DURABILITY OF RESIN-TREATED PAPER HONEYCOMB CORE

By

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Abstract

This report presents the results of tests to determine the durability of resin-treated paper honeycomb core. Durability was determined by flatwise compression and tension tests of core alone and core in sandwich with thin plywood and with aluminum facings that had been exposed to outdoor weathering and to accelerated aging. The investigation showed that facings provided enough protection to core so that weathering for 5 years had only slight deleterious effect on the core. Bare core, however, retained only about 35 percent of its tensile and 55 percent of its compressive strength after 5 years of weathering. Accelerated aging had little effect on core strength.

Introduction

One of the factors that determine the usefulness of a product is its durability. Even though the product of manufacture and resecarch is strong enough to withstand applied loads, the product must also be durable enough to withstand changes in climatic conditions over a period of time. The durability of building materials is especially important because their usefulness must usually be extended over long periods.

Information on the durability of a new product such as sandwich panels with paper honeycomb cores is especially meager. Exposures and subsequent mechanical tests can be used to determine the degree of deterioration when the material is exposed in nonstressed condition. Aging tests of book and document papers stored for extremely long periods of time show that the quality of papers made with purified rag and wood pulp fibers would be good after several

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

decades or more if they were not exposed to acidic atmospheres.[2,3,4] However, information on the aging of resin-treated papers, especially in sandwich construction, is needed. This research on aging and durability of a sandwich--type building material was undertaken to fill that gap. In cooperation with the Douglas Aircraft Company of Santa Monica, Calif., an evaluation was made of the effects of accelerated aging cycles and of 5 years of natural weathering cycles on cores and sandwich panels.

This investigation is intended to offer a comparison of the detrimental effects of a standard accelerated aging environment and of natural aging outdoors. The cycles of accelerated aging are, of course, conducted under controlled laboratory conditions, while the cycles of natural weathering were experienced outdoors under varying conditions at two sites. One outdoor weathering location was at Madison, Wis., and the other near Los Angeles, Calif.

This report presents the results of observations and mechanical tests on sandwich panels and paper honeycomb core material after exposure to the various environments. Mechanical tests were made in tension and compression in a direction parallel to the flutes of the core, that is, flatwise to the sandwich panel. The various environments include a control condition (at 75° F. and 64 percent relative humidity), outdoor weathering in Wisconsin and California, and accelerated aging that consisted of cycles of extreme temperature and relative humidity conditions.

Material

The sandwich panels and core panels were furnished by the cooperator. The core panels consisted of a resin-treated paper honeycomb core made of 125-pound kraft paper, expanded to a honeycomb having 7/16-inch hexagonal cells, and then treated with 35 percent of an alcohol-soluble phenolic resin, Sections of this core material were evaluated (1) alone or without facings, (2) with plywood facings, and (3) with aluminum facings.

The plywood facings, 0.070 inch thick, consisted of three-ply exterior grade yellow-poplar. The aluminum facings consisted of 0.064-inch-thick alclad 7075 aluminum. These facings were bonded to the paper cores with a phenolic-polyvinyl butyra1 adhesive according to the standard procedure of the cooperator.

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[2] Kimberly, A. E., and Emley, A. L. A Study of the Deterioration of Book Papers in Libraries. National Bureau of Standards Misc. Pub. NO. 140, April 1933.

[3] Jarrenn, T. D., Haskins, J. M., and Veich, F. P. Deterioration of Paper As Indicated by Gas Chamber Tests. U. S. Dept. Agr. Technical Bulletin No. 605, 1938.

[4] Scribner, B. W. Comparison of Accelerated Aging of Record Papers With Natural Aging for 8 Years. National Bureau of Standards Research Paper R.P. 1241, 1939.

The cooperator supplied twenty-two 14- by 12- by 2-3/8-inch thick panels for each of the three kinds of constructions--core alone, plywood-faced sandwich, and aluminum-faced sandwich. Each group of 22 panels had been processed and bonded simultaneously and their cores had been taken from the same lot of honeycomb.

Test Procedure

In order to evaluate the effects of accelerated aging and natural weathering, the core and sandwich panels with unprotected edges, 2-3/8 by 12 by 14 inches, as received from the cooperator, were exposed to the various conditions. About 1 inch of the unprotected edges was trimmed off and discarded. Mechanical tests were then conducted in tension and compression on specimens cut from the center of these panels. The measure of degree of weathering would be in terms of loss in strength. The test program of this investigation was originally designed to conduct the accelerated weathering work first, then subject panels to natural weathering for exposure periods of 0, 1, 9, 18, and 36 months. Actually, mechanical strength was measured after all these periods except the 36-month exposure. Instead, the 36-month panels were held for a 5-year exposure.

The various exposure conditions are:

(1) Control condition.--Exposure conditions were kept constant so only the effects of time would be shown. This exposure was at 75° F. and 64 percent relative humidity. Representative panels (one panel from each of the three constructions) were exposed to this condition for periods of 0, 1, 18, and 62 months. At the end of each of these periods, specimens were cut from the 12- by 14-inch panels and were tested for strength.

(2) Natural Weathering.--Two natural weathering sites were used for exposure. One site was the exposure to a climatic condition in a temperate zone; the panels were located on the south roof of the Forest Products Laboratory at Madison, Wis. Madison is at about 43° latitude where summers are warm and humid and winters are cold and snowy. Air temperature in this zone ranges between +95° F. in summer and -20° F. in winter. This zone is characterized by extreme weather changes and strongly contrasting seasons with daily changes in degree of precipitation, humidity, winds, and sunshine.

The panels (one from each construction for each exposure period) were mounted January 5, 1954, on a rack on the roof of the Laboratory (fig.1) where local conditions cause the climatic condition to be slightly different from that officially reported by the Weather Bureau several miles away. Being on the south side of the building, the rack is sheltered from northwest winds. Because of its location, it also receives soot from the chimney of the heating plant. Representative panels were exposed to this condition beginning January 5, 1954, for 0, 1, 9, 18, and 62 months. At the end of each period three panels were removed, dimensional and weight observations were made, and then specimens were cut from the panels for strength tests. These mechanical test specimens were conditioned to temperature and weight equilibrium at 75° F. and 64 percent relative humidity before mechanical tests were conducted.

The other natural weathering site was also in a temperate zone, but was located on the seashore, within 100 yards of the ocean, at El Segundo, Calif. This location is at 33° latitude in a temperate zone where the summer and winter air temperatures range from 100° F. to 35° F. However, there are contrasting daily changes in temperature, humidity, and wind velocity. The site is protected by a 4-foot bank of broken chunks of concrete, but the wind carries highly humid air and salt spray to the panels. Representative panels were exposed here as at Madison, Wis. After their respective periods of exposure they were shipped to the Forest Products Laboratory for observations, cutting, conditioning, and testing. The periods of exposure were 0, 1, 9, 18, and 60 months, beginning February 23, 1954,

(3) Accelerated Weathering.--The accelerated weathering consisted of a series of controlled conditions of extreme temperature and relative humidity. Each cycle consisted of the following exposures:

(a) Immersed in water at 122° F. for 1 hour.

(b) Sprayed with wet steam at 194° to 200° for 3 hours.

(c) Stored at 10° F. for 20 hours.

(d) Heated in dry air at 212° F. for 3 hours.

(e) Sprayed with wet stream at 194° to 200° F. for 3 hours.

(f) Heated in dry air at 212° F. for 18 hours.

Representative panels were exposed for from zero to six cycles, and after each cycle the panels were conditioned to equilibrium temperature and weight conditions at 75° F. and 64 percent relative humidity. Then observations of weight and dimensions were made before cutting the panels into specimens. The specimens were again conditioned and tested at 73° F. and 50 percent relative humidity. Mechanical strength tests were tension and compression.

