PRODUCTION AND EVALUATION OF SINGLE-WALL FIBERNEER

The previous pilot production of double-wall Fiberneer indicated that, by use of paper-overlaid thin veneer, combining could be done on conventional equipment. It appeared that single-wall Fiberneer could be produced on conventional equipment. Therefore, an additional pilot production was attempted in realization of the magnitude of some of the scoring problems.

To run paper-overlaid thin veneer on a conventional corrugator, it was necessary to have the material in roll form. The original pilot production indicated that the grain of the veneer should be perpendicular to the machine direction of the paper, and thus parallel to the flutes of the corrugated medium. Even with this arrangement, it was difficult to feed the material into conventional corrugating equipment. It was agreed that the stiffness of the paper-overlaid veneer for use as facings should not exceed that of regular 90-pound kraft linerboard. This material is about the stiffest that can be readily handled by a standard corrugator. The results of the stiffness test (17) were used solely for comparing stiffness of the paper-overlaid veneer and the 90-pound kraft linerboard, This test gives a numerical value that can be used for comparison.

A literature search indicated that the simplest and possibly most economical mans of reducing the stiffness of the overlaid veneer was by a process called flexing. This process is being used by several companies to produce flexible wood wall covering for decorative use in homes and offices. Flexing can apparently be accomplished in many ways. One of the simplest, and the method chosen for this work. consisted of passing the overlaid veneer between a large-diameter roll (covered with semihard rubber) and a small-diameter steel roller slightly imbedded in the rubber. The material was flexed from one side and then reversed and flexed from the other side. Material so treated was said to be flexed both sides.

Since the choice of papers for overlaying the veneer was almost limitless, a number of different combinations were selected to cover a range of strengths. Those selected were: (1) approximately 16-pound extensible bag kraft (50 pounds per ream of 3,000 square feet); (2) approximately 33-pound extensible bag kraft (100 pounds per ream of 3,000 square feet); and (3) 33-pound corrugating linerboard.

Because of flexing and present combining equipment limitations, the grain of the veneer must be perpendicular to the machine direction of the paper. Samples were made using 1/64-inch-thick veneer with each of the three paper-overlaid materials. After flexing and conditioning at 73° F. and 50 percent R.H., comparative stiffness values were obtained to compare the flexural rigidity (17) in the machine direction. The following tabulation gives the results in conjunction with the corresponding value for 90-pound linerboard.

Material	Average flexural rigidity (g. cm.)
16-pound extensible kraft to one side of 1/64-inch-thick gum veneer	5
33-pound extensible kraft to one side of 1/64-inch-thick gum veneer	11
33-pound corrugating linerboard to one side of 1/64-inch-thick gum veneer	29
16-pound extensible kraft to both sides of 1/64-inch-thick gum veneer	118
33-pound extensible kraft to both sides of 1/64-inch-thick gum veneer	208

33-pound corrugated liner-board to both sides of 1/64-inch-thick gum veneer	474
90-pound linerboard (control)	486

All of the flexed paper-overlaid veneers had values less than for the control material and thus should be runnable on conventional corrugating equipment. The flexing, however, caused severe wrinkling of the samples with the 33-pound corrugating linerboard. Undoubtedly, this wrinkling would have caused severe problem during subsequent combining operations. Thus, 33-pound corrugating linerboard was deleted from further consideration,

Materials

Gum veneer, 1/64 inch in thickness, overlaid both sides with 33-pound extensible kraft paper, was selected. The veneer was cut and dried in east central Mississippi and was classified as "special log run rotary-cut veneer," Certain defects were acceptable: Knots and knotholes not to exceed 2-1/2 inches in diameter, and splits not exceeding 3/4 inch wide or 12 inches long. Decay not permitted.

The veneer was dried in a gas-fired dryer with conveyor rollers on 4-inch centers. The temperature was 200° F. and the time was 10 minutes. Attempts to dry the thin veneer in a dryer with the rollers on 9-inch centers were unsuccessful because the thin veneer jammed in the dryer.

The paper for overlaying the veneer was obtained from a mill in Arkansas as American Extensible Converting Grade, and was approximately 33-pound extensible bag kraft (100 pounds pes ream of 3,000 square feet).

To control the water-resistant properties, the bond between the paper and veneer was required to meet the ply-separation requirements of Federal Specification PPP-B-636c(19). An extended urea resin adhesive of the following formulation, which met the requirements. was used:

Component	Parts by weight
Urea resin	10
Wheat flour	15
Water	24
Catalyst	0.8

The veneer and paper were combined by a hot press, operating at 100 p,s.i. and 260° F. with a press time of 30 seconds. The adhesive was sprayed onto the inside surfaces of each paper web at a rate of 13.2 pounds liquid weight per 1,000 square feet. The veneer was assembled between the paper webs by hand. Care was taken so that the edges of adjoining veneer pieces did not overlap. Actually a slight gap. not more than 3/8 inch, resulted In the best operation and performance of the overlaying operation. If the veneer pieces were overlapped, a bump resulted and, also, a "blow" generally occurred when the press was opened. After overlaying the veneer with paper, the combined material was flexed, both sides, perpendicular to the machine direction of the paper (parallel to the veneer grain). This combined material. was used as the facings, being combined with 30-pound semichemical corrugating medium

In combining the facings and corrugated medium, it was stipulated that the adhesive must provide a joint that meets the water-resistant ply-separation requirements of Federal Specification PPP-B-636 (19). Laboratory tests indicated that at least two adhesives could be used with conventional combining equipment to produce a satisfactory bond of the material. These were commercially available starch-resorcinol and starch-urea-formaldehyde adhesives.

