WET-STRENGTHENED FIBERBOARD FROM RECLAIMED FIBER

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WET-STRENGTHENED FIBERBOARD FROM RECLAIMED FIBER[1]

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Abstract

By means of laboratory and mill trials of fiberboard production, an evaluation was made of (1) the influence of wet-strengthening treatments on the quality of solid fiberboards made entirely of reclaimed fiber, (2) the comparative value of wet-strengthening resins, sizing agents, and laminating adhesives, and (3) the quality of wet-strengthened and non-wet-strengthened V2s boards after prolonged immersion in water and exposure to 97 percent relative humidity.

The results obtained indicate that wet-strengthening of paperboard is technically feasible in commercial production. They also show that the quality of board made entirely of reclaimed fiber is definitely improved with the proper combination of wet-strengthening resin, sizing agent, and laminating adhesive. These improvements were obtained in dry board as well as wet, although the greater improvement was in the wet condition. For example, in a mill trial, a 0.100-inch solid fiberboard made from six plies of wet-strengthened jute board containing only reclaimed fiber combined with asphalt as the adhesive for the liners and polyvinyl resin adhesive for the filler, met specifications for the V2s grade in which up to 65 percent new kraft is ordinarily used. This six-ply as well as other wet-strengthened boards showed much higher strength retention and resistance to water absorption after prolonged immersion in water than did a V2s board.

Introduction

This report deals with a limited study of the influence of wet-strengthening treatments used in conjunction with asphalt sizing and various laminating adhesives on the quality of fiberboard made entirely of reclaimed fiber. Results of performance tests of boxes made from this type of board

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[1] Based on studies of the U. S. Forest Products Laboratory at Madison, Wis., in cooperation with the Office of Production Research and Development, of the War Production Board.

are presented in a separate report.[2] The work was undertaken in cooperation with the Office of Production Research and Development of the War Production Board, as a result of the indication from previous work at the Forest Products Laboratory that wet-strengthening might offer possibilities for improving the performance of a given grade of board or for achieving adequate performance with lighter weight board.

Previous Work at the Forest Products Laboratory

Previous work[3] at the Forest Products Laboratory on wet-strengthened fiberboard evaluated both as such and in the form of boxes had shown wet-strengthened new kraft board to be outstandingly better in quality than the best commercial V1s grade also made of all new kraft pulp. For example, experimental test panels of 0.100-inch boards, made from either southern or northern kraft pulps were, when wet, twice as rigid, three times as strong in score strength, and 25 to 51 percent less absorptive of water in comparison with the V1s grade.

The improvement in board properties was reflected in the performance in "rough handling" hexagonal drum tests of containers made from board having six plies of 0.016-inch Fourdrinier kraft board wet-strengthened with 3 percent melamine resin and laminated with asphalt for the liners and a polyvinyl resin adhesive for the filler. In these tests, the wet-strengthened boxes when wet withstood 1732 falls before failing but the V1s boxes, when wet, failed at 180 falls.

On the basis of load required to produce a 1-inch deflection in top to bottom compression the wet-strengthened boxes in both dry and wet conditions were about 75 percent stiffer than the V1s boxes.

Further, wet-strengthened boards made entirely from reclaimed fiber typical in composition of mill usage showed improvements in wet strength up to 35 percent for bursting strength and 100 percent for tensile and score strengths. A six-ply solid fiberboard weighing 415 pounds per thousand square feet made from 0.016-inch Fourdrinier board composed of 21 percent old kraft containers, 62 percent corrugated containers, 17 percent boxboard trimmings, 8 percent emulsified asphalt sizing, and 3 percent urea-formaldehyde resin for wet-strengthening met specifications for the V2s grade. Up to 65 percent new kraft pulp is commonly used in the manufacture of V2s board. Furthermore, the wet tensile strength of the experimental board was twice that of the V2s grade and the wet score strength was 50 percent higher. These board properties appear to influence considerably the resistance of a box to rough handling.

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[2] Mimeograph R1470, "Tests of Solid Fiberboard Boxes Made from Wet-Strengthened Reclaimed Material," by K. E. Skidmore and E. C. Myers.

[3] "Weatherproof Solid Fiberboard. An evaluation of the Quality of Commercial Boards and the Development of an Improved Weatherproof Board," by F. A. Simmonds, J. N. McGovern, and C. O. Seborg. Mimeograph No. R1444.

Objective and Scope of the Present Study

The objective of the work done in cooperation with the Office of Production Research and Development was to determine commercially feasible methods for improving the quality, particularly resistance to water absorption and wet strength, of solid fiberboards made entirely of reclaimed fiber.

The scope of the work included (1) a mill trial, arranged for by the cooperator, of the production of wet-strengthened solid fiberboard and boxes to provide containers for testing at the Forest Products Laboratory in comparison with V2 boxes, (2) experimental board production and evaluation at the Forest Products Laboratory for determining the effect of wet-strengthening resins, sizing agents, and laminating adhesives on the quality of chipboard and low-grade jute board in comparison with the V2s and V3s grades, and (3) a comparison of the quality of wet-strengthened and non-wet-strengthened V2s board after prolonged immersion in water and exposure to 97 percent relative humidity.

Methods Used for Testing the Fiberboards

Only those methods and terms requiring special mention are described.

The term "air-dry" as used in this report means an equilibrium condition at 50 percent relative humidity and 75° F.

For Ply Materials

(1) Thickness and the weight per 1,000 square feet of board were determined on air-dry specimens.

(2) Size number was determined by folding a specimen to form a square cup, placing water in the cup to a depth of about 1/4 inch and measuring the time in seconds at the first evidence of water at the outside bottom of the sample. To calculate the size number, the number of seconds is divided by the square of the thickness of the sample in mils.

(3) Immersion number was determined by immersing a weighed, air-dry, 6-inch by 6-inch specimen horizontally to a depth of 1 inch in tap water at 73° F. ± 2° for 10 minutes, removing excess water by placing the specimen between blotters and passing this sandwich three times through a clothes wringer set for only a very light roll pressure. The gain in weight expressed as centigrams is the immersion number.

For Solid Fiberboards

(1) Thickness and weight per 1,000 square feet were determined on air-dry specimens.

(2) The stiffness or rigidity of flat panels, expressed as the modulus of elasticity in bending, was determined by the cantilever beam stiffness tester, using a specimen 2 inches wide on a 2-inch span.

