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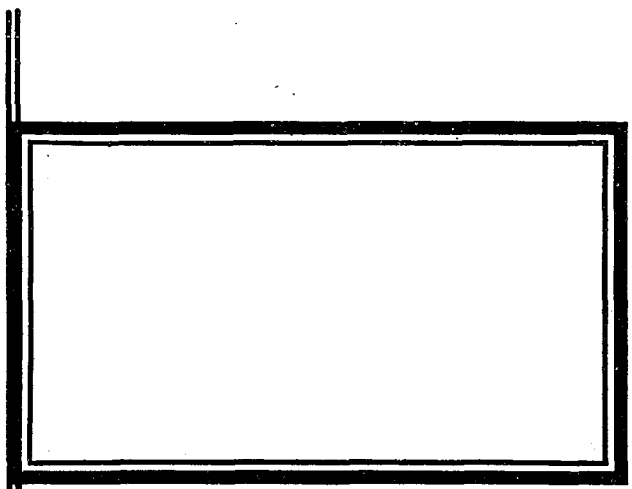

407 252

Puget Sound Naval Shipyard
Bremerton, Washington

13ND PSNS 5600/3

LIGHTWEIGHT REINFORCED PLASTIC FACED SANDWICH CONSTRUCTION (S-R007-03-04) Task 1008

Report P-565

June 1963

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ABSTRACT

The values of impact and flexure properties of sandwich panels with polyurethane foam and balsa wood cores with laminated glass-resin faces are shown.

SUMMARY PAGE

THE PROBLEM

The stiffness, impact resistance, and strength to weight ratio of sandwich panels with laminated resin-glass faces and 6 lbs/ft^3 polyurethane foam cure were to be determined and compared with the values obtained with similar panels where 2 lbs/ft^3 polyurethane foam core had been used. (Panel 4, reference (b)). In addition, these properties were to be determined on end grain (grain parallel to panel thickness) balsa panels and compared to similar panels in which the end grain was perpendicular to the panel thickness (panel 3, reference (b)).

THE FINDINGS

The use of 6 lbs/ft^3 urethane foam instead of 2 lbs/ft^3 urethane for the core of a sandwich panel similar to Panel 4 of reference (b) caused the following property changes:

(1) The unit weight of the panel was increased approximately 16%.

(2) The stiffness factor was increased approximately 300%.

(3) The ultimate load sustaining capacity was increased 500-700%.

(4) The impact resistance was increased approximately 1,000%.

(5) The stiffness factor expressed as a per cent of that of a beam of aluminum, steel, or teak of equal weight and thickness, was increased approximately 300%.

SUMMARY PAGE (Cont'd)

The use of end grain balsa (with the grain parallel to the panel thickness) in the core of a sandwich panel similar to Panel 3 of reference (b) did not change the unit weight of the panel. But the following changes in properties did occur:

(1) The stiffness factor was increased approximately 30%.

(2) The ultimate load sustaining capacity was increased approximately 100%.

(3) The impact resistance was increased approximately 1,000%.

(4) The stiffness factor, expressed as a per cent of that of a beam of aluminum, steel, or teak of equal weight and thickness, was increased approximately 30% in one direction and reduced approximately 30% in the other direction.

ADMINISTRATIVE INFORMATION

Ref: (a) BUSHIPS ltr 4120/5510 ser 634C3-840 of 18 Sep 1962
(b) NAVSHIPYDBREM MAT LABS Final Report P-505-3 of May 1962
(c) NAVSHIPYDBREM MAT LABS Progress Report P-505-1 of Oct 1960
(d) 1961 ASTM Standards, Part 5

Reference (a) authorized this Laboratory to determine the properties of sandwich panels similar to those of Panels 3 and 4 from reference (b).

Reference (c) contained a description of the impact test used to determine the impact resistance of the panels prepared for this investigation.

Reference (d) contained a description of the flexure test used in this investigation.

The Navy Identification Number for this investigation is 35-5510-1. Local Test Number P-565 has been assigned to this investigation.