Two pilot runs were made on commercial combining equipment using the starch-urea-formaldehyde adhesive with a final viscosity of 30-38 seconds at 100° F. The facings were the previously combined and flexed paper-overlaid veneer, and the corrugations were A-flute. Roll settings were 640 to 660 pounds for the pressure roll and 460 and 490 pounds for the corrugator roll. The single-face facing was given a full wrap over the preheater; speeds were 80 to 124 feet per minute. The glue rolls at both the single facer and double backer were set at 0,019 inch,

At the double backer, the single-face web was given a three-fourths to full wrap over the preheater with the outer facing being given a one-fourth to seven-eighths swap under the preheater.

Little or no trouble was encountered in these pilot runs, and acceptable single-wall board was the result. There was some evidence of leaning flutes that appeared to be corrected by reducing the pressure on the bels of the hot plate section,

Subsequent evaluation of the material revealed that the single-face glue bond produced during the second run was not as satisfactory as that produced during the first run. It was evident that there was not sufficient glue on the flute tips of the corrugated medium, apparently caused by insufficient glue roll adjustment to compensate for the higher speed of the second run.

After completion of the second run, the material was converted into equal quantities of regular-slotted boxes and tubes, with inside dimensions of 18-9/16 inches long, 12-3/8 inches wide, and 14 inches deep; or 18 inches long, 18 inches wide, and 20 inches deep.

Finishing

Some difficulty was anticipated in producing the horizontal scores (perpendicular to the grain of the veneer) that are normally produced at the corrugator just before the cutoff. Consequently, no scoring was done on the corrugator as is the usual practice. This arrangement permitted some experimentation in developing a technique for making these scores. All of the available contours of rotary scoring heads in the cooperator's plant were tried as was bar scoring. In all instances, the outer extensible kraft facings fractured when the flaps were folded through 90°.

An attempt was made to develop a progressive scoring technique in which the material was passed through three successive sets of roller score heads, each set adjusted to give a slightly deeper score than the previous one. The first set was adjusted to make minimum indentation; the second set was adjusted for scoring nominal A-flute material; and the third set adjusted for scoring nominal B-flute material. With this arrangement, the material was run through the scoring rollers without fracture, and folding the flaps 90° resulted in only minute fracturing. Moistening or dampening the score lines entirely eliminated the fracturing. The body scores, those scores parallel to the grain direction of the veneer, and the slotting were accomplished on a standard printer-dotter without difficulty using normal operating procedures and settings.

The manufacturer's joint in the box blanks was stitched on conventional equipment using standard wire stitches. Spacing and location of the stitches conformed to Federal Specification PPP-B-636c(19).

Evaluation

The boxes and sheet stock of single-wall Fiberneer, fabricated in the two pilot plant production runs, were used to evaluate the behavior and performance characteristics of the material.

The basis weight in pounds per 1,000 square feet of the Fiberneer components as well as of the combined board was determined when conditioned at 73° F. and 50 percent R.H.

Suitable samples of the material produced in the pilot production of single-wall Fiberneer were subjected to: (1) the water-resistance tests (ply separation) of Federal Specification PPP-B-636c (19); (2) the short-column test (7); (3) the static bending teat (5, 6, and 13) and (4) the puncture test described in ASTM Standard D 781-59 T (1). Wherever possible these tests were conducted after conditioning the material at 73° F. and 50 percent RH., 80° F. and 90 percent R.H., or 24-hour water submersion.

Regular slotted boxes and rectangular tubes of two sizes (18-9/16 by 12-3/8 by 14 inches and 18 by 18 by 20 inches inside length, width, and depth, respectively) were subjected to top-to-bottom compression tests of ASTM Standard D 642-47 (2) after exposure to one of the three previously mentioned conditions. Further, rough handling capability was measured by subjecting loaded regular slotted cartons (RSC boxes) (18-9/16 by 12-3/8 by 14 inches) to the single-drop test of ASTM Standard D 775-61 (3) after conditioning at one of the three exposures. These boxes were loaded with 12 No. 10 cans to provide a load of 135 pounds.

Results

The average basis weight of the components and the combined board at 73° E. and 50 percent R.H. was:

	(Lb. per 1,000 sq. ft.)
Liners (paper-over laid gum veneer)	120

Corrugated medium (semichemical)	29
Combined Fiberneer	294

Fiberneer is about 30 percent lighter than triple–wall and 25 percent lighter than double-wall (10). These values will vary depending upon the materials combined to form the sheets.