(3) The resistance of scored specimens to failure in combined tension and bending, expressed as a "score strength number," was determined by the Carlson score tester.[4] The boards were scored with a bar scorer having a 3/16-inch male die and a 1/2-inch female die. Test strips 1 inch wide were cut with the score perpendicular to the length of the specimen.

(4) The tensile strength of a board was determined on a strip 0.59 inch wide and 6 inches long.

(5) Water absorption was determined on a 7- by 9-inch specimen after immersion in tap water at 75° F. ± 1° for 24 hours according to the Joint Army-Navy Specification, JAN-P-108 and also on the 2- by 4-inch specimens used in determining the stiffness of boards after 48 hours of immersion. The water absorption value was based on the air-dry weight of the specimen.

(6) The bursting strength of the boards was determined according to Joint Army-Navy Specification, JAN-P-108.

The bending modulus, score-strength number, and tensile-strength determinations were made on air-dry specimens conditioned as described and on specimens after immersion in water for 48 hours, but cut to size prior to immersion. The test values reported are the averages of determinations in and across the machine direction of the boards.

Laminating Procedure

The adhesives used are listed in table 2 and were prepared for application according to the recommendations of the manufacturers. They were applied at room temperature to individual plies by means of a film caster. In using asphalt with this method, instead of as a hot-melt as is done commercially, it is necessary to thin it with benzene to obtain a workable consistence. End results are, however, the same.

The caster made for applying the adhesives consists of a steel plate base 12 inches wide and 10 inches long with a verticle plate supported by grooved uprights placed 2 inches from one end in which the plate is free to move vertically. It thus serves as a gate and the clearance between it and the base is adjusted by shims for controlling the film thickness of wet adhesive to obtain the desired weight of adhesive solids per thousand square feet of glue line.

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[4] U. S. Patent 1,612,415. "Fiberboard Score Test."

The laminating procedure was as follows:

A single-ply board, 8 inches by 10-1/2 inches, was placed on the horizontal platform of the film caster and the adhesive poured on the board to form a pool back of the gate. The board was then drawn under the gate adjusted to the proper clearance above the board to give the desired film thickness.

As the first board was drawn under the bar it was followed by another ply forming a close butt joint to prevent the excess adhesive from running onto the platform when the first sheet cleared the gate. The sheets were stacked one upon another until the desired number, less one ply, was coated. The last ply, having no adhesive, was placed on top of the stack. The sandwich of plies was then placed between paper covers and run through an ordinary clothes wringer witn rubber rolls. Just enough pressure was applied by the rolls to compact the plies into continuous contact.

The laminated boards were stacked and pressed 16 hours at 15 pounds per square inch, then dried 4 days at room conditions while stacked with spacers exposing both sides of each board to the atmosphere. The entire stack was loaded with a 20-pound weight to prevent warping. After being dried in this way, the boards were conditioned 4 days at 50 percent relative humidity prior to testing.

When asphalt was used as an adhesive for top and bottom liners, the filler plies were first laminated and dried according to the procedure just described. The liners were then applied according to the regular laminating and drying procedure and the completed board conditioned prior to testing.

Laminated boards prepared according to this procedure showed the same strength properties, within experimental error, as boards of the same ply material which had been laminated commercially.

Specifications for V-boards

Since the V-grades of solid fiberboard are referred to in this report for purposes of comparison, their specifications are given in table 1.

Table 1.--Joint Army-Navy Specification JAN-P-108
(Minimum requirements for solid fiberboard)

Grade	Symbol	Nominal caliper	Minimum average bursting strength		Maximum permissible ply separation (wet)
			Dry	After 24-hour immersion	
		Inch	Lb.	Lb.	Inch
1	V1s	0.100	750	500	1/4
2	V2s	.090	550	500	1/4
3	V3s	.090	400	150	1/4

Mill Trial of Wet-strengthened Jute Board made Entirely of Reclaimed Fiber

Since experimental results available at the time the mill trial was made indicated the possibility of obtaining a board which would meet V2s specifications, this grade was set up as the objective, utilizing 0.016-inch and 0.024-inch ply material, respectively. Although the furnish used for the experimental boards which were the basis for the mill trial contained 17 percent boxboard trimmings, this component was replaced in the mill run with old containers upon the recommendation of the mill superintendent. His opinion was that otherwise, under the mill operating conditions, a V2s grade could not be produced.

Composition of Furnish

The following furnish was used for both the 0.016-inch and 0.024-inch ply material, for which the respective bursting strength requirements were 90 and 140 pounds:

For top and bottom liners of each ply material

20 percent all-kraft waste paper

80 percent old containers

3 percent urea-formaldehyde resin for wet-strengthening

For filler of each ply material

20 percent all-kraft waste paper

80 percent old containers

3 percent urea-formaldehyde resin for wet-strengthening

For top and bottom liners of each ply material	For filler of each ply material
3 percent rosin sizing	3 percent emulsified asphalt sizing
6 percent alum	3 percent alum
4 percent nitre cake	3 percent nitre cake

The above percentages of non-fibrous furnish components are based on the weight (moisture-free) of fiber.

When making the 0.016-inch board, the mill superintendent found it necessary to reduce the machine speed to about 20 percent below normal (the actual speed was reported as 165 feet per minute) in order to attain the desired bursting strength. This was not found necessary when the 0.024-inch board was made.

Construction of Solid Fiberboards

A six-ply solid fiberboard was made from the 0.016-inch material, the liners being combined with 20 pounds of asphalt per 1,000 square feet of glue line and the filler with 2 pounds of polyvinyl resin adhesive per 1,000 square feet.

A four-ply solid fiberboard was made from the 0.024-inch material, all plies being combined with the polyvinyl resin adhesive. Samples of both the ply materials and the solid fiberboards were tested at the Forest Products Laboratory and also solid fiberboards which were laminated at the Forest Products Laboratory from the ply materials. The results are recorded in table 2.

Containers for Testing

Both of the solid fiberboards were used in fabricating regular slotted boxes for 24 No. 2 food cans, sufficient quantities of each type being shipped to the Forest Products Laboratory where they were tested in comparison with standard V2s boxes.