4) Mechanical Tests.--The mechanical tests consisted of tension and compression in a direction parallel to the flutes of the core material. Each 12- by 14-inch panel, sandwich, or core panel was cut into at least five 4- by 4-inch compression specimens and five 2- by 2-inch tensile specimens. The compression specimens were therefore about 2-5/8 by 4 by 4 inches, having the 2-5/8-inch dimension parallel to the flutes of the core. The sandwich specimens, of course, had facings, but the core alone had none. The bearing ends of the flutes of the core specimens were stiffened with a cast of resin.

All the specimens were tested between the heads of a universal-type testing machine. The upper head held a spherical seat through which the load was applied, and it traveled at a head speed of 0.006 inch per minute. During the test, at regular intervals of load, deformation data were obtained by means of a Marten's mirror compressometer of 1-inch gage length mounted on two opposite sides of the specimen.

The tensile specimens were 2-5/8 by 2 by 2 inches. These specimens were also tested in a direction parallel to the flutes. The load on the plywood facings, and hence on the flutes, was applied through 2- by 2- by 2-inch maple blocks. The load on the aluminum-faced specimens and on the core-only specimens was applied through aluminum blocks of the same size. The 2-inch cubes were glued to their specimens with an epoxy resin set at 200° F. under pressure of 15 pounds per square inch. The load was applied to the 2-inch cubes by bolts that were perpendicular to the flutes and at right angles to each other. The load was applied through a head speed of 0.025 inch per minute in a universal-type test machine.

Presentation of Data

Table 1 presents observations after the various periods of exposure relative to appearance, dimensions, and weight of each panel. The observations are on sandwich and core panels subjected to only the control conditions--75° F. and 64 percent relative humidity. The effect of exposure to this constant condition is negligible. It can be seen that there is very little dimensional or weight change and no change in appearance.

Table 2 presents observations on sandwich and core panels subjected to Wisconsin outdoor weathering. According to these observations and data (1) the aluminum-faced panels became corroded and discolored by soot, (2) the core-only panels became distorted and discolored, and (3) the plywood-faced panel after 5 years had its top ply completely eroded to the glue film.

Table 3 presents observations on sandwich and core panels subjected to California outdoor weathering. According to these observations and without benefit of original data before exposure, California outdoor exposure causes the core panel to be distorted. The discoloration of aluminum-faced panels is toward a whitish gray due to the salt deposit, and the top ply of plywood eroded away.

Figures 1 through 7 show the appearance of weathered panels.

Table 4 presents the observations on sandwich and core panels subjected to the accelerated exposure. The dimensions at zero cycles are those observed after conditioning at 75° F. and 64 percent relative humidity; at the indicated number of cycles these dimensions were observed again. Then after the indicated observations, the respective panels were cut into specimens for machanical tests. Each cycle represents 6 exposures, so that the first panel was evaluated for strength after 6 exposures while the last panel was evaluated after 36 exposures. The data show minor dimensional and weight changes but in general all panels appeared to withstand this accelerated aging exposure.

Tables 5, 6, and 7 present the tensile and compressive properties of the aluminum-faced, plywood-faced, and core-only panels after they had been subjected to their respective exposure end reconditioned to equilibrium conditions.

Discussion of Results

The results presented in this investigation bring out four degrees of severity of weathering or exposure on three constructions. These three constructions were basically paper honeycomb cores with three degrees of protection. One construction with aluminum facings had the protection of a metal on two sides which shielded the core at the center of the panel, greatly retarded the movement of moisture, and reflected the sun's rays. The construction with plywood facings also protected the core material but to a lesser degree as shown in figure 8, The core alone, however, was entirely unprotected so that it received the full amount of temperature change, moisture, and sun's rays.

The factors that influence the effect of aging and weathering in the four exposure conditions may be recognized as follows: (1) The control panels were exposed to constant temperature and relative humidity conditions with the absence of sunlight; (2) the accelerated weathering panels were exposed to variable temperature and moisture conditions for short periods of time and also with the absence of sunlight; (3) the panels weathered outdoors in California were exposed to variable temperatures, humidity, sunlight, and salt spray; and (4) the Wisconsin panels were also exposed to variable temperature, humidity; and sunlight, but the local conditions caused a temperature range that was greater than that in California. No salt spray was experienced but snow, hail, and soot was added.

The mechanical property that best measures the effects of these various degrees of aging on the core is the maximum compressive strength parallel to the flutes. In this compression test only the paper core, after its respective aging, resisted the compressive forces until failure occurred. In the tension test, however, the weakest link, such as paper-to-face bond or plywood-face tensile strength, would fail at the lowest stress and hence was a measure of the resistance of the sandwich to aging.

The effect of the four types of weathering on the maximum compressive strength is shown in figure 8 for the three constructions. The aluminum-faced panels consistently show the highest compressive strength. In the controlled atmosphere, the panels at each period of exposure have a compressive strength about 45 pounds per square inch stronger than the other two types of panels. The core alone is the weakest, and the plywood-faced panels appear to have intermediate strength.

The sandwich panel facings protected the cores to the extent that no appreciable damage was done to the cores during either natural or accelerated aging and weathering. Each of the points on figure 8 are the average of five specimens so they show a trend in spite of the scatter of individual results shown on the tables. It can be observed that there was somewhat of an increase in strength for the earlier periods of exposure, This trend was probably due to additional curing of the resin. The core panels had no protection and hence the three exposures reduced the core strength. The accelerated exposure caused about 10 percent reduction in strength and the outdoor exposures caused about a 5 percent reduction. The sunlight may have had a detrimental effect on the unprotected core material.

Tensile strengths of the paper honeycomb sandwich constructions after aging are summarized in figure 9. The tensile strength shown here represents the flatwise strength of the entire sandwich construction. Upward trends in strength for earlier periods of exposure probably reflect additional cure in resin or adhesives. The plywood-faced sandwich had the lowest tensile values because its failure was in the plywood perpendicular to the grain. This type of failure only indicates that the strength of the bond between facing and core and the strength of the core exceeded the observed values. For the aluminum-faced sandwich, the failures usually occurred in the bond between the facing and the core. This type of failure again only indicates that the core is stronger than the bond. For the core-only material, failures usually occurred in the paper core and hence the values shown are indicative of the effect of aging. Tensile strength of the core-only material shows that the steady controlled exposure and the accelerated aging had very little effect *on* the strength. However, there is a substantial reduction in strength due to natural outdoor exposure. That reduction is about 60 percent, which again may be due to the effect of the sunlight on the unprotected paper honeycomb.

These mechanical tests have shown four degrees of exposure in which deterioration due to accelerated aging was compared to that due to natural aging and weathering. The deterioration due to accelerated aging, unfortunately, was not severe enough to develop a definite trend. The scatter of individual results obscures the slight trend that might exist. Since there is not a measurable deterioration due to six cycles of accelerated aging, there is not a correlation between the number of cycles of accelerated aging and the number of years of natural weathering.

Conclusions

Results of 5 years of natural aging and six cycles of accelerated aging show that:

(1) Aging in constant temperature and relative humidity conditions had no effect on the strength of sandwich and core panels after 5 years,

(2) Accelerated aging by six cycles of variable temperatures and relative humidity had only a slight tendency to reduce strength.

(3) Natural weathering at Wisconsin and California outdoor sites caused only a slight reduction in strength of sandwich construction.

(4) Aluminum or plywood facings provided protection to the core material, so that the latter was only slightly affected by natural weathering.

(5) Unprotected core material, however, retained only about 35 percent of its tensile strength and 55 percent of its compressive strength after 5 years of natural exposure.