Samples from the first run of the pilot production, subjected to the water–resistant test of Federal Specification PPP–B–636c(19), passed these requirements. Samples from the second run definitely had an inferior glue bond at the single facer (fig. 5). This naturally influenced the performance of boxes and tubes fabricated from this material, especially after soaking in water 24 hours. Subsequent review of the data, recorded at the time of the two pilot production runs, indicated that the probable cause was failure to adjust the single–face glueline to compensate for a higher combining speed,

The minimum, maximum, and average short-column test results for three different size specimens after each of three exposure conditions are given in table 6. Fiberneer retained approximately 58 percent of ita dry short-column strength after exposure to high humidity. Fiberneer's apparent retention after 24–hour water soak was extremely low. This was undoubtedly caused by the variability in the single–face glueline and because of the bow of the specimen after water soak This bowing might be caused by the different coefficient of expansion for paper and wood. The short-column strength retention after exposure to high humidity is as good as that experienced by some corrugated fiberboards treated to increase wet strength (7). Similar laboratory tests of A–B double–wall gave an average value of 137 pounds per inch, a C-B double–wall material averaged 127, while one of the highest triple–wall materials averaged 178 pounds per inch in the short-column test. Triple–wall material retained about 44 percent of its dry short column value after exposure to high humidity.

Average short–column results of single–wall Fiberneer were not significantly different than the best values obtained from the double–wall Fiberneer of the initial pilot production runs. The single–wall material was not subjected to the short-column test with the flutes perpendicular to the loading force as was the double-wall Fiberneer. This is because the veneer was

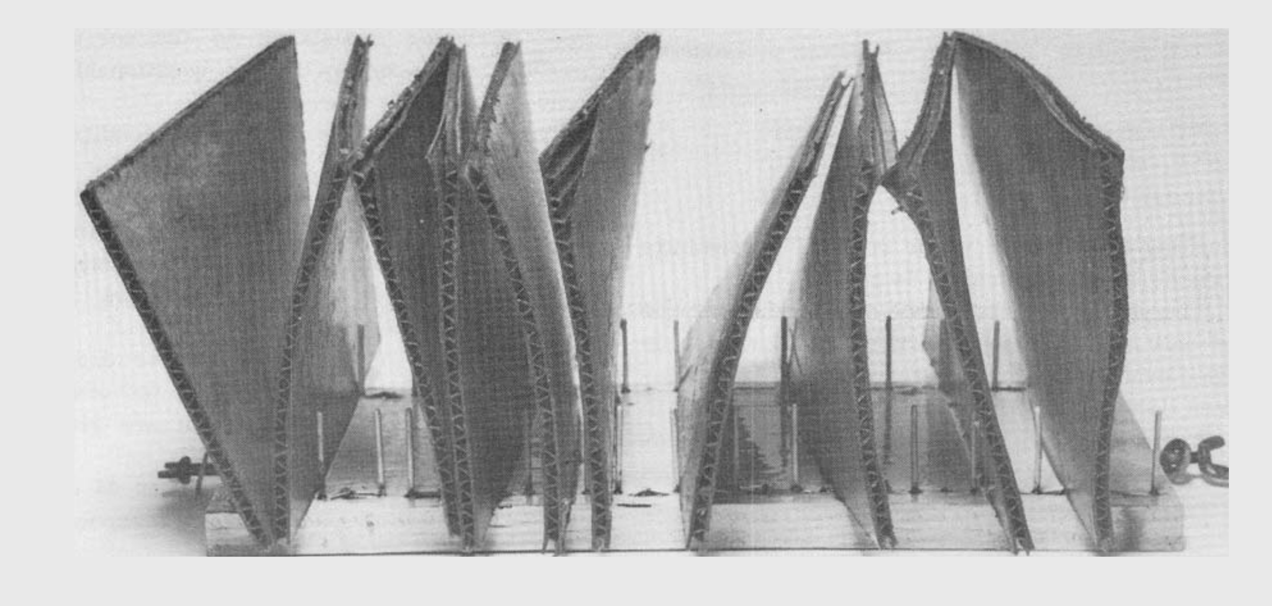

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Figure 5.––Condition of pilot–produced single–wall Fiberneer samples after water–resistant test of Federal Specification PPP–B–636. The failure of some specimens indicates inferior single-face glue bonds.

Table 6.--Results of short-column tests on different sizes of specimens of pilot-produced single-wall Fiberneer

Exposure conditions	Results	Specimen size (inches)[1]		
		2 by 1-1/4	2 by 2	2 by 1-1/2
		Lb./in.	Lb./in.	Lb./in.
73° F. - 50 percent R.H.	Minimum	249	248	229
	Maximum	315	343	291
	Average[2]	279	283	262
80° F. - 90 percent R.H.	Minimum	151	150	137
	Maximum	169	176	171
	Average[2]	162	161	151
24-hour soak[3]	Minimum	21	18	20
	Maximum	42	47	42
	Average[2]	30	28	30

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[1] Specimens 2 by 1-1/4 and 2 by 2 had wax-dipped ends. The 2- by 1-1/2-inch specimens were circularly necked-down to I inch.

[2] Average of 10 specimens.

[3] Specimens bowed after soaking, causing failure by bending and influencing the results.

oriented with its grain parallel to the flutes.