REPORT OF INVESTIGATION

INTRODUCTION

Reference (a) authorized this Laboratory to determine the rigidity and impact strength of sandwich panels identical, except for the core structure, to Panels 3 and 4 of reference (b). For this phase of the investigation, nominal 6 lbs/ft^3 polyurethane foam was substituted for the nominal 2 lbs/ft^3 polyurethane foam used in Panel 4 of reference (b); and laminated balsa with the grain parallel to the thickness of the panel was substituted for the balsa core with the grain perpendicular to the panel thickness used in Panel 3, reference (b).

Except for the substitutions of core materials, the preparation and testing of the present series of sandwich panels was identical to that of Panels 3 and 4 of reference (b). Thus a comparison of the properties of the present sets of sandwich panels with those previously reported, can be used to determine the effects of the core material substitutions.

SANDWICH PANEL FABRICATION

Two sets of sandwich panels were made. The first set of 3 panels had cores of nominal 6 lbs/ft^3, hand poured, polyurethane foam, contained three pieces of polyurethane foam, 9 inches by 27 inches by 1 inch thick, glued together to form three 27 inch square by one inch thick cores. The adhesive used to cement this foam together was formulated as shown in TABLE I.

TABLE I

FOAM CORE ADHESIVE

Material	Parts by Weight
Polyester Resin 1	100
Accelerator N	1.0
MEK Peroxide	1.0
Powdered Mica	33.3

The second set of panels had balsa wood cores. Each of these three panels was composed of 3 inch square, nominal 10 lbs/ft^3, pieces of balsa wood glued together to form three 27 inch square, one inch thick. In these panels the end grain of the balsa was parallel to the one inch dimension. Adhesive 1 was used to glue the balsa wood together.

The skins of the newest balsa wood and the polyurethane panels were identical to each other and to those of Panels 3 and 4 of reference (b). Thus, the top laminate of all of these panels consisted of Polyester Resin 1, formulated as shown in TABLE II, reinforced with three layers of woven roving (MIL-C-19663, Style 605-604 Volan A Finish) between an outer and inner ply of .010 inch thick asbestos mat. The bottom laminate consisted of the same polyester resin formulation reinforced with only two layers of woven roving and no asbestos mat.

TABLE II

LAMINATING RESIN FORMULATION

Material	Parts by Weight
Polyester Resin 1	100
Accelerator N	0.5
MEK Peroxide	0.5

To fabricate the skins, the roving was first impregnated with resin and allowed to soak for approximately three hours prior to use. Then a wetting coat of resin was applied to the core followed by squeegeeing of each ply of reinforcement. After the skin was in place, "Mylar" film was placed over the liquid laminating resin and a plywood platen was placed on top of the "Mylar" film. Finally, sufficient weight was placed on the plywood to give a load of 0.3 lb/in^2 to insure a smooth and uniform laminated skin.

Core density, panel weight per square foot, and the calculated per cent of glass plus asbestos in the laminate for each of the six sandwich panels are listed in TABLE III.

TABLE III

CORE DENSITY, PANEL WEIGHT PER SQUARE FOOT, AND PER CENT OF REINFORCEMENT IN SKIN

Panel No.	Core	Core Density, Lbs/ft^3	Panel, Weight Lbs/ft^2	Per cent of Glass and Asbestos in Laminate
1	Urethane Foam	6.54	2.64	46.0
2	Urethane Foam	6.54	2.51	49.0
3	Urethane Foam	6.70	2.62	46.7
4	Balsa Wood	10.3	3.02	44.5
5	Balsa Wood	10.3	2.82	49.2
6	Balsa Wood	10.3	2.80	49.7

IMPACT AND FLEXURE TESTS

Samples from each of the six panels were subjected to both impact and flexure tests.

Test specimens for the impact test were 18 inches square. These specimens were subjected to the same falling ram impact test that was

described in reference (c). The method of conducting the impact test was identical to that described in reference (b), except that a heavier ram was used on two of the balsa wood panels. The high impact strength of these latter two panels necessitated the change in rams.

The flexure test specimens were 24 inches long, 3 inches wide and approximately 1.2 inches thick. Two specimens, whose lengths were perpendicular to each other on the original panel, were taken from each of the six sandwich panels.