Comparison of Commercial and Experimental Laminating

In table 2, boards Nos. 117, 118, 119, and 120 are those relating to the mill trial. Nos. 117 and 118 were laminated at the Forest Products Laboratory from the 0.016-inch and 0.024-inch ply materials made at the mill, and Nos. 119 and 120 are the solid fiberboards laminated at the mill from the same ply materials. In the experimental laminating the adhesives

Table 2.--Properties of solid fiberboards and component plies varying in fiber composition, wet-strengthening agents, and laminating adhesive

EXPERIMENTAL BOARDS MADE ENTIRELY OF RECLAIMED FIBER

Description of boards	Solid fiberboard number	Run number	Composition and properties of individual ply: Amount of rosin	Amount of emulsified asphalt	Amount of urea-formaldehyde	Amount of melamine	Thickness	Weight	Density	Bursting strength: Air-dry	Bursting strength: Air-dry	Bursting strength: Wet 24-hr.	Bursting strength: Wet 48-hr.	Tensile strength: Air-dry	Tensile strength: Wet[1]	Tearing strength	Size number	Immersion number	Laminating adhesive: For liners	Laminating adhesive: For filler	Number of plies	Properties of solid fiberboards: Thickness	Weight	Mullen: Air-dry	Mullen: Wet[2]	Tensile strength: Air-dry	Tensile strength: Wet[1]	Bending modulus: Air-dry	Bending modulus: Wet[1]	Score strength (Carlson number)[3]: Air-dry	Score strength: Wet[1]	Water absorption: 24 hours	Water absorption: 48 hours
			Percent[4]	Percent[4]	Percent[4]	Percent[4]	Inch	Lb. per 1,000 sq. ft.	Gm. per cc.	Pts. per lb. per ream 25x40-500	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Gm. per lb. per ream 25x40-500	Sec. per (mil)[2]	Cc.				Inch	Lb. per 1,000 sq. ft.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.	1,000 lb. per sq. in.			Percent	Percent
MILL-MADE CYLINDER BOARDS																																	
High-grade jute furnish[5]																																	
4-ply boards																																	
Laminated at mill	119	--	[6]3	[6]8	3	0	--	--	--	--	--	--	--	--	--	--	--	--	[7]P	P	4	0.097	375	510	405	3,570	980	237	63	47	18	37	46
Laminated at Forest Products Laboratory	118	--	[6]3	[6]8	3	0	0.025	92	0.71	0.43	140.6	77.0	59.0	3,400	1,226	1.60	4.5	160	P	P	4	.096	396	500	433	3,800	1,050	214	59	44	20	36	40
6-ply boards																																	
Laminated at mill	120	--	[6]3	[6]8	3	0	--	--	--	--	--	--	--	--	--	--	--	--	[8]A	P	6	.106	444	638	522	3,290	1,030	240	51	39	19	20	41
Laminated at Forest Products Laboratory	117	--	[6]3	[6]8	3	0	.017	65	.75	.49	110.5	41.0	38.0	3,540	1,108	1.50	2.9	175	A	P	6	.104	443	617	655	4,335	1,140	220	59	39	31	17	35
LABORATORY-MADE FOURDRINIER BOARDS																																	
Chipboard furnish[9]																																	
Non-wet-strengthened. Rosin sized.	132	2,544	3	0	0	0	.017	58	.65	.14	28.0	8.3	7.6	1,574	87	1.04	2.0	170	P	P	6	.103	375	234	105	1,655	360	166	46	14	2	55	50
Non-wet-strengthened. Asphalt sized.	125	2,537	0	8	0	0	.016	60	.71	.20	41.4	14.4	13.7	2,125	557	1.57	5.2	95	P	P	6	.093	383	276	232	1,945	680	273	63	14	12	29	26
Urea-formaldehyde wet-strengthened. Rosin sized.	124	2,534	[10]3	0	3	0	.016	52	.62	.17	31.7	20.4	14.3	1,880	706	1.23	2.0	100	P	P	6	.090	329	242	223	2,175	1,020	211	55	15	13	33	23
Urea-formaldehyde wet-strengthened. Rosin sized.	131	2,534	[10]3	0	3	0	.016	52	.62	.17	31.7	20.4	14.3	1,880	706	1.23	2.0	100	A	P	6	.091	328	245	266	1,720	890	149	54	--	--	16	44
Urea-formaldehyde wet-strengthened. Asphalt sized.	122	2,535	0	8	3	0	.017	61	.74	.21	43.8	26.2	20.5	2,440	864	1.53	4.4	95	P	P	6	.097	404	323	280	2,435	1,205	238	59	19	15	22	32
Urea-formaldehyde wet-strengthened. Asphalt sized.	123	2,535	0	8	3	0	.017	61	.74	.21	43.8	26.2	20.5	2,440	864	1.53	4.4	95	A	P	6	.097	435	326	383	2,485	1,025	243	80	17	16	16	26
Urea-formaldehyde wet-strengthened. Asphalt sized.	127	2,535	0	8	3	0	.017	61	.74	.21	43.8	26.2	20.5	2,440	864	1.53	4.4	95	[11]P+A	P+A	6	.099	420	352	324	2,410	1,055	234	58	21	15	22	33
Urea-formaldehyde wet-strengthened. Asphalt sized.	128	2,541	0	8	3	0	.023	78	.65	.18	47.9	25.9	23.3	1,945	723	1.41	4.0	105	P	P	4	.086	320	215	153	2,220	765	236	73	17	12	28	43
Urea-formaldehyde wet-strengthened. Asphalt sized.	129	2,541	0	8	3	0	.023	78	.65	.18	47.9	25.9	23.3	1,945	723	1.41	4.0	105	P	P	8	.172	650	531	476	2,060	595	154	46	--	--	19	38
Melamine wet-strengthened. Asphalt sized.	126	2,538	0	8	0	3	.016	62	.75	.21	44.2	30.8	28.5	2,500	1,184	1.43	5.5	95	P	P	6	.091	389	326	260	2,865	1,518	293	76	20	25	28	29
Urea-formaldehyde wet-strengthened. Asphalt sized.	130	2,543	0	8	[12]3	0	.018	66	.70	.17	38.0	16.8	17.3	2,300	671	1.46	5.7	90	P	P	6	.108	421	313	215	2,257	660	218	51	--	--	26	39
Low-grade jute furnish[13]																																	
Non-wet-strengthened. Asphalt sized.	149	2,557	0	8	0	0	.015	63	.81	.32	70.5	14.3	16.0	3,520	630	1.55	4.9	140	P	P	6	.090	420	523	342	3,925	650	292	83	38	12	40	60
Urea-formaldehyde wet-strengthened. Asphalt sized.	140	2,547	0	8	3	0	.018	65	.69	.25	57.2	30.8	30.1	2,410	990	1.96	3.1	130	P	P	6	.105	397	517	417	3,166	1,080	258	86	23	15	28	42
Urea-formaldehyde wet-strengthened. Asphalt sized.	141	2,547	0	8	3	0	.018	65	.69	.25	57.2	30.8	30.1	2,410	990	1.96	3.1	130	A	P	6	.105	413	433	422	2,936	1,400	238	83	23	17	14	30
Urea-formaldehyde wet-strengthened. Asphalt sized.	142	2,547	0	8	3	0	.018	65	.69	.25	57.2	30.8	30.1	2,410	990	1.96	3.1	130	[14]PE	PE	6	.107	404	415	380	3,000	935	239	76	23	20	25	46
Urea-formaldehyde wet-strengthened. Rosin-wax sized.	148	2,558	[15]3	0	3	0	.017	62	.70	.18	38.4	19.8	16.3	2,370	785	1.63	2.1	160	P	P	6	.099	408	370	270	2,510	870	228	65	27	14	32	40
COMMERCIAL V2s and V3s BOARDS																																	
Average values of three V2s boards	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.098	403	633	574	3,950	595	214	65	56	15	40	99
Average values of four V3s boards	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.103	333	460	297	3,150	540	212	62	39	14	47	70