Table 1.--Sandwich panels subjected to aging and controlled expossure at 75° F. and 64 percent relative humidity--Continued

Period of exposure	Length	Width	Average thickness	Weight	Warp	Observations
Mo.	In.	In.	In.		In.	
ALUMINUM FACING AND PAPER HONEYCOMB CORE						
0	13.81	12.04	2.502	1,436.2	....	Control.
0	13.86	12.12	2.493	1,345.0	....	
1	13.86	12.12	2.493	1,345.0	0	No change in appearance.
0	13.78	12.02	2.497	1,362.0	....	
9	13.77	12.03	2.492	1,360.3	0	No change in appearance.
0	13.79	12.00	2.494	1,363.8	....	
18	13.78	12.07	2.492	1,360.1	0	No change in appearance.
0	13.73	11.99	2.504	1,423.0	....	
62	13.75	12.00	2.503	1,421.2	0	No change in appearance.
PAPER HONEYCOMB CORE ONLY						
0	13.62	11.60	2.386	387.4	....	Control.
0	13.12	11.50	2.383	394.8	....	
1	13.15	11.50	2.381	393.2	0	No change in appearance.
0	13.33	12.03	2.381	401.2	....	
9	13.73	12.05	2.384	399.8	0	No change in appearance.
0	13.80	11.30	2.381	406.9	....	
18	13.80	12.00	2.378	403.9	0	No change in appearance.
0	13.80	11.62	2.382	408.2	....	
62	13.80	12.00	2.376	407.0	0	No change in appearance.

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Table 1.--Sandwich panels subjected to aging and controlled exposure at 75° F. and 64 percent relative humidity--Continued

Period of exposure	Length	Width	Average thickness	Weight	Warp	Observations
Mo.	In.	In.	In.		In.	
			PLYWOOD FACING AND PAPER HONEYCOMB CORE			
0	14.04	12.02	2.517	732.3	....	Control.
0	14.03	12.01	2.517	699.5	....	
1	14.03	12.02	2.517	699.5	0	No change in appearance.
0	14.02	12.01	2.513	712.0	....	
9	14.03	12.02	2.513	710.0	0	No change in appearance.
0	14.04	12.01	2.514	725.9	....	
18	14.05	12.00	2.512	723.4	0	No change in appearance.
0	14.03	12.04	2.519	728.2	....	
62	14.03	12.03	2.519	726.5	0	No change in appearance.

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Table 2.--Sandwich panels subjected to Wisconsin outdoor exposure

Period of exposure	Length	Width	Average thickness	Weight	Warp	Observations
Mo.	In.	In.	In.		In.	
ALUMINUM FACING AND PAPER HONEYCOMB CORE						
0	13.70	12.00	2.493	1,224.0	0	Control.
0	13.79	12.08	2.500	1,426.0	.01	
1	13.80	12.08	2.502	1,431.0	0	No visible damage.
0	13.79	12.02	2.501	1,439.0	.01	
1	13.76	12.04	2.503	1,444.0	.01	No visible damage.
0	13.81	12.07	2.495	1,352.0	0	
18	13.82	12.07	2.494	1,347.6	0	Aluminum facing corroded and specked with soot.
0	13.82	12.08	2.495	1,347.0	.01	
62	13.80	12.09	2.506	1,419.0	.01	Aluminum facing corroded and discolored by soot.
PAPER HONEYCOMB CORE ONLY						
0	13.90	12.05	2.381	387.0	0	Control.
0	13.85	12.05	2.379	415.0	0	
1	14.03	12.05	2.392	424.0	0	No visible damage.
0	13.85	12.05	2.380	399.0	0	
9	14.35	11.47	2.378	426.0	0	Cells expanded more in central area.
0	14.00	12.00	2.379	384.0	0	
18	14.35	11.80	2.377	382.6	0	Cells expanded more in central area than at edges.
0	14.00	12.02	2.383	376.0	0	
62	14.68	11.50	2.363	385.4	0	Panel is not square. Paper is discolored by soot. Some flute ends are damaged.

Table 2.--Sandwich panels subjected to Wisconsin outdoor exposure--Continued

Period of exposure	Length	Width	Average thickness	Weight	Warp	Observations
Mo.	In.	In.	In.		In.	
			PLYWOOD FACING AND PAPER HONEYCOMB CORE			
0	13.99	12.05	2.520	733.0	0	Control.
0	14.05	12.02	2.518	708.0	0	
1	14.03	12.03	2.522	716.0	0	No visible damage.
0	14.02	12.00	2.520	700.0	0	
9	14.00	12.00	2.526	727.0	.02	Top face badly discolored, with a slight warp.
0	14.03	12.05	2.523	718.0	0	
18	14.01	12.05	2.516	703.2	.02	Top face weathered loss in thickness and weight.
0	14.00	12.02	2.517	729.0	0	
62	13.98	12.01	2.502	682.6		Top ply eroded away to glue film.

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Table 3.--Sandwich panels subjected to California outdoor seaside) exposure

Period of exposure	Length	Width	Average thickness	Weight	Warp	Observations
Mo.	In.	In.	In.		In.	
ALUMINUM FACING AND PAPER HONEYCOMB CORE						
0	13.81	12.00	2.502	1,437.8	0	Control.
1	13.82	12.03	2.500	1,403.3	....	No change.
9	13.85	12.12	2.500	1,448.0	0	Spotted white and gray.
18	13.77	12.06	2.505	1,447.0	0	Face pitted and gray.
60	13.82	12.09	2.496	1,347.5	0	White deposit on top face.
PAPER HONEYCOMB CORE ONLY						
0	14.50	12.00	2.380	412.11	0	Control.
1	14.78	11.66	2.380	414.5	....	No noticeable change.
9	14.50	11.75	2.350	412.0	.12	
18	14.62	11.60	2.365	414.0	0	
60	14.48	11.60	2.365	352.3	0	Panel not square. Paper is whitish.
PLYWOOD FACING AND PAPER HONEYCOMB CORE						
0	14.02	12.00	2.520	772.1	0	Control.
1	14.01	12.02	2.519	715.8	....	Slightly darker.
9	14.00	12.01	2.520	740.0	....	Slightly darker.
18	13.96	12.02	2.507	728.0	....	Dark gray.
60	13.96	12.02	2.507	698.0	....	Top ply of facing eroded to glue film.

Table 4.--Sandwich panels subjected to accelerated weathering

Number of cycles[1]	Length	Width	Thickness	Weight	Warp	Observations
	In.	In.	In.		In.	
ALUMINUM FACING AND PAPER HONEYCOMB CORE						
0	13.82	12.08	2.500	1,436	0	
0	13.79	12.01	2.502	1,401	0	
1	13.79	12.01	2.494	1,384	0	All aluminum-faced panels except one came through the aging in good shape.
0	13.87	12.11	2.493	1,348	0	
2	13.87	12.11	2.487	1,323	0	
0	13.80	12.07	2.497	1,319	0	
3	13.80	12.07	2.489	1,297	0	
0	13.78	12.06	2.492	1,330	0	
4	13.78	12.06	2.484	1,307	0	
0	13.85	12.07	2.493	1,242	0	Some delamination at one corner.
5	13.85	12.07	2.485	1,221	0	
0	13.77	12.07	2.483	1,246	.01	
6	13.77	12.07	2.473	1,220	.01	
PAPER HONEYCOMB CORE ONLY						
0	13.90	12.05	2.388	390	0	
0	13.90	12.05	2.391	394	0	
1	14.00	11.75	2.363	374	0	With the exception of dimensional changes, all cores came through the aging in good condition.
0	13.90	12.05	2.390	410	0	
2	14.00	11.75	2.366	383	0	
0	13.80	12.10	2.391	407	0	
3	13.60	11.95	2.365	386	0	
0	13.90	12.00	2.384	403	0	
4	12.13	12.50	2.352	377	0	
0	13.80	12.15	2.387	387	0	
5	13.00	11.97	2.364	361	0	
0	13.80	12.08	2.383	390	0	
6	13.35	11.90	2.362	365	0	

Table 4.--Sandwich panels subjected to accelerated weathering--Continued

Number of cycles[1]	Length	Width	Thickness	Weight	Warp	Observations
	In.	In.	In.		In.	
PLYWOOD FACING AND PAPER HONEYCOMB CORE						
0	14.00	12.02	2.521	727	0	
0	14.05	12.00	2.515	718	0	
1	14.00	12.00	2.511	1,008	0	All plywood-faced panels came through the aging in very good
0	14.04	12.03	2.519	712	0	condition. Poplar facings were
2	14.00	12.00	2.512	673	....	discolored but were in good shape.
0	14.01	12.01	2.516	726	0	
3	13.94	11.96	2.507	684	....	
0	14.04	12.04	2.519	713	0	
4	13.99	12.00	2.511	677	0	
0	14.00	12.02	2.518	728	0	
5	13.91	11.97	2.507	674	0	
0	14.03	12.00	2.519	720	0	
6	13.95	11.93	2.414	667	0	

[1] One cycle represents 6 exposures.