The flexural properties of these beams were determined in accordance with the procedures given in ASTM Test Method C-393-61T (Flexure Test of Flat Sandwich Constructions) of reference (d) for 1/4 point loading.

The beams were placed on the test jig with the heavier face in compression. Load-deflection readings and ultimate load prior to failure were recorded for each of the twelve beams.

RESULTS

a. Impact Tests

The data recorded for the impact tests on each of the six panels are shown in Tables A-I through A-VI of Appendix A. This same data is shown graphically in Figures 1 through 6. On these graphs, the ratio of rebound energy to impact energy has been plotted against impact energy. For the polyurethane foam core panels (Figures 1 through 3), every recorded point was plotted. For the balsa wood cored panels (Figures 4 through 6), only those point necessary to outline the curves were plotted to prevent overlapping on these figures.

Although the curves in the six figures were not smooth, the general pattern was a curve whose slope approached infinity until an abrupt and significant change in the slope occurred. The point of discontinuity is indicated in each of the six figures and corresponds fairly closely with a point of significant increase in the observed damage to each panel. In practical terms, this point of discontinuity can be defined as the point at which the panel no longer reacted to the blow as a homogeneous unit. Therefore, this point of discontinuity was used to indicate the impact strength of these panels. The impact energy at the point of discontinuity taken from each of the six figures is shown in Column 8 of TABLE IV.

b. Flexure Tests

The data derived from the flexure tests of beams cut at right angles to each other on each of the sandwich panels, is also summarized in TABLE IV. In this Table, Columns 1 and 2 contain, respectively, the identification of the sandwich panel and the core material. Column 3 contains the load range in which the stiffness factors in Columns 4 and 5 were calculated. Columns 6 and 7 contain the highest load recorded prior to failure of each of the beams. As previously stated, Column 8 contains the impact strength for each of the panels. The last column, Column 9, contains the unit weight in lbs/ft^2 of the completed panels.

The stiffness factor, listed in Columns 4 and 5, is a measure of the rigidity of a beam and it is equal to the slope of the load-deflection curve within the load range indicated.

In TABLE IV, values for the stiffness factor and the ultimate load are presented for both the weakest and the strongest direction. It was assumed that the weakest beams would be those whose length was parallel to the 4 strands of the 4 by 5 weave of the woven roving. However, other variations in some panels resulted in strength properties not related to directional properties of the glass reinforcement.

EVALUATION OF RESULTS

a. Polyurethane Foam Core Panels

A comparison of the properties of Panel #4 from reference (b) with those of the averages of the present Panels 1, 2, and 3 indicates that the substitution of 6 lbs/ft^3 foam for 2 lbs/ft^3 foam produced the following changes:

(1) Based on the data in Column 9 of TABLE IV the weight per square foot was increased about 16%.

(2) The stiffness factor in both the weakest and strongest direction was approximately tripled as indicated by the data in Columns 4 and 5.

(3) The ultimate load was increased approximately six times in each direction as indicated by the data in Columns 6 and 7.

(4) The impact resistance was increased approximately ten times. Thus, with only a small increase in overall weight, the strength properties of this group of panels was greatly improved by using 6 lbs/ft^3 foam in place of the 2 lbs/ft^3 foam.

TABLE IV

STIFFNESS FACTORS, ULTIMATE LOADS, IMPACT STRENGTH AND UNIT WEIGHT OF SANDWICH PANELS

Sandwich Panel (1)	Core Material (2)	Load Range For Stiffness Facts or Calculation, Lbs. (3)	Stiffness Factor, Lbs/In Weakest Direction (4)	Stiffness Factor, Lbs/In Strongest Direction (5)	Ultimate Load, Lbs. Weakest Direction (6)	Ultimate Load, Lbs. Strongest Direction (7)	Impact Strength, In-Lbs (8)	Unit Weight of Sandwich Panel, Lbs/ft^2 (9)
1	6Lbs/ft^3 Foam	0-360	1820	1740	826	824	480(a)	2.64
2	" "	0-360	1465	1700	701	814	288	2.51
3	" "	0-360	1790	1840	826	841	320	2.62
Average 1,2,3		0-360	1690	1760	784	826	304	2.59
4(b)	2Lbs/ft^3 Foam	0-60	550	582	126	146	32	2.23
4	Balsa Wood	0-600	3280	3720	2301	1601	2160	3.02
5	" "	0-600	3350	3220	1191	1196	3250	2.82
6	" "	0-600	3530	3470	1670	2191	3250	2.80
Average 4,5,6	" "	0-600	3390	3470	1721	1663	2890	2.88
3(b)	" "	(c)	2600	5140	708	962	320	2.84