[1] Immersion for 48 hours in tap water at 75° F. ± 1°.

[2] Immersion of a 7- by 9-inch panel for 24 hours in tap water at 75° F. ± 1°.

[3] Specimen size 2- by 4-inches.

[4] Based on weight of pulp on moisture-free basis.

[5] All-kraft wastepaper, 20 percent, old containers, 80 percent.

[6] Three percent rosin size in liners, 8 percent emulsified asphalt in filler.

[7] Polyvinyl resin adhesive, 2.7 pounds applied per 1,000 square feet of glue line except boards Nos. 119 and 120 in which 2.0 pounds was applied.

[8] Asphalt, 20 pounds applied per 1,000 square feet of glue line.

[9] Boxboard trimmings. Two percent alum (except in runs Nos. 2534 and 2544 in which the amount was 3 percent) in conjunction with sufficient sulfuric acid to lower the pH value to 4.5 which was also maintained on the paper machine with this acid.

[10] In addition to the rosin size, 1 percent of a material claimed to increase the efficiency of rosin size, was used.

[11] Polyvinyl resin adhesive extended with emulsified asphalt, 3.5 pounds applied per 1,000 square feet of glue line.

[12] Three percent starch, based on pulp, cooked with the resin.

[13] Sixty percent boxboard trimmings, 35 percent corrugated containers, 5 percent all-kraft containers, 2 to 3 percent alum was used in conjunction with sulfuric acid to control pH value at 4.5.

[14] A proprietary extended polyvinyl resin adhesive, 2.7 pounds applied per 1,000 square feet of glue line.

[15] Rosin, 80 percent, wax, 20 percent.

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used were the same as those used at the mill, but 2.7 pounds of polyvinyl resin adhesive per 1,000 square feet of glue line were required in the experimental application as compared with 2.0 pounds in the commercial operation. The larger amount was necessary to obtain a continuous film of adhesive under the conditions of application but it had no appreciable effect on board properties. This is indicated by the generally fair agreement in the test values for the commercially and experimentally laminated boards. Similar agreement has been observed in previous work.

Comparison of the Mill-made Four- and Six-ply Boards

The greater weight of the six-ply board was due chiefly to the added weight of asphalt used for combining the liners. In bursting strength the six-ply board, wet and dry, averaged 27 percent higher than the four-ply. The only other indication of possible superiority of the six-ply board in performance quality as a box, and then only in the wet condition, is the fact that its resistance to water absorption upon prolonged immersion was almost 1.5 times greater than that of the four-ply board when measured on specimens large enough in area to minimize edge effect. See figure 1. The bending modulus and score strength of the air-dry six-ply board actually averaged 22 percent lower than those for the four-ply, the wet score strength of the two boards being the same. Reference to the previously mentioned report[3] on tests of boxes made from these boards shows, however, that the six-ply board was superior in performance.

Comparison of the Four- and Six-ply Boards with Specifications for Solid V-boards

In the commercial production of solid V-boards, the V1 grade is usually made entirely of new kraft pulp, the V2 grade with up to 65 percent, and the V3 grade up to 30 percent new kraft pulp.

Reference to table 1 giving the minimum requirements for solid V-board, shows the six-ply board was 15 percent below the bursting strength specification for air-dry V1s board and 15 percent above the required value for the V2s grade, air dry. The bursting strength requirement for wet board is the same for the V1s and V2s grades and this was met in the case of the six-ply board.

The four-ply board was 8 percent below the bursting strength specification for air-dry V2s board and 20 percent below the requirement for wet board. In comparison with V3s specifications, it exceeded the dry requirement 27 percent and the wet, 170 percent.

The Four- and Six-ply Boards Compared with Commercial V2s and V3s Boards

The four-ply board, in comparison with the commercial V2s boards, was inferior in wet and dry bursting strength, dry tensile strength, and dry score strength, the over-all average being 18 percent. The greatest difference was in wet bursting strength which was 33 percent lower. Bending modulus, wet and dry, and wet score strength were about the same. The wet tensile strength was, however, 65 percent higher. Water resistance on 24 hours immersion was about the same but over longer periods definitely better.

Compared with commercial V3s boards, the four-ply board was definitely superior in all properties except bending modulus. The outstanding points of superiority were a 46 percent higher wet bursting strength, a 110 percent higher wet tensile strength, and a 43 percent higher wet score strength.

The six-ply board, compared with commercial V2s boards, was 10 percent lower in wet bursting strength, 17 percent lower in dry tensile strength, averaged 19 percent lower in wet and dry bending modulus, and was 30 percent lower in dry score strength. Dry bursting strength was about the same, as was wet score strength. The wet tensile strength was 73 percent higher. Water resistance at 24 hours immersion was about the same but upon prolonged immersion was greatly superior.

In comparison with V3s boards, the six-ply board was markedly superior in all properties except bending modulus in which it averaged, wet and dry, 17 percent lower.

Tests of Containers Made from the Four- and Six-ply Boards

As previously mentioned, results of a study comparing containers made from the wet-strengthened four- and six-ply boards of reclaimed fiber with containers made of V2s grade of board are discussed in a separate report.[3] As a matter of convenience, however, the results in general are briefly summarized as follows:

Compression tests of fiberboard boxes made of the six-ply 0.108-inch board showed them superior in stacking properties under all three conditions -- dry, moist, and wet -- (a) to boxes made of the four-ply 0.098-inch board and (b) to containers of V2s board. In the rough-handling tests under dry and moist conditions the V2s containers showed some advantage over the two other types of box. Under wet conditions, the containers made of the six-ply board were superior in all tests. The results of this study indicated this type of board should prove more satisfactory than V2s board for export shipment.