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Table 5.--Strength of structural sandwich material after being subjected to various exposures

ALUMINUM FACING AND PAPER HONEYCOMB CORE

Exposure:	Control				Wisconsin outdoor				California outdoor			
Period	Tension	Compression			Tension	Compression			Tension	Compression		
	Maximum stress	Modulus of elasticity	Proportional limit stress	Maximum stress	Maximum stress	Modulus of elasticity	Proportional limit stress	Maximum stress	Maximum stress	Modulus of elasticity	Proportional limit stress	Maximum stress
Mo.	P.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.
0	230	77.7	129	339	221	83.4	129	326	334	96.6	167	355
	283	86.0	139	327	206	87.6	176	334	345	80.4	102	337
	269	74.3	149	316	198	92.3	185	330	352	99.5	167	343
	286	84.4	167	344	238	100.4	139	318	333	95.6	139	311
	245	84.8	170	351	202	80.4	120	302	266	103.8	130	318
Av...	263	81.4	151	335	213	88.8	150	322	326	95.2	141	333
1	264	86.4	92	320	344	97.0	112	296	328	75.6	149	319
	284	100.5	240	330	295	82.4	130	294	325	85.5	149	308
	261	96.2	158	332	392	96.3	102	293	263	98.4	102	293
	320	101.7	130	320	275	85.5	…	255	292	65.2	130	302
	245	118.8	83	305	305	81.0	130	274	278	99.2	196	313
Av...	275	100.7	141	321	322	88.4	118	282	297	84.8	145	307
9	269	81.0	158	338	392	93.1	102	348	372	117.3	93	377
	328	…	…	328	330	84.4	168	355	358	135.0	99	381
	364	103.2	139	336	331	95.2	121	359	358	95.4	99	361
	342	…	…	324	362	101.2	131	355	405	110.0	136	351
	290	69.0	186	345	401	92.6	103	345	354	104.3	112	336
Av...	319	84.4	161	334	363	93.3	125	352	369	112.4	108	361
18	378	109.7	137	386	325	96.8	168	372	270	90.0	99	338
	441	100.9	168	383	405	101.3	150	380	294	106.8	111	336
	424	119.1	131	404	370	109.8	162	390	430	144.4	87	356
	361	107.8	132	368	296	114.5	112	385	405	100.7	148	352
	366	106.9	150	367	290	146.7	175	390	506	116.0	87	343
Av...	394	108.9	144	382	337	113.8	153	383	381	111.6	106	345
60	430	91.8	124	380	306	82.6	136	359	306	72.2	236	364
	439	105.3	212	412	269	94.8	174	341	267	100.0	137	366
	445	97.8	137	401	311	101.0	87	351	317	98.9	149	357
	413	66.9	87	327	314	103.5	160	360	347	92.1	161	334
	359	85.4	136	331	321	93.2	173	361	315	100.1	136	334
Av...	417	89.4	139	370	304	95.0	146	354	310	92.7	164	351

Accelerated				
Number of cycles	Tension	Compression		
	Maximum stress	Modulus of elasticity	Proportional limit stress	Maximum stress
	P.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.
0	314	104.3	194	318
	288	94.2	139	324
	320	96.0	120	323
	304	90.0	138	355
	344	91.7	129	332
Av...	314	95.2	144	330
1	270	68.9	92	306
	308	94.5	121	320
	358	86.3	148	315
	369	98.2	102	288
	272	80.5	121	293
Av...	315	85.7	117	304
2	288	88.4	83	302
	271	86.2	166	308
	294	97.6	129	311
	375	113.7	148	356
	356	95.8	129	351
Av...	317	96.3	131	326
3	260	85.5	138	307
	331	96.4	111	314
	319	84.7	102	308
	330	91.9	175	304
	230	99.4	129	309
Av...	294	91.6	131	308
4	396	81.5	111	298
	385	83.2	102	292
	414	122.0	65	289
	360	92.4	102	321
	375	80.3	129	326
Av...	386	91.9	102	305
5	226	92.2	176	326
	234	108.6	92	314
	230	71.2	102	306
	218	60.8	93	285
	194	84.0	148	291
Av...	220	83.4	122	304
6	270	89.0	166	328
	282	…	…	344
	354	81.8	92	338
	342	…	…	…
	285	92.4	138	331
Av...	307	87.7	132	335

Table 6.--Strength of structural sandwich material after being subjected to various exposures

PLYWOOD FACING AND PAPER HONEYCOMB CORE

Exposure	Control				Wisconsin outdoor				California outdoor			
Period	Tension	Compression			Tension	Compression			Tension	Compression		
	Maximum stress	Modulus of elasticity	Proportional limit stress	Maximum stress	Maximum stress	Modulus of elasticity	Proportional limit stress	Maximum stress	Maximum stress	Modulus of elasticity	Proportional limit stress	Maximum stress
Mo.	P.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.
0	275	86.1	112	280	229	92.5	198	318	248	95.3	167	289
	250	72.1	87	270	267	112.0	185	328	255	151.4	158	299
	254	74.0	80	273	243	84.4	211	326	256	80.3	159	309
	236	84.2	186	301	239	110.0	136	299	223	88.6	103	320
	224	96.8	111	296	268	106.0	174	301	194	87.7	176	326
Av...	248	82.6	115	284	249	101.0	181	314	235	100.7	153	309
1	180	77.4	83	276	220	75.6	92	306	233	92.0	129	305
	195	64.8	102	279	246	77.8	121	293	237	142.0	110	302
	194	79.2	112	290	200	80.7	...	274	230	...	...	302
	78	105.4	132	307	218	81.5	159	315	224	...	...	289
	75	97.2	150	297	216	101.8	145	285	237	...	...	290
Av...	144	84.8	116	290	220	83.5	129	295	232	117.0	119	297
9	275	103.3	65	293	188	80.6	93	285	226	89.6	99	353
	205	64.3	130	295	220	119.5	84	285	242	99.8	149	352
	198	85.7	121	305	212	80.5	139	280	205	102.5	99	346
	228	91.7	130	310	169	86.2	126	318	216	85.6	111	307
	261	87.8	140	300	162	67.4	103	307	221	99.2	87	308
Av...	233	86.6	117	301	190	86.8	109	295	222	95.3	109	333
18	264	84.6	160	325	210	133.0	112	327	214	100.6	149	331
	274	95.6	148	320	210	92.1	123	319	246	122.5	135	308
	292	86.1	123	335	227	139.8	74	326	209	96.2	122	310
	269	98.6	137	337	188	104.2	137	328	235	103.4	122	321
	282	96.9	136	315	204	128.5	100	321	206	105.3	147	313
Av...	276	92.4	141	326	208	119.5	109	324	222	105.6	135	317
60	211	94.6	124	323	159	103.2	161	365	150	94.8	123	332
	163	89.8	99	314	145	89.2	111	370	120	92.9	136	320
	135	104.4	123	319	154	86.2	86	356	159	71.3	99	302
	190	106.1	111	305	221	118.4	124	338	176	88.2	111	322
	222	99.4	148	319	186	140.2	123	319	132	108.2	160	326
Av...	184	98.9	121	316	173	107.4	121	350	147	91.1	126	320