Exposure to high humidity did not materially influence the performance of Fiberneer in the puncture test. Average results are given in the following tabulation:

Condition	Average inch-ounces per inch of tear
73° F.-50 percent R.H.	581
80° F.-90 percent R.H.	601
24-hour water soak	268

Soaking 24 hours in water reduced the puncture resistance approximately 54 percent.

The puncture performance at normal conditions is only about 50 percent of the minimum specified puncture resistance requirement for triple-wall corrugated fiberboard (20).

From the bending stiffness tests, the stiffness value EI (6) was calculated and these results are given in the following tabulation:

Condition	Stiffness (Lb.-in^2 per in. width)
73° F.-50 percent R.H.	672
80° F.-90 percent R.H.	482
24-hour water soak	65

Single-wall Fiberneer retained almost 72 percent of its dry stiffness value after exposure to high humidity. The retention of less than 10 percent after 24-hour water soak was less than expected, This poor performance can be attributed to the lack of water resistance in the corrugating medium and possibly to the questionable glue bend at the single facer.

The stiffness value at normal conditions is somewhat better than a value of 644 for a 600-pound test A-B double-wall fiberboard, evaluated recently at the Laboratory. Also, it is considerably higher than the majority of the 600-pound test double-wall. hoards for which stiffness values have been obtained.

The results of the single-corner drop test and the top-to-bottom compression test of single-wall Fiberneer boxes and tubes axe given in tables 7 and 8, respectively.

Fiberneer tubes retained between 65 and 75 percent of their dry strength after exposure to high humidity but the strength retention after 24-hour soak was rather low, ranging from 6 to 10 percent (tables 7 and 8). The strength retention of the boxes was approximately 60 percent after exposure to high humidity, but the retention dropped to 8 to 13 percent after the 24-hour water soak.

Table 7.––Performance index values for single–wall pilot-produced Fiberneer boxes[1] carrying 135–pound can load

Average box weight	Test conditions	Moisture content	Boxes strapped	Maximum height of no failure	Minimum height to cause failure	Performance index
Lb.		Percent		In.	In.	In.
3.8	73° F. and 50 percent R.H.	7.7	No	24	24	24
5.0	73° F. and 50 percent R.H.	7.8	Yes[2]	48	42	45
5.0	80° F. and 90 percent R.H.	17.1	No	114	96	105
(3)	24-hour water soak	136.3	No	(3)	(3)	(3)

[1] Inside box size (inches)--18-9/16 long, 12–3/8 wide, and 14 deep.

[2] Boxes strapped with one girthwise and one longitudinal flat metal band, 1/2 by 0.020 inch.

[3] Boxes could not be tested because of a delamination at the single-face glueline.

Table 8.––Average[1] results of top–To–bottom compression tests on pilot-produced single-wall Fiberneer tubes and boxes

Size -- inside dimensions			Condition	Tubes				Boxes			
Length	Width	Depth		Moisture content	Average load	Average load per perimeter inch	Average compression	Moisture content	Average load	Average load per perimeter inch	Average compression
In.	In.	In.		Percent	Lb.	Lb./in.	In.	Percent	Lb.	Lb./in.	In.
18-9/16	12-3/8	14	73° F. - 50 percent R.H.	8.1	6,950	112	0.123	8.1	3,010	49	0.528
18-9/16	12-3/8	14	80° F. - 90 percent R.H.	16.9	5,110	83	.100	16.8	1,800	29	.515
18-9/16	12-3/8	14	24-hour water soak	130.0	400	7	.120	129.0	250	4	.444
18	18	20	73° F. - 50 percent R.H.	7.8	6,440	89	.154	8.2	3,840	53	.584
18	18	20	80° F. - 90 percent R.H.	16.4	4,100	57	.147	16.7	2,280	32	.635
18	18	20	24-hour water soak	132.0	650	9	.125	128.0	490	7	.367

[1] Average based on 10 replicates.