Strength Retention Upon Long Exposure to Adverse Moisture Conditions

In considering the value of wet-strengthened fiberboard for containers, questions have arisen repeatedly as to strength retention upon long soaking or exposure to high relative humidity and also as to the comparative effectiveness of the melamine and urea-formaldehyde resins under such conditions. Accordingly, upon the initiation of the present study, immersion and exposure tests were started with boards then available.

Properties Tested and Conditions

Tensile strength and stiffness of specimens cut in the machine direction, bursting strength, and water absorption were the properties measured after immersion in tap water at 75° F. ± 1° and after exposure to 97 percent relative humidity and temperature of 80° F. The sizes of specimens were as described previously under "Methods Used for Testing the Fiberboards". Water and moisture absorption values were determined on the specimens used for testing bursting strength.

Materials Tested

The boards used in the immersion tests were:

1. Standard V2s board, six plies, not wet-strengthened, asphalt adhesive for liners, polyvinyl resin adhesive extended with asphalt for filler.

2. Mill-made 0.100-inch board, six plies, new kraft wet-strengthened with 3 percent melamine resin, asphalt adhesive for liners, polyvinyl resin adhesive for filler.

3. Mill-made 0.100-inch board, six plies, reclaimed fiber wet-strengthened with 3 percent urea-formaldehyde resin, asphalt adhesive for liners, polyvinyl resin adhesive for filler.

4. Single ply of 0.016-inch board used in board No. 3 above.

5. Mill-made 0.100-inch board, four plies, reclaimed fiber wet-strengthened with 3 percent urea-formaldehyde resin, adhesive for all plies, polyvinyl resin adhesive.

6. Single ply of 0.024-inch board used in board No. 5 above.

The boards used in the exposure tests were:

Items Nos. 1, 3, and 5 in the above list.

Immersion Tests

The results of the immersion tests are presented graphically in figure 1.

In specimens used in determining the tensile strength and stiffness, the proportion of edge area to surface area is large and consequently rate of water absorption is high compared to that for the 7- by 9-inch specimens used in determining bursting strength.

Tensile strength.--About 90 percent of the total decrease in tensile strength occurred in all of the six materials tested after 2 days of immersion. After 3 to 4 days, there was no further decrease during the balance of the testing period.

The wet-strengthened boards retained, on an average, 30 percent of the dry tensile strength, the V2s board only about 10 percent. The actual wet tensile strength of the wet-strengthened boards was 180 percent greater than that of the V2s board.

The melamine resin showed no practical advantage over the urea-formaldehyde resin in this comparison.

Stiffness (in terms of bending modulus).--At least 90 percent of the total decrease in stiffness occurred in the three materials tested at the end of 2 days' immersion with little if any further change during the rest of the immersion period.

At maximum stiffness decrease, the V2s and the four-ply wet-strengthened boards retained about 35 percent of the original values and the six-ply wet-strengthened board retained about 25 percent. The six-ply and the V2s boards were then equal in stiffness but the four-ply was about 50 percent stiffer than either.

Bursting strength and water absorption.--When the wet-strengthened solid fiberboards were at equilibrium water absorption, the melamine-treated kraft board absorbed 100 percent water and retained essentially 100 percent of the bursting strength. The six-ply reclaimed fiber, urea-formaldehyde-treated board absorbed 65 percent water and retained 66 percent of the bursting strength. In the four-ply reclaimed fiber, urea-formaldehyde-treated board at 90 percent water absorption, the retention was 40 percent. For the non-wet-strengthened V2s board, at a water absorption of over 110 percent, the retention was about 26 percent. Retention of bursting strength in the two single-ply materials tested averaged about 40 percent.

In the air-dry condition the non-wet-strengthened V2s and the six-ply, reclaimed fiber, wet-strengthened boards were approximately equal in bursting strength. When they were thoroughly wet, however, the wet-strengthened board was 2.5 times the higher in bursting strength. Compared to the four-ply, reclaimed fiber, wet-strengthened board, the V2s was initially about 40 percent higher in bursting strength but when thoroughly wet no better.

The six-ply wet-strengthened board is comparable in construction with the V2s board with respect to the number of plies and laminating adhesives. The greater water resistance (40 percent) of the six-ply board is attributed chiefly to the asphalt sizing used in this board. With asphalt size, the increase in sizing effectiveness with increase in quantity apparently extends beyond the limiting value for rosin size.

Exposure Tests

The results of the exposure tests are shown graphically in figure 2. These experiments dealt only with the non-wet-strengthened and the four- and six-ply, reclaimed fiber, wet-strengthened boards.

Tensile strength.--The rate of decrease in tensile strength when the boards were exposed to 97 percent relative humidity was about half the rate during water immersion and the maximum loss was considerably less. At equilibrium, retention for the four- and six-ply boards was 67 percent; for the V2s, 42 percent. The four- and six-ply boards were about 40 percent stronger than the V2s and the four-ply was about 20 percent stronger than the six-ply. Thus the relative rating of the three boards was the same as in the water immersion tests.

Stiffness.--The rate of decrease was about a third slower than under immersion and the maximum loss was considerably less. The relative rating of the three boards was the same as in water immersion, the four-ply being the highest and the six-ply and V2s boards being approximately the same. Retentions were 58 percent for the four-ply, 82 percent for the six-ply, and 63 percent for the V2s.

Bursting strength.--There was essentially no change in bursting strength and so the relative rating was that of the initial strength, namely, V2s, six-ply wet-strengthened, four-ply wet-strengthened.

Moisture absorption.--Extrapolation of the curves shown in figure 2 indicates that for highly sized solid fiberboards as tested, an equilibrium moisture content of about 20 percent can be expected at the end of 40 days exposure to 97 percent relative humidity at 80° F.

In contrast to the results of water immersion tests in which the V2s board absorbed a much greater amount of water than either the four- or six-ply boards, during exposure to 97 percent relative humidity but prior to equilibrium, the moisture absorption of the V2s and the six-ply boards was the same, and that of the four-ply was about 80 percent higher.

Advantage of Wet-strengthening

The results of the immersion tests show wet-strengthening to be a means for maintaining such qualities as tensile and bursting strengths of an otherwise relatively low-grade solid fiberboard at an even higher level than those of a relatively high-grade board after long soaking in water.

Wet-strengthened Chipboard

Since chipboard represents the very low strength range of paperboard, usually being made entirely from low-strength grade reclaimed fiber, it appeared desirable to obtain information for this type of board on the influence of wet-strengthening agents in conjunction with commercially used sizing agents and also on the laminating adhesive.