Accelerated				
Number of cycles	Tension	Compression		
	Maximum stress	Modulus of elasticity	Proportional limit stress	Maximum stress
	P.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.
0	296	53.7	130	288
	250	78.0	121	285
	220	63.3	111	285
	215	98.0	131	299
	208	79.8	121	289
Av...	238	74.6	123	289
1	269	82.1	56	233
	236	60.6	83	230
	200	67.7	111	234
	160	130.4	83	274
	216	87.3	93	264
Av...	216	85.6	85	247
2	195	102.0	112	258
	194	119.0	92	267
	224	147.7	93	279
	216	105.0	130	307
	207	111.7	112	298
Av...	207	117.1	108	282
3	241	87.3	94	288
	228	121.0	121	305
	207	105.8	121	293
	243	86.2	102	285
	224	79.6	111	259
Av...	229	96.0	110	286
4	242	94.6	148	307
	190	182.6	65	280
	230	94.2	130	291
	206	88.4	93	230
	158	94.2	93	261
Av...	205	110.8	106	274
5	240	118.4	92	318
	298	111.8	103	336
	252	81.5	148	314
	237	135.0	103	287
	262	77.5	92	258
Av...	258	104.8	108	303
6	245	113.5	102	294
	215	96.7	130	307
	228	125.6	74	292
	224	117.9	101	278
	220	127.7	120	289
Av...	226	116.3	105	292

Table 7.--Strength of structural sandwich material after being subjected to various exposures

PAPER HONEYCOMB CORE ONLY

Exposure: Period	Control: Tension: Maximum stress	Control: Compression: Modulus of elasticity	Control: Compression: Proportional limit stress	Control: Compression: Maximum stress	Wisconsin outdoor: Tension: Maximum stress	Wisconsin outdoor: Compression: Modulus of elasticity	Wisconsin outdoor: Compression: Proportional limit stress	Wisconsin outdoor: Compression: Maximum stress	California outdoor: Tension: Maximum stress	California outdoor: Compression: Modulus of elasticity	California outdoor: Compression: Proportional limit stress	California outdoor: Compression: Maximum stress
Mo.	P.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.
0	478	86.0	74	255	630	64.8	83	268	513	66.0	102	323
	416	87.8	92	258	496	87.6	147	259	583	83.0	140	303
	479	96.2	139	257	474	79.2	101	258	487	79.0	121	316
	584	78.2	102	261	401	108.6	84	272	556	79.5	111	291
	477	103.0	102	288	525	86.8	121	267	614	69.0	176	288
Av...	487	90.2	102	264	505	85.4	107	265	551	75.3	130	304
1	560	139.3	139	279	532	105.0	92	264	563	114.5	100	239
	575	83.2	120	274	614	82.7	111	268	590	85.4	91	240
	614	78.5	74	288	523	85.2	111	272	573	102.6	172	245
	523	63.7	129	296	510	87.0	120	284	638	82.3	127	247
	556	83.2	111	309	605	72.0	112	291	513	94.4	135	223
Av...	566	89.6	115	289	557	86.4	109	276	575	95.8	125	239
9	540	119.8	131	287	512	54.2	165	236	430	81.2	56	172
	462	90.5	92	291	470	58.4	91	241	320	79.6	104	202
	614	106.1	131	286	511	79.2	120	226	418	77.1		187
	524	111.5	111	278	546	93.0		242	370	102.8		152
	471	75.6		268		70.9		229	389	72.4		209
Av...	522	100.7	116	282	510	71.1	125	235	385	82.6	80	184
18	555	96.2	138	350	326	85.1	92	218	386	97.3	119	181
	491			327	395	73.2		192	381	64.2		177
	581	98.0	134	334	374	78.7	85	210	421	47.9	104	175
	524	125.5	174	334	396	70.6	102	190	319	55.2		173
	589	110.2	124	337		56.9	63	193	309	55.8	85	181
Av...	548	107.5	142	336	373	72.9	86	201	363	64.1	103	177
60	619	76.2	87	310	174	55.2		130	131	75.6	98	204
	542	72.1	98	309	233	49.6		119	228	69.8	68	160
	620	104.8	159	319	102	39.1	63	149	200	52.1	93	183
	635	84.1	134	313	270	59.5		156	240	100.0	105	217
	496	59.4	172	327	212	50.2	38	135	182	69.5	111	207
Av...	582	79.3	130	316	198	50.7	50	138	196	73.4	95	194

Accelerated: Number of cycles	Tension: Maximum stress	Compression: Modulus of elasticity	Compression: Proportional limit stress	Compression: Maximum stress
	P.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.
0	587	140.5	157	286
	590	109.7	83	285
	515	82.7	83	287
	470	60.0	111	242
	616	51.5	65	270
Av...	556	88.9	100	274
1	555	57.6	90	213
	471	62.2	93	233
	568	74.2	74	232
	519	74.2	74	232
	615	82.8	65	232
Av...	546	70.2	79	228
2	615	63.4	167	263
	582	75.5	74	265
	545	59.6	119	267
	614	67.8	101	282
	540			291
Av...	579	66.6	115	274
3	650	40.5	139	257
	700			267
	680	104.0	102	261
		108.0	130	253
		104.0	93	257
Av...	677	89.1	116	259
4	691	76.9	129	242
	657	94.7	101	257
	635	90.8	94	267
	562	93.5	108	263
	586	122.6	93	244
Av...	626	95.7	105	255
5	576	82.0	112	256
	577	110.5	83	247
	600	124.9	84	241
	600	53.8	111	251
	610	69.0	74	250
Av...	593	88.0	93	249
6	580	73.6	84	254
	552	102.6	66	239
	562			236
	600	94.6	102	266
	506	104.0	122	258
Av...	560	93.7	93	251