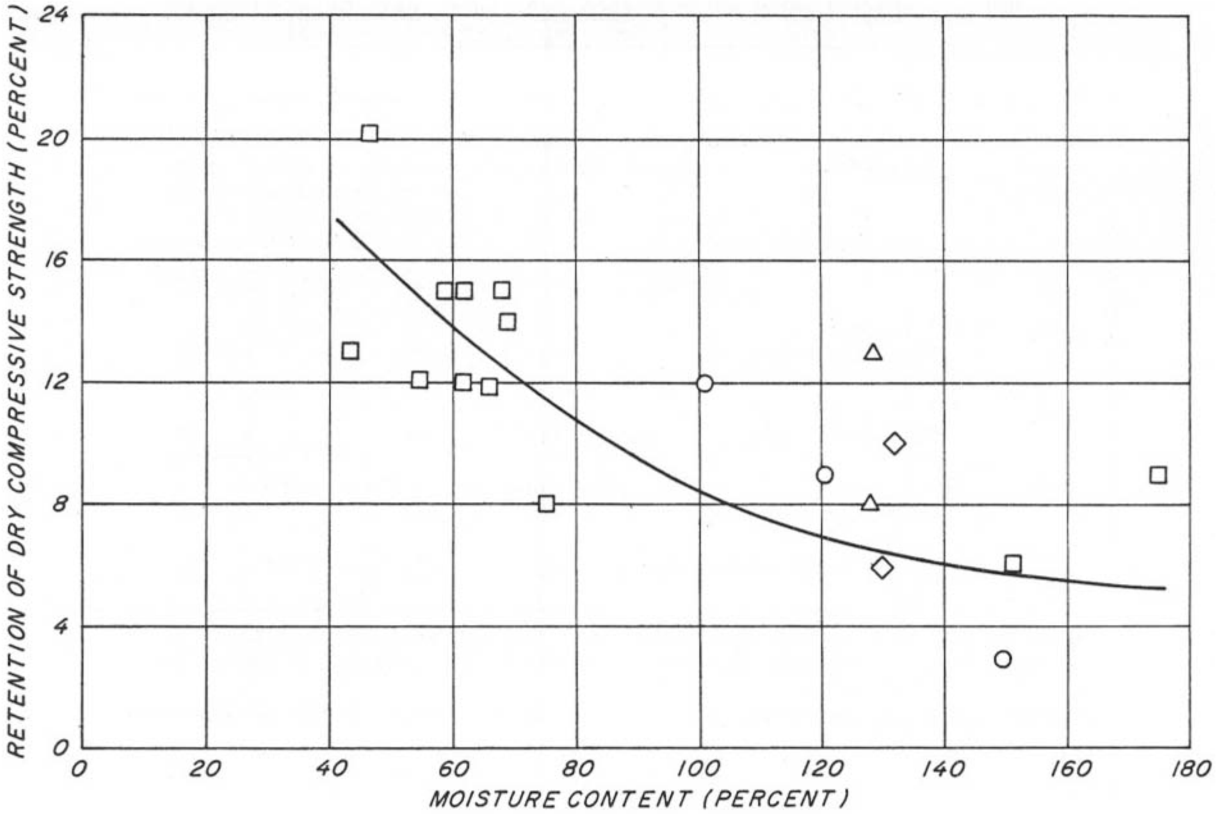

Figure 6.--Compressive strength retention of various corrugated containers as related to moisture content after 24-hour water soak. Legend: ○, untreated single-wall corrugated boxes; □, treated single-wall corrugated boxes; ◇, single-wall Fiberneer tubes; and △, single-wall Fiberneer boxes,

These retention values after exposure to high humidity are as good or better than those experienced by the Laboratory in investigating the effectiveness of various treatments for improving the ability of corrugated boxes to retain their dry strength when wet, The best of the treatments showed a 60 percent retention of the dry strength when exposed to 80° F. and 90 percent R.H. The rest of the treatments ranged between 44 and 57 percent retention, Untreated boxes retained 38 to 48 percent under similar exposures. After 24-hour water soak, the Fiberneer strength retention was 6 to 13 percent of the dry strength. This is similar to the effectiveness of some wet-strength retention treatments previously evaluated at the Forest Products Laboratory. These gave percentages between 6 and 15 percent with one treatment retaining 21 percent of the dry strength.

The plot of figure 6 indicates that the compressive strength retention as a percent of the dry compressive strength after 24-hour water soak is, generally, inversely related to the moisture content of the material--as the moisture content increases, the retention percent age decreases. The points for the Fiberneer tubes and boxes indicate that their retention percentage is as good or better than that generally obtained for treated or untreated single-wall corrugated board with similar moisture content. Undoubtedly, if a more water-resistant corrugated medium were used for the Fiberneer, instead of conventional semichemical paper, an improved retention percentage should result.

The top-to-bottom compressive strength of the boxes ranged from 35 to 78 percent of the tube strength, depending upon the size and exposure conditions. Typical conditions of tubes and boxes. after compression testa, axe shown in figures 7, 8, and 9.

Kellicutt (8) explains that this relationship of box to tube strength for units of similar size is an indication of the quality of the box scores. The higher the percentage the better the box

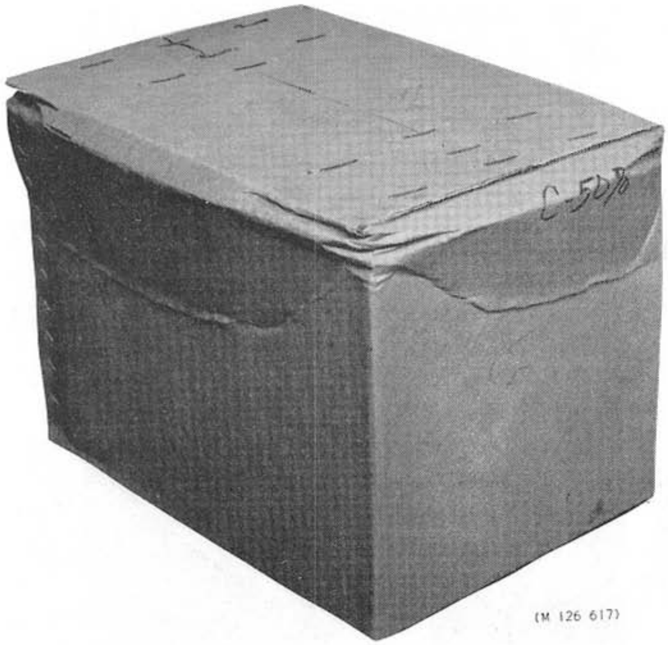

Figure 7.--Condition of pilot-produced single-wall Fiberneer box subjected to top-to-bottom compression after conditioning at 73° F. and 50 percent relative humidity.