NOTE:

(a) This value was not used to calculate the average impact strength for these Panels (1, 2, and 3) because there was a possible point of discontinuity in Figure 1, lower than the one used.

(b) From reference (b).

(c) Load range varied from 0-350-to 9-900 lbs.

A comparison of the stiffness factor of both the 6 lbs/ft^3 and the 2 lbs/ft^3 from cored beams is shown in TABLE V. In this Table, the stiffness factor of both types of foam beams are expressed as a per cent of the stiffness factors of aluminum, steel, and teak beams of equal weight and thickness to those of the foam cured panels assuming the span and method of loading to be identical. The data in this Table indicates that the average stiffness factor for the 6 lbs/ft^3 foam cored beams was approximately 30% of that of the aluminum, steel, and teak as compared to approximately 10% for 2 lbs/ft^3 foam.

b. Balsa Wood Core Panels

For the balsa wood core beams the substitution of a core with the end grain of the wood running parallel to thickness instead of perpendicular to the thickness resulted in the following changes in properties:

(1) As might be expected, the weight per square foot was increased negligibly.

(2) The anistropy of the panel was virtually eliminated resulting in a stiffness factor somewhat higher than that for Panel 3 (reference (b)) in one direction, and somewhat lower than that reported for Panel No. 3 in the other direction.

(3) An ultimate load approximately twice as great.

(4) Impact strength of at least nine times as great.

A comparison between the stiffness of similar beams of aluminum, steel, and teak and that of both the end grain balsa wood cored beams and

of Panel 3, reference (b), is made in TABLE V. The data in this Table shows that beams of end grain balsa had a stiffness factor of approximately 50% of those for aluminum steel and teak compared to approximately 40% for Panel 3, reference (b), in the weakest direction. In the strongest direction, the substitution of end grain balsa reduced the stiffness factor from approximately 80% of that for the aluminum, steel, and teak to approximately 50%.

CONCLUSIONS

The use of 6 lbs/ft^3 urethane foam instead of 2 lbs/ft^3 urethane for the core of a sandwich panel similar to Panel 4 of reference (b) caused the following property changes:

(1) The unit weight of the panel was increased approximately 16%.

(2) The stiffness factor was increased approximately 300%.

(3) The ultimate load sustaining capacity was increased 500-700%.

(4) The impact resistance was increased approximately 1,000%.

(5) The stiffness factor expressed as a per cent of that of a beam of aluminum, steel, or teak of equal weight and thickness, was increased approximately 300%.

The use of end grain balsa (with the grain parallel to the panel thickness) in the core of a sandwich panel similar to Panel 3 of reference (b) did not change the unit weight of the panel. But the following changes in properties did occur:

(1) The stiffness factor was increased approximately 30%.

(2) The ultimate load sustaining capacity was increased approximately 100%.

(3) The impact resistance was increased approximately 1,000%

4. The stiffness factor, expressed as a per cent of that of a beam of aluminum, steel, or teak of equal weight and thickness, was increased approximately 30% in one direction and reduced approximately 30% in the other direction.