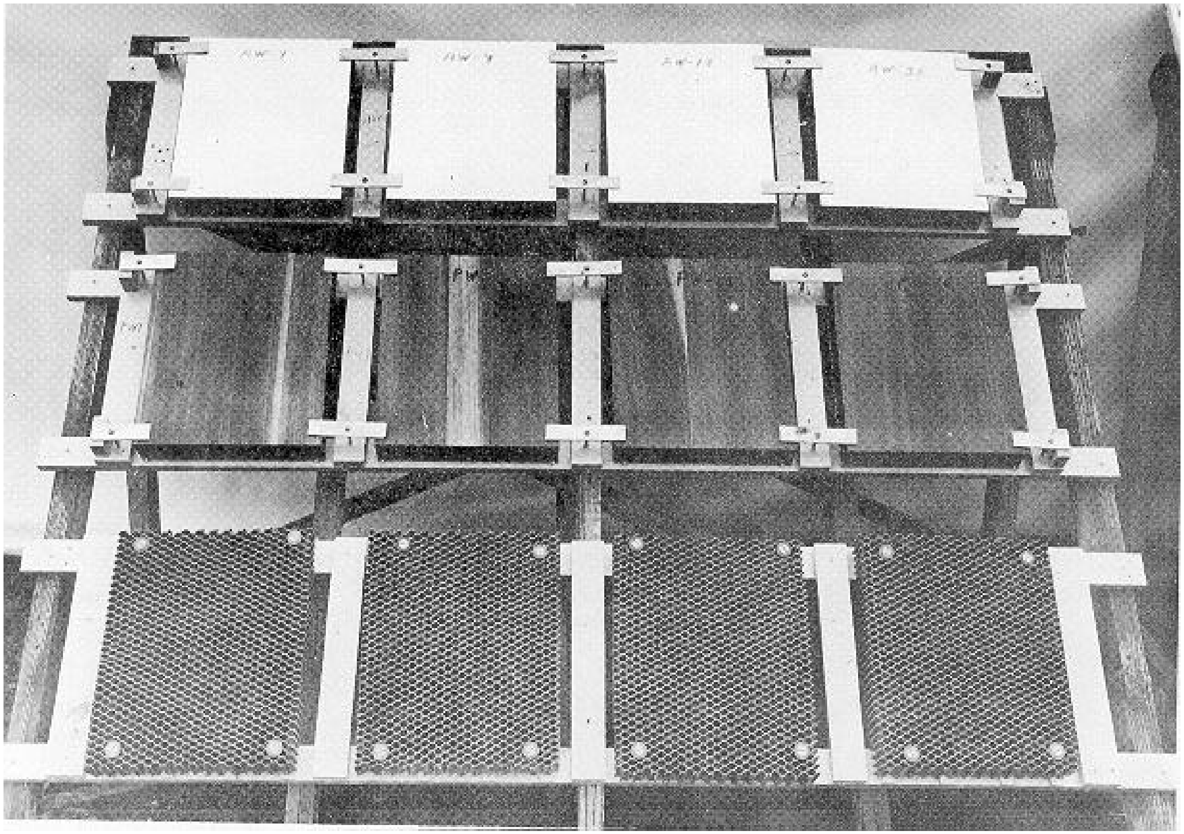


Figure 1. --Sandwich and core panels on exposure rack at Madison Wis., as they appeared after one day of exposure.

ZM 95274 F

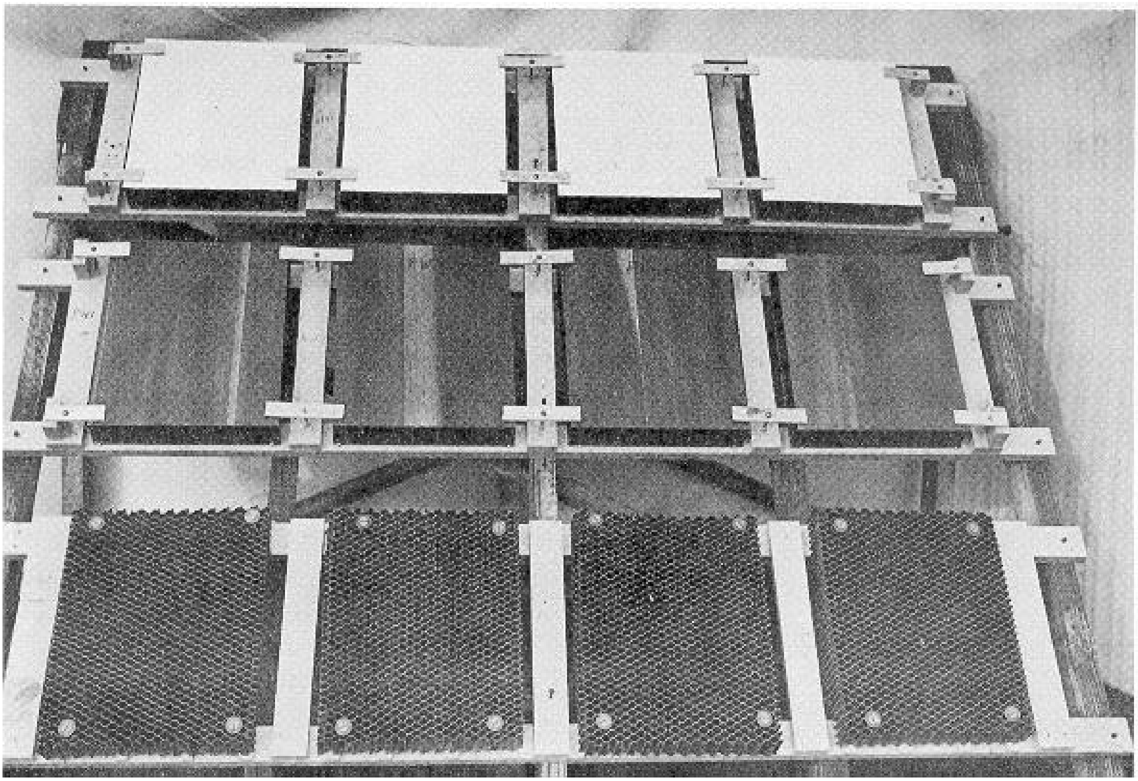


Figure 2. --Sandwich and core panels on exposure rack at Madison, Wis., after 1 month of exposure.

ZM 95499 F

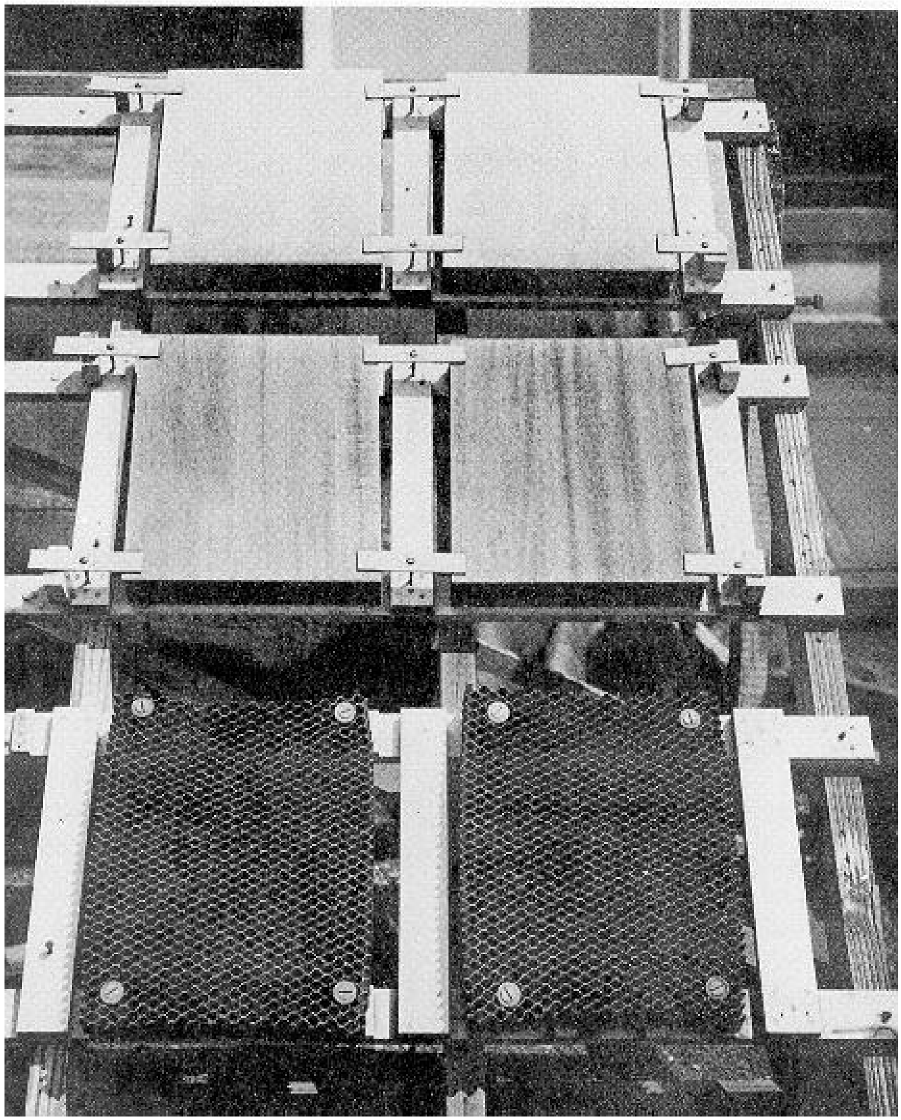


Figure 3. --Sandwich and core panels on exposure rack at Madison, Wis., after exposure for 18 months.