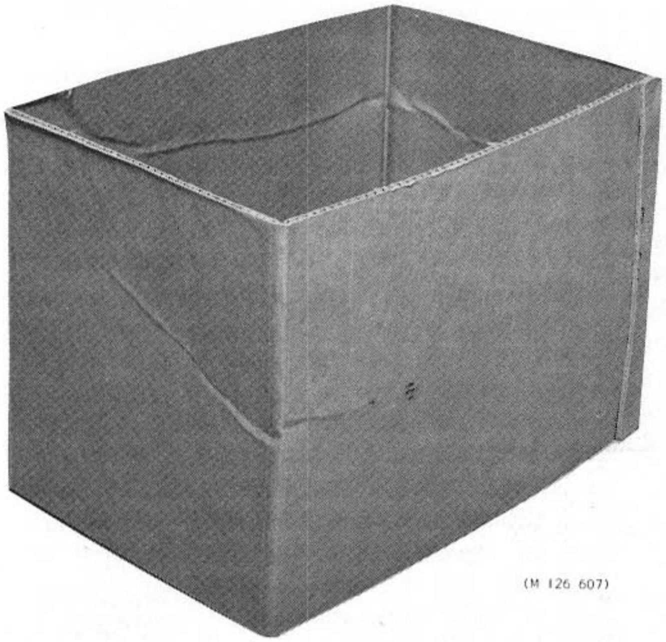

Figure 8.--Failure of pilot-produced single-wall Fiberneer tube subjected to compression test after storage at 80° F. and 90 percent relative humidity.

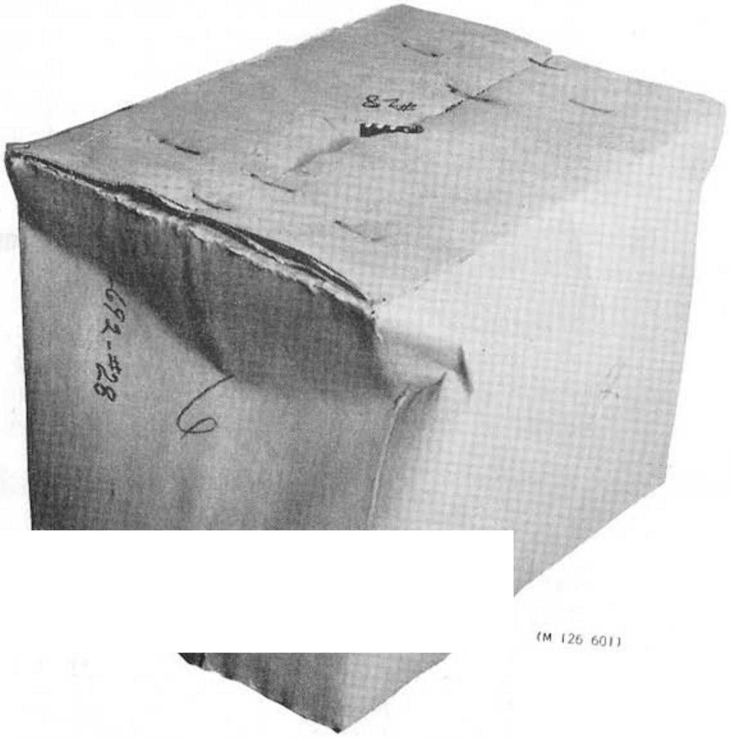

Figure 9.--Failure of pilot-produced single-wall Fiberneer box subjected to top-to-bottom compression after 24-hour water soak. Note fractures at horizontal scores and separation at edges of top flaps.

scores. A value of 70 percent has been established as a reasonably good figure; since most of the box-tube relationships were below this, the quality and effectiveness of the scores is subject to question.

An examination of the individual tests indicates there were some rather wide variations in maximum loads (table 9), Many of the low values could be traced to a poor glue bond at the single-face side. It is generally accepted that poor glue bonds or glue skips[5] materially influence the top-to-bottom compression performance of the containers (9).

As might be expected, the resistance to rough handling was improved almost 100 percent by the addition of two reinforcing straps. Table 8 also indicates that exposure to high humidity will improve the performance index. Previous work with corrugated fiberboard (12) substantiates this and that optimum rough handling performance

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[5] Any lack of glue or proper adhesion between the flute tips and the facing material.