The composition and properties of a series of single-ply materials and the corresponding solid fiberboards made for this purpose are given in table 2. Included in the table are test values from V2s and V3s boards for purposes of comparison.

Within the limitation of a single experimental run of board for each variation, the results on chipboard afford the following comparisons.

Quality as Compared with the V3s Fiberboards Tested

V3s board contains up to 30 percent new kraft pulp and so the quality of the fiber furnish is higher than that used in the experimental chipboards.

Experimental board 126, laminated with the polyvinyl resin adhesive from six plies of 0.016-inch material wet-strengthened with 3 percent melamine and sized with 8 percent asphalt, is the one used for comparison. The bursting strength of this board, when dry, was 30 percent less and, when wet, 12 percent less than the V3s boards. However, boards with liners combined with asphalt have a wet bursting strength usually higher than the dry strength and, if asphalt were used as the laminating adhesive for the liners, a wet bursting strength could be expected in the experimental board exceeding that of the V3s. The dry stiffness of the experimental board was 40 percent higher and the wet stiffness, 20 percent higher than the V3s board. The dry score strength was only 50 percent of the V3s but the wet score strength was 78 percent higher. The water absorption of the experimental board was 60 percent less than the V3s. The tensile strength of the experimental board when dry was 10 percent less than that of the V3s board but when wet, was 180 percent higher than that of the V3s, likewise wet.

Comparison of Asphalt and Rosin Sizing Agents

Board 125 having 8 percent asphalt sizing, as compared with board 132 having 3 percent rosin sizing, was 18 percent higher in dry and 120 percent higher in wet bursting strength, 18 percent higher in dry and 89 percent higher in wet tensile strength, 65 percent higher in dry and 37 percent higher in wet stiffness, the same in dry score strength but six times higher in wet score strength and was 50 percent lower in water absorption.

Little practical gain in sizing effect results with amounts of rosin above 3 to 4 percent in board furnishes but the limiting value appears to be higher for asphalt.

Improvement Due to Wet-strengthening

Urea-formaldehyde resin, rosin sizing.--Board 124 with 3 percent urea-formaldehyde for wet-strengthening and 3 percent rosin sizing when compared with board 132 having 3 percent rosin sizing only was slightly higher in dry but 112 percent higher in wet bursting strength, 31 percent higher in dry and 183 percent higher in wet tensile strength, 27 percent higher in dry and 20 percent higher in wet stiffness, about the same in dry score strength but six times higher in wet score strength. Water absorption was 20 percent less. These improvements due to wet-strengthening were obtained in a board containing at least 10 percent less fiber than the non-wet-strengthened board.

Urea-formaldehyde resin, asphalt sizing.--Board 122 with 3 percent urea-formaldehyde and 8 percent asphalt when compared with board 125 having 8 percent asphalt sizing only was 11 percent higher in dry and 14 percent higher in wet bursting strength (corrected for difference in weight), 25 percent higher in dry and 77 percent higher in wet tensile strength, averaged 10 percent low in dry and wet stiffness, was 36 percent higher in dry and 25 percent higher in wet score strength, and water absorption was 24 percent less.

Urea-formaldehyde-asphalt compared with urea-formaldehyde-rosin.--Replacing rosin with asphalt in conjunction with urea-formaldehyde (Boards 122 and 124) resulted in an improvement in water resistance of 30 percent and an average of about 15 percent in other properties, dry and wet, except wet Mullen in which there was no improvement.

Melamine resin-asphalt compared with asphalt alone.--Board 126 made with 3 percent melamine and 8 percent asphalt as compared with Board 125 made with 8 percent asphalt only averaged about 15 percent higher in dry and wet bursting strength, 47 percent higher in dry and 123 percent higher in wet tensile strength, was about the same in dry stiffness but about 21 percent higher in wet stiffness, 43 percent higher in dry and 100 percent higher in wet score strength. Water absorption was about the same.

Melamine compared with urea-formaldehyde, asphalt sizing.--Board 126, with 3 percent melamine and 8 percent asphalt as compared with Board 122, having 3 percent urea-formaldehyde was equal to it in dry and a little lower in wet bursting strength. This latter value is questionable, however, since the melamine-treated ply material used in it was 40 percent higher in wet bursting strength than the urea-formaldehyde-treated ply material used in the other board, No. 122. Tensile and score strengths, dry and wet, averaged about 25 percent higher, water absorption was the same, dry score strength the same, but the wet score strength was 67 percent higher.

Variations in Laminating Adhesive

The adhesives used in laminating the boards described in table 2 were asphalt, polyvinyl resin adhesive, polyvinyl resin adhesive extended with emulsified asphalt, and a proprietary extended polyvinyl resin adhesive. Asphalt as used for combining liners to filler was thinned with benzene to a consistence suited to application at room temperature by means of the film caster previously described. When the emulsified asphalt was used as an extender the proportions were, based on solids, 65 percent asphalt and 35 percent polyvinyl adhesive.

Most of the boards were laminated with the use of polyvinyl resin in all glue lines.

A urea-formaldehyde-starch formulation was not used as a laminating adhesive in the present study because it is understood to be less satisfactory in bonding properties than certain others in the commercial laminating of boards containing appreciable amounts of asphalt sizing in the liners. However, this adhesive has been applied successfully to asphalt-sized boards in previous experimental work by means of the method described on page 4.

From the results of the three variations in adhesive made in Boards 122, 123, and 124, all laminated from the same run of ply material, is indicated that replacing either polyvinyl resin or the polyvinyl resin asphalt mixture with asphalt in the top and bottom glue lines reduces water absorption, improves wet bursting strength, wet stiffness and possibly dry stiffness. There is also the indication that bursting strength retention upon soaking is somewhat better with the polyvinyl resin asphalt mixture in all glue lines than with polyvinyl resin in all glue lines.

Variation in Ply Thickness

A comparison is made between the six-ply, rosin-sized, 0.090-inch Board 124 and the four-ply, asphalt-sized, 0.086-inch Board 128. Although the sizing agents are different, the physical properties of the ply materials are so nearly alike that comparison appears warranted.

The two boards differed appreciably in the wet but only little in the dry condition. In the standard 24-hour water absorption test with a 7- by 9-inch specimen, the four-ply board absorbed 18 percent less water than did the six-ply board. However, in the 48-hour test with a 2- by 4-inch specimen (used afterward for the wet stiffness determination) where equilibrium is approached, the four-ply board absorbed 87 percent more water than did the six-ply board.