ZM 106 150

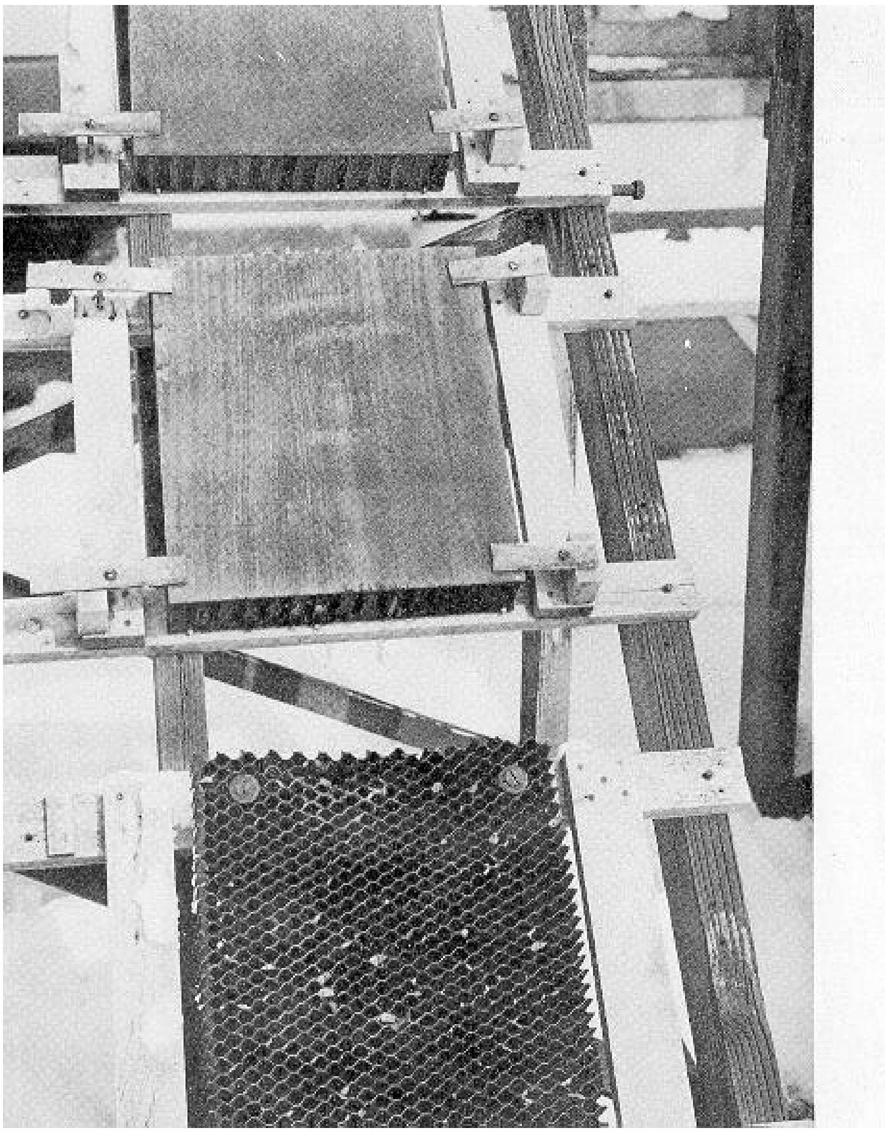


Figure 4. --Sandwich and core panels on exposure rack at Madison, Wis., after being exposed for 5 years. Small patches of snow show on the frames.

ZM 115 289

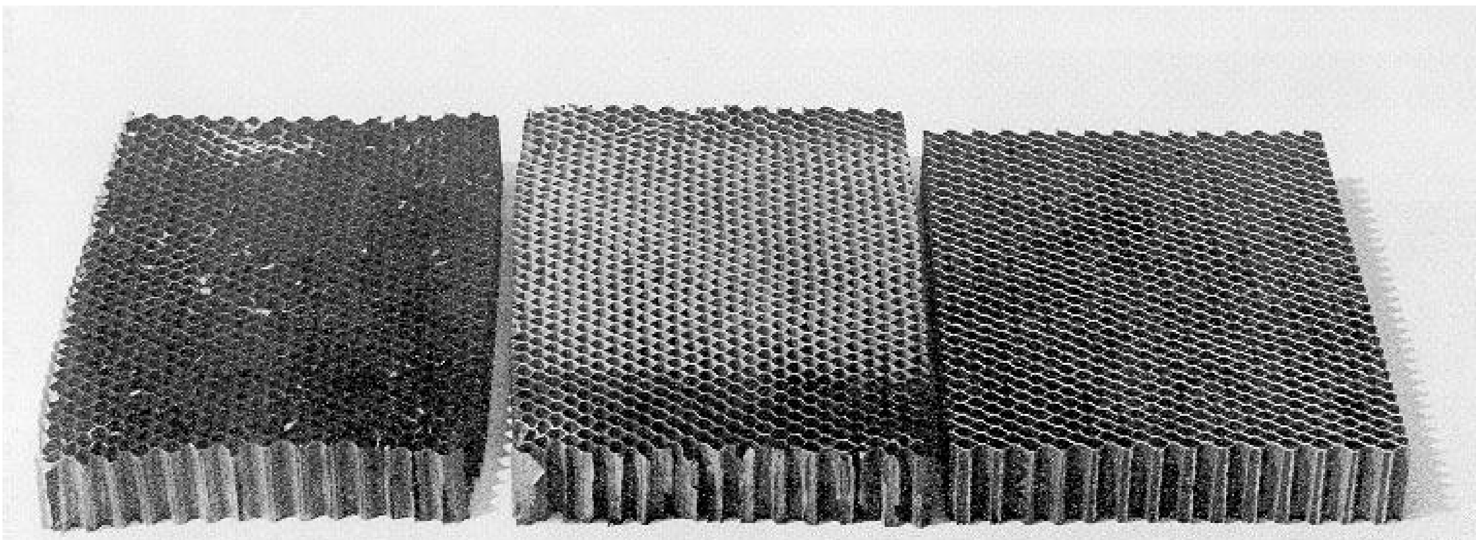


Figure 5.--Core panels after 5 years' exposure to Wisconsin outdoors (left), California outdoors (center), and control (right).