TABLE V

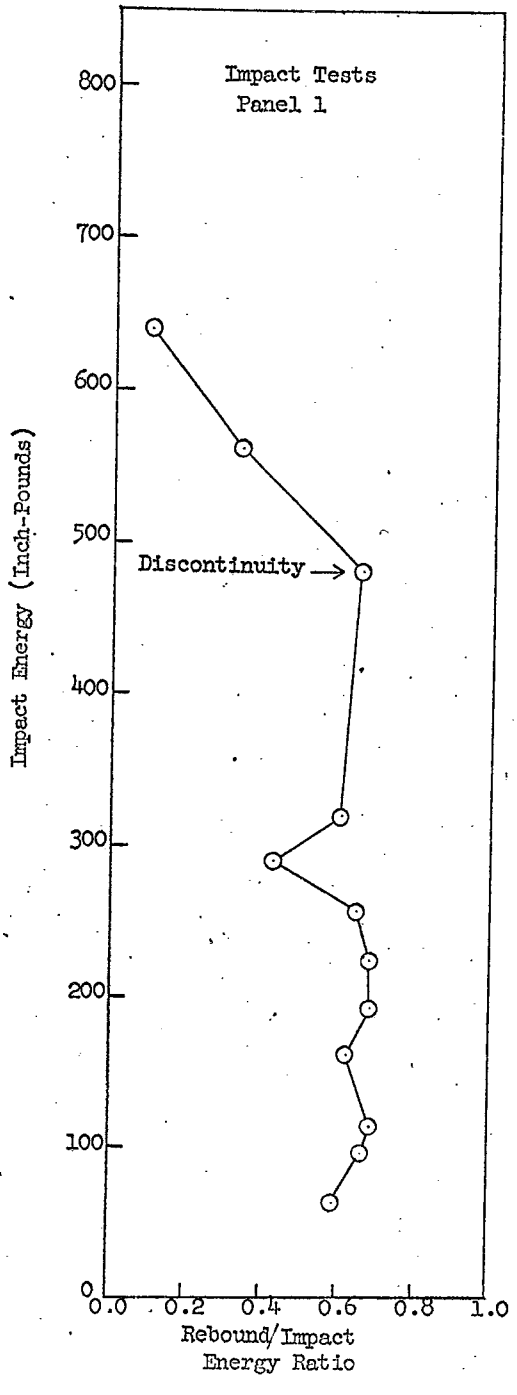
AVERAGE STIFFNESS FACTORS OF SANDWICH PANELS EXPRESSED AS PER CENT OF THE STIFFNESS OF THREE MATERIALS

Sandwich Panel Identification	Core Material	Average Stiffness Factor of Assumed Weakest Beams Divided by the Stiffness Factor of a Comparable Beam of Aluminum, Steel, or Teak			Average Stiffness Factor of Assumed Strongest Beams Divided by the Stiffness Factor of a Comparable Beam of Aluminum, Steel, or Teak		
		Aluminum Beam, %	Steel Beam, %	Teak Beam, %	Aluminum Beam, %	Steel Beam, %	Teak Beam %
Panel #4 (a)	2 lbs/ft^3 Foam	10.2	11.1	11.3(b)	10.8	11.7(b)	12.0(b)
Average of Panels 1, 2, & 3	6 lbs/ft^3 Foam	27.5	30.0	30.6	28.7	31.2	31.9
Panel #3 (a)	Balsa Wood	38.7	42.4	43.0(b)	76.4	83.0(b)	84.8(b)
Average of Panels 4, 5, & 6	Balsa Wood	50.5	54.9	56.1	51.7	56.2	57.4

NOTES:
(a) From reference (b)
(b) These are revised figures.