The wet stiffness of the four-ply board was 33 percent higher than that of the six-ply board, despite the much greater water content. It will be recalled that in this test of the four- and six-ply boards of reclaimed fiber made in the mill trial, the four-ply board was, at a 12 percent higher water content, 23 percent stiffer than the six-ply board. Yet this indication was not confirmed in the container tests. It appears that a need is indicated for a study of factors influencing the stiffness of fiberboard.

The six-ply board was, however, 44 percent higher in wet bursting strength and 33 percent higher in wet tensile strength than the four-ply board.

A Possible Application of Wet-strengthened Chipboard

In cooperation with the War Food Administration, the Forest Products Laboratory has undertaken the development of an improved fiber cheese drum suitable for export shipping. In preliminary tests, a wet-strengthened chipboard drum cylinder, as compared with a commercial chipboard drum cylinder, not only contained 8 percent less fiber but, in top to bottom compression, was almost twice as strong in the air-dry condition and almost 2.5 times as strong in the wet condition.

Boards Made From Low-grade Jute Furnish

Boards shown in table 2 made from a low-grade jute furnish comprise a part of a series which, at the time the present study was discontinued, was in progress to provide materials for a study of factors not previously covered and for making more complete comparisons of factors previously touched upon. The results reported, though of limited scope, do provide some comparisons of board quality.

The fiber furnish used for the boards in this series was made up of 60 percent boxboard trimmings, 35 percent corrugated containers, and 5 percent all-kraft containers.

Comparison with V2s and V3s Grades

Board 140, wet-strengthened with 3 percent urea-formaldehyde and sized with 8 percent asphalt, when compared with the V2s boards tested, averaged about 23 percent lower in wet and dry bursting strength, was about 20 percent lower in dry and 82 percent higher in wet tensile strength, and was 20 percent higher in dry and 32 percent higher in wet stiffness. Although the dry score strength of the experimental board was much lower than the V2s boards, it was equal in the wet score strength. Water absorption in the standard test of the jute board was 30 percent under the V2s boards.

Board 140, compared with the V3s grade, was about the same in dry and 25 percent higher in wet bursting strength when corrected for its greater weight, was about the same in dry and 100 percent higher in wet tensile strength, was 22 percent higher in dry and 39 percent higher in wet stiffness, was 40 percent lower in dry but equal in wet score strength, and water absorption was 40 percent lower.

The superiority of the experimental board in wet tensile, dry and wet stiffness, resistance to water absorption and its equality in wet score strength in comparison with the V2s and V3s grades indicates that such a board would have a fairly good performance quality, particularly in the wet condition.

Comparison with Chipboard

Jute board 140 compared with chipboard 122 was 60 percent higher in dry and 50 percent higher in wet bursting strength, 30 percent higher in dry and about the same in wet tensile, about the same in dry and 46 percent higher in wet stiffness, 20 percent higher in dry and equal in wet score strength and water absorption was about 27 percent higher.

Improvement Due to Wet-strengthening

Board 140, having 3 percent urea-formaldehyde resin for wet-strengthening and 8 percent asphalt sizing compared with Board 149 having only the 8 percent asphalt sizing was 29 percent higher in wet bursting strength, 66 percent higher in wet tensile, only slightly higher in wet stiffness and score strength, and water absorption was 25 percent less.

Because the density of the non-wet-strengthened board was 20 percent higher than that of the wet-strengthened board, comparisons of the dry strength properties are not warranted.

Advantage of Asphalt Sizing Over Rosin Sizing

As was observed with chipboard, the asphalt size in conjunction with urea-formaldehyde resin resulted in a board (No. 140) definitely superior, except in score strength, to a board (No. 148) made with the practicable limit of rosin sizing and likewise wet-strengthened.

Conclusions

Conclusions drawn from the foregoing results and as qualified in the report are as follows:

1. The use of wet-strengthening treatments in the commercial production of fiberboard is technically feasible.

2. The quality of boards made entirely of wet-strengthened reclaimed fiber, compared with that of corresponding non-wet-strengthened boards, is definitely improved in both the dry and wet conditions, but the degree of improvement is greater in the wet condition.

3. Wet-strengthening in conjunction with a good grade of reclaimed fiber and suitable solid fiberboard construction offers a means for producing fiberboard having a quality at least equal to the non-wet-strengthened V2s boards which normally contain up to 65 percent new kraft pulp.

4. Since wet-strengthening improved quality for a given grade, it is likely to provide a means for obtaining adequate performance with less fiber.

5. Wet-strengthened boards maintain a definitely higher strength than non-wet-strengthened boards when both are subjected to prolonged immersion in water.