ZM 115 292

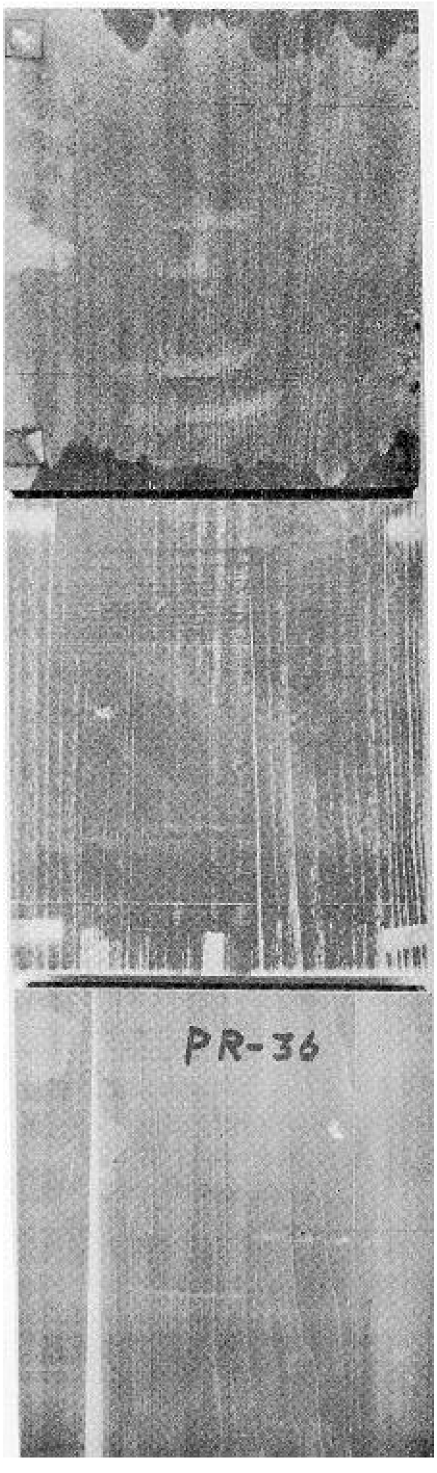
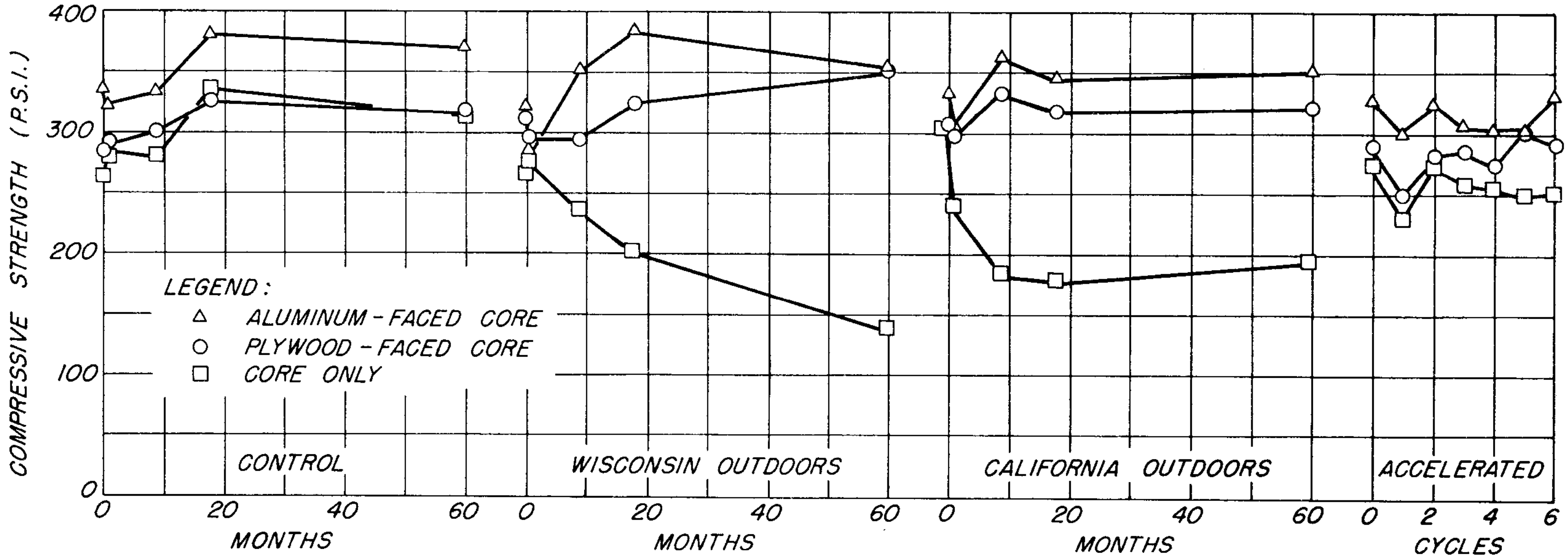


Figure 6.--Plywood-faced sandwich panels after 5 years' exposure to Wisconsin outdoors (top), California outdoors (center), and control (bottom).

ZM 115 291

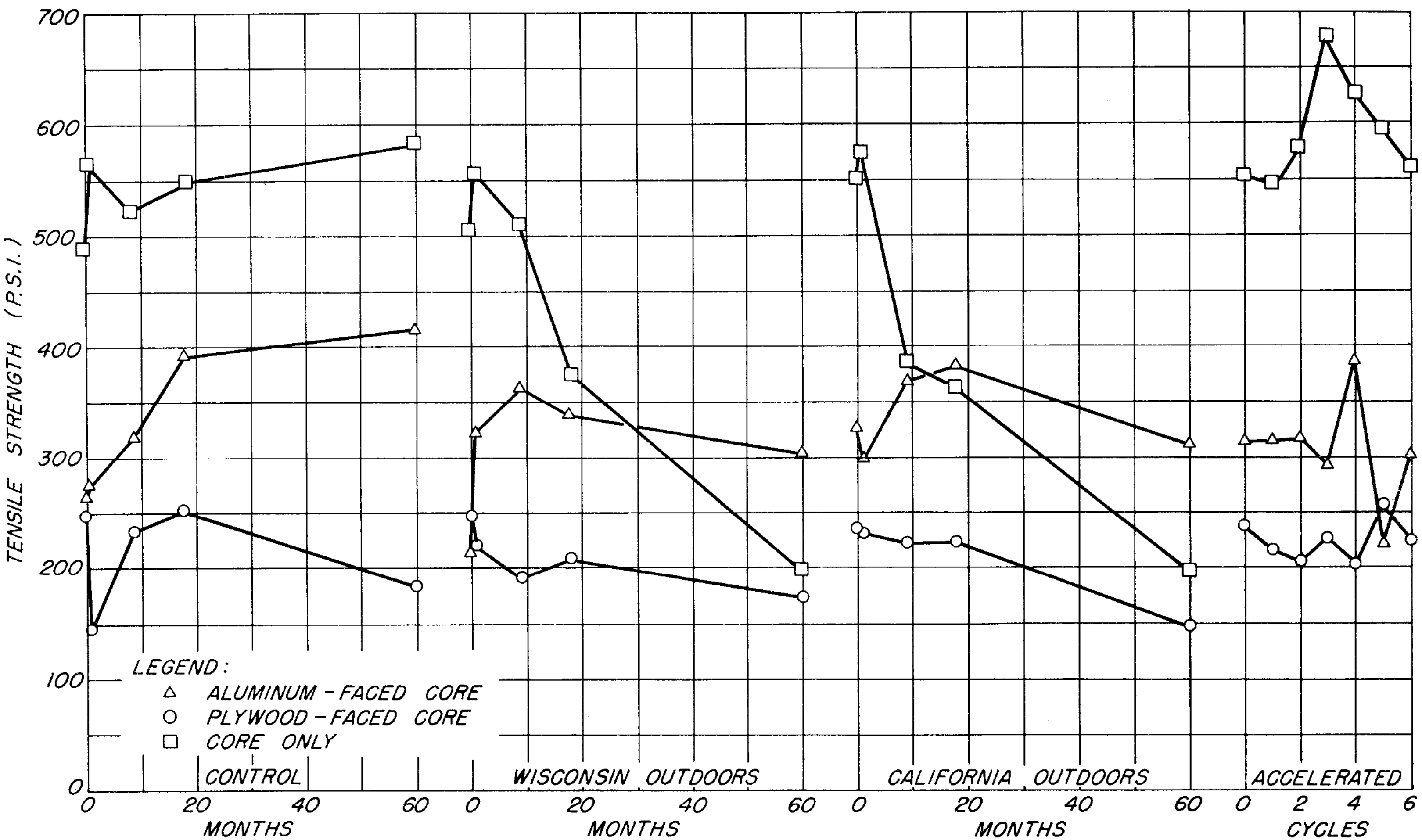
Figure 7. --Aluminum-faced sandwich panels after 5 years' exposure to Wisconsin outdoors (top), California outdoors (center), and control (bottom).

ZM 115 290



Z M 116 338

Figure 8. --Compressive strength of paper honeycomb core after aging.



Z M 116 339

Figure 9. --Tensile strength of paper honeycomb sandwich after aging.