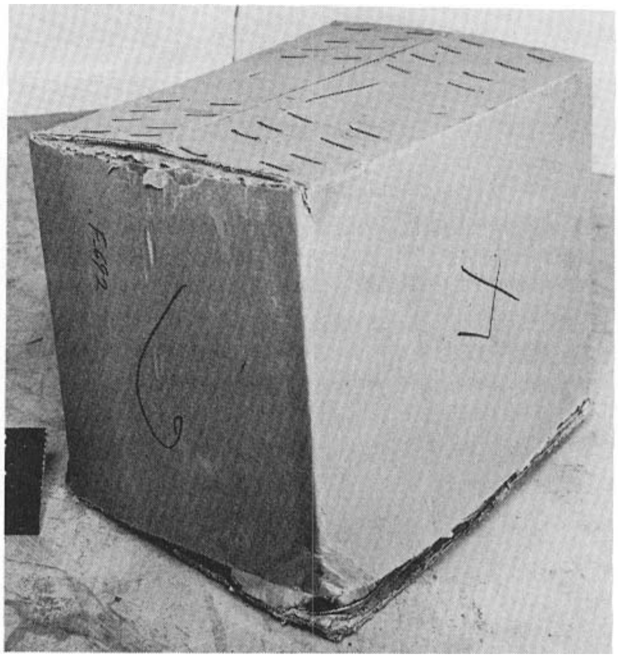
would be at about 20 percent moisture content. When the moisture content of fiberboard increases to 30 percent or more, resistance to rough handling decreases. No usable results were obtained after a 24-hour water soak because of the varying quality of the single-face glue bond.

The performance index of 24, obtained at normal conditions without straps, compares well with similarly sized and loaded boxes of single-wall 275-pound test A-flute with and without treatments for retaining dry strength when wet. The following tabulation shows that of 15 lots, only 1 untreated control lot and 3 treated lots had a higher performance index than did the Fiberneer boxes.

Lot No.	Material treatment	Performance index
489	None	18
483A	None	32
491	None	20
490	V3c[6]	24
483B	Treated	21
487	Treated	9
494	Treated	23
495	Treated	32
496	Treated	18
502	Treated	24
505	Treated	18
508A	Treated	23
508B	Treated	20
508C	Treated	29
512	Treated	41

After 4 hours of water soaking, eight of the treated lots and the V3c boxes had a performance index, ranging from a poor 9 to an excellent 115; whereas the three untreated boxes and three of the treated containers were similar to the Fiberneer boxes after 24-hour water soak--they could not be handled or subjected to the test. No data are available to compare the rough handling performance of treated boxes and Fiberneer boxes when exposed to high humidities.

Typical results of the drop test are shown in figures 10 and 11. In addition to the wide variation in quality of the single-face glue bond, the horizontal scores (those perpendicular to the grain of the veneer) also contributed to the mediocre rough handling performance of the Fiberneer boxes after exposure to 73° F. and 50 percent R.H. It was noticed that when these scores were folded, some cracking of the outer paper overlay occurred. Also, slight splintering and breaking of the veneer caused an uneven score, and contributed to the fracturing of the outer paper overlay. Since folding the scores in effect bends the veneer, the principles of bending wood might be applicable. These principles (21) indicate that successful bending is accomplished if restraint is placed on the outer or convex side so that the wood to be bent is placed in compression. To simulate this restraint, some additional boxes had the horizontal scores reinforced with 2-inch-wide scrim back gum tape. When these boxes were set up and loaded, there were no apparent difficulties when folding the flaps (fig. 12). Furthermore, the performance index of these boxes when tested unstrapped at normal conditions (73° F. and 50 percent R.H.) was 55 inches--an increase of 129 percent over similar boxes without the tape restraint, The use of the tape reinforcement and subsequent improved scores resulted in a performance index better than the one obtained by reinforcing the Fiberneer boxes with flat metal bands.



(M 126 606)

Figure 10.--Failure of pilot-produced single-wall Fiberneer box subjected to single-drop test from 24 inches after conditioning at 73° F. and 50 percent relative humidity.

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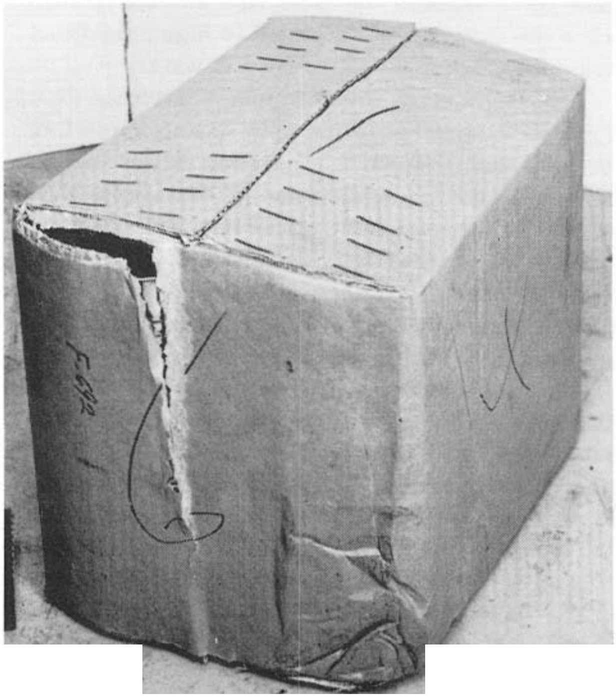
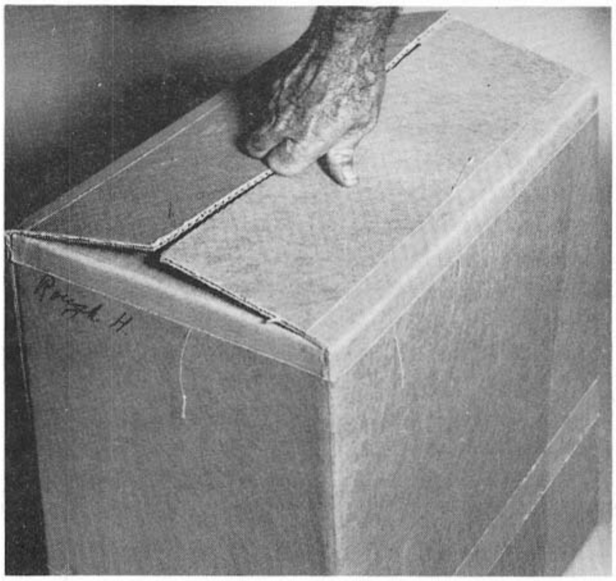
[6] Meets requirements of Federal Specification PPP-B-636c.