6. Asphalt is superior to rosin as a sizing agent for reclaimed fiber in fiberboard production.

7. For the same quantity, melamine is superior to urea-formaldehyde in wet-strengthening effect.

8. Both melamine and urea-formaldehyde resins appear to increase the efficiency of asphalt and rosin sizing agents.

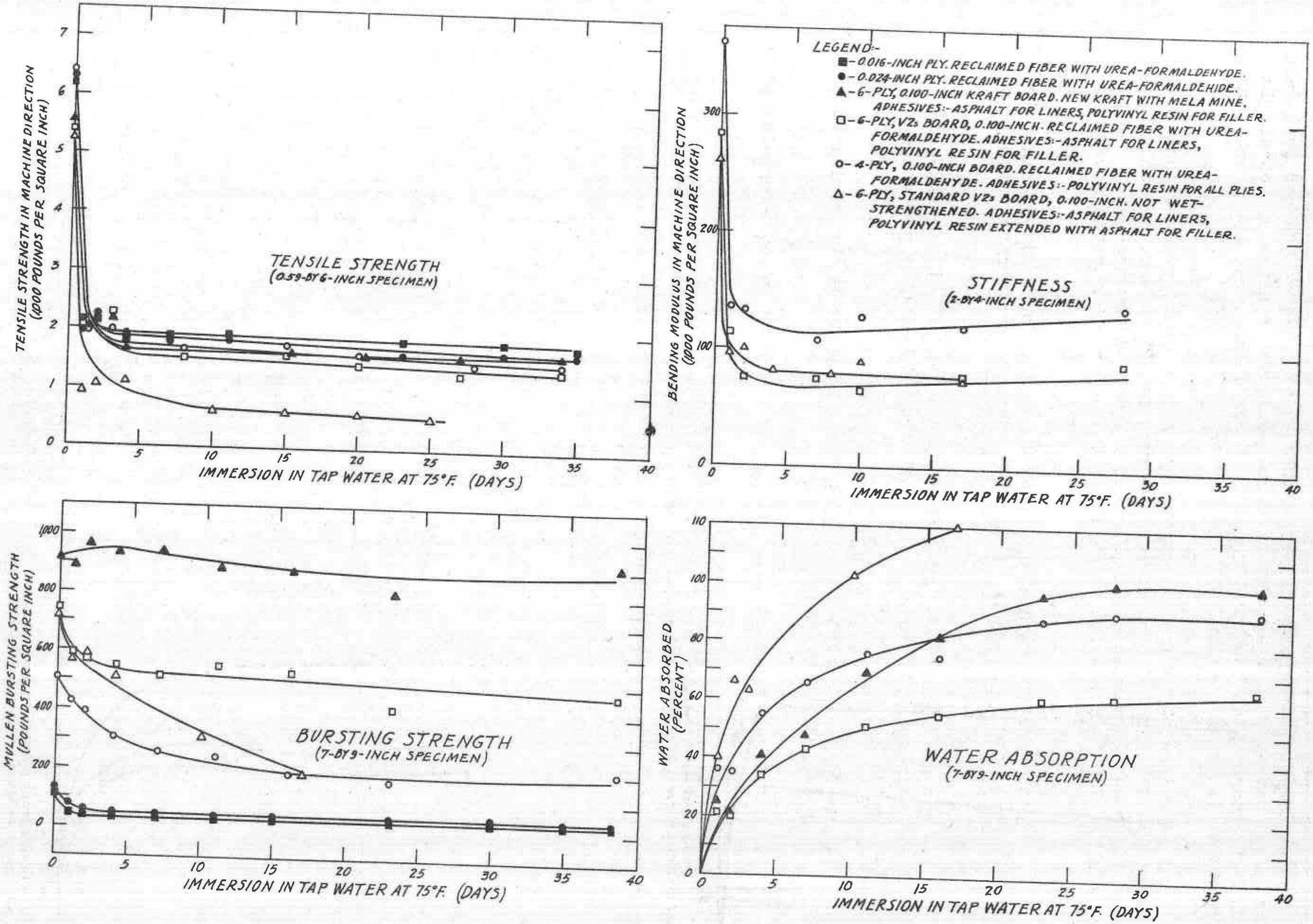

Figure 1.--Effect of prolonged immersion on certain properties of experimental wet-strengthened mill-made fiberboards and of standard V2s fiberboard.

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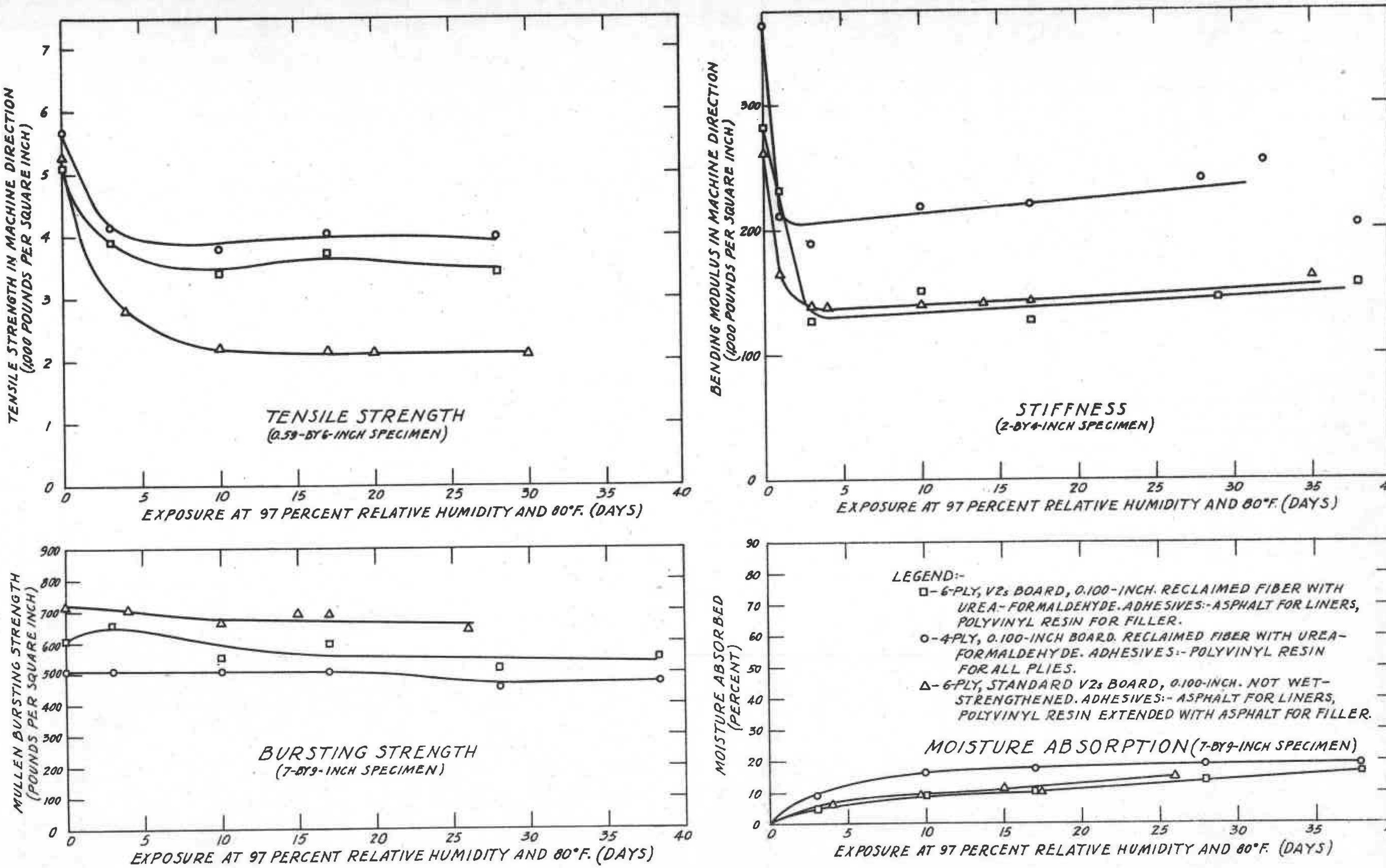

Figure 2.--Effect of prolonged exposure to high humidity on certain properties of experimental wet-strengthened mill-made fiberboards and of standard V2s fiberboard.

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