(M 126 604)

Figure 11.--Pilot-produced single-wall Fiberneer box subjected to 93-inch single-drop after exposure to 80° F. and 90 percent relative humidity. Although the box is torn, it was not regarded as a "failure" Since there is no loss of contents nor complete score cut.



(M 126 815)

Figure 12.--Single-wall Fiberneer box with horizontal scores reinforced with 2-inch-wide scrim back gum tape.

Table 9.--Minimum and maximum compression test results for pilot-produced single-wall Fiberneer tubes and boxes

Size--inside dimensions			Condition	Tubes		Boxes	
Length	Width	Depth		Minimum	Maximum	Minimum	Maximum
In.	In.	In.		Lb.	Lb.	Lb.	Lb.
18-9/16	12-3/8	14	73° F. - 50 percent R.H.	6,000	7,710	2,720	3,530
18-9/16	12-3/8	14	80° F. - 90 percent R.H.	3,600	6,840	1,330	2,170
18-9/16	12-3/8	14	24-hour water soak	270	610	190	320
18	18	20	73° F. - 50 percent R.H.	5,330	7,540	3,460	4,250
18	18	20	80° F. - 90 percent R.H.	2,110	5,410	1,670	2,570
18	18	20	24-hour water soak	380	870	400	630

CONCLUSIONS

The production of single-wall A-flute corrugated Fiberneer utilizing paper-overlaid 1/64-inch-thick gum veneer as facings appears to be commercially feasible without altering present conventional combining equipment.

The resulting board can be fabricated into regular slotted boxes but special precautions are necessary to make the scores at right angles to the grain of the veneer.

Before folding the flaps, it is necessary to have the material at a moisture content of 8 percent or more to avoid severe fracturing of the liner when folding scores across the grain of the veneer. The use of tape, such as scrim backed gum tape, improves the horizontal scores. It is evident that further research and development could be done on scoring single-wall Fiberneer. Tubes, sheets, or other articles or applications only requiring scores and folding parallel to the grain of the veneer may be fabricated without regard to special techniques or handling processes.

It is also evident that some precautions should be taken to insure a uniformly successful glue bond at the single facer. As experience is gained in sunning the material and handling the flexed paper-overlaid veneer liners, improved bonds should result.

A further improvement in the performance characteristics of the material would no doubt result if a more water-resistant corrugated medium were combined with the paper-overlaid veneer facings. This would be especially true in compression and rough handling when wet or after exposure to free water.

The difference in the coefficient of expansion between wood and paper creates some problems. It definitely causes rather high stresses at the glue bond between the flute tips and the facings when the material is subjected to high humidities and especially when submerged in water.

The results of these studies indicate that Fiberneer possesses certain compressive strength and performance characteristics worthy of a container material. Some of the combinations approach the strength properties exhibited by triple-wall corrugated fiberboard and exceed those of double-wall corrugated material, while being thinner and lighter in weight than triple-wall and no thicker than double-wall.

Some difficulties were encountered in the attempted pilot production of double-wall Fiberneer with the plain veneer as the center liner. However, this material did exhibit some interesting performance characteristics and did not present the problems associated with the horizontal scoring of the single-wall material.

The pilot production of the single-wall Fiberneer. using the flexed paper-overlaidveneer, indicated that such material could be run on conventional equipment. Therefore, it seems reasonable and quite probable that flexed paper-overlaid thin veneer could be run on conventional equipment to produce a double-wall material with the paper-overlaid veneer as the center liner. Indications are that this arrangement may actually achieve the desired performance characteristics, when subjected to high humidities and free water, and overcome the horizontal scoring problem Because of the insulating characteristic of wood, the dryer belt section may present some difficulties with proper adhesive cure.

When combining Fiberneer on present equipment, it is necessary to have the grain direction of the veneer parallel to the flutes. This eliminates the possibility of developing more uniform strength characteristics, regardless of flute direction, by orienting the grain of the veneer at right angles to the flutes.

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