PSNS MAT LABS P-565

Figure 1



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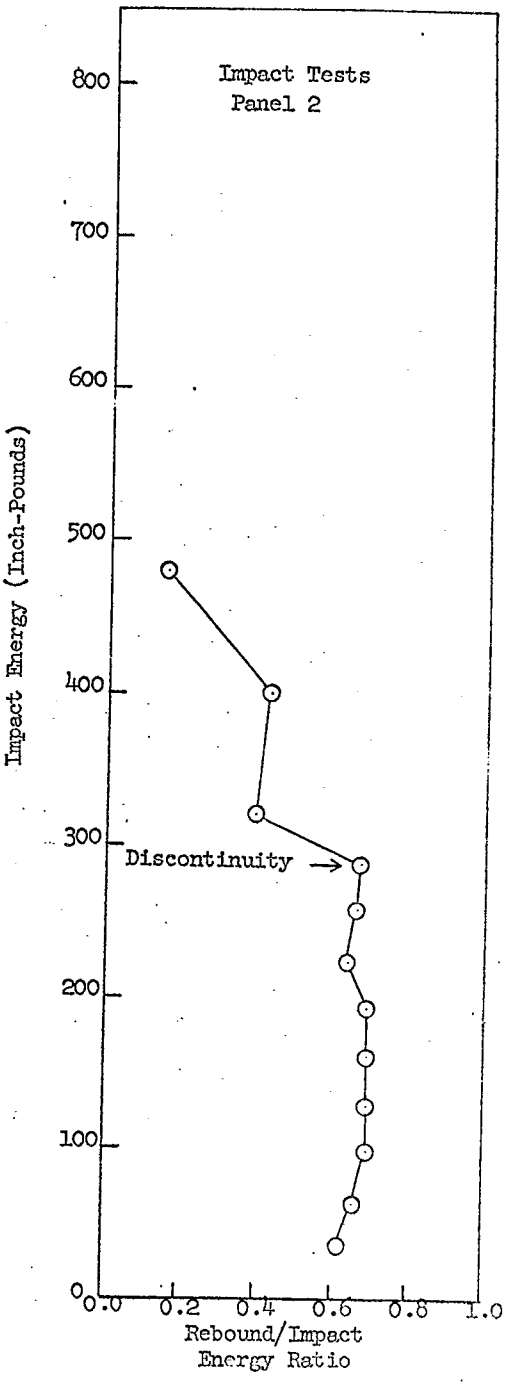


Figure 3

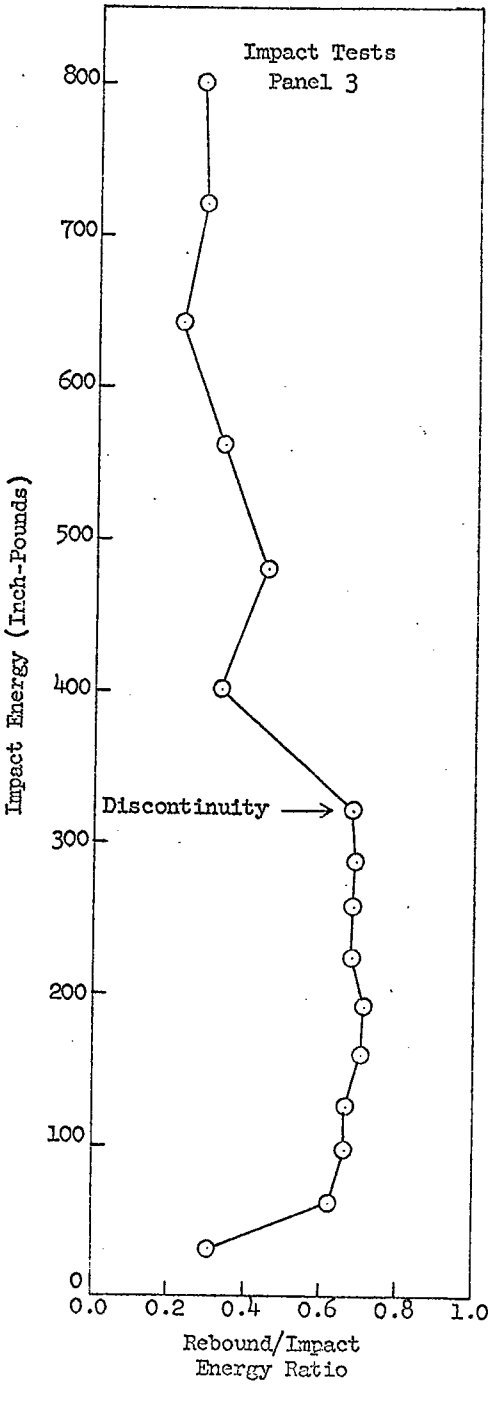

Impact Tests
Panel 3
800
700
600
500
400
300
200
100
0
Impact Energy (Inch-Pounds)
Discontinuity
0.0
0.2
0.4
0.6
0.8
1.0
Rebound/Impact
Energy Ratio

Figure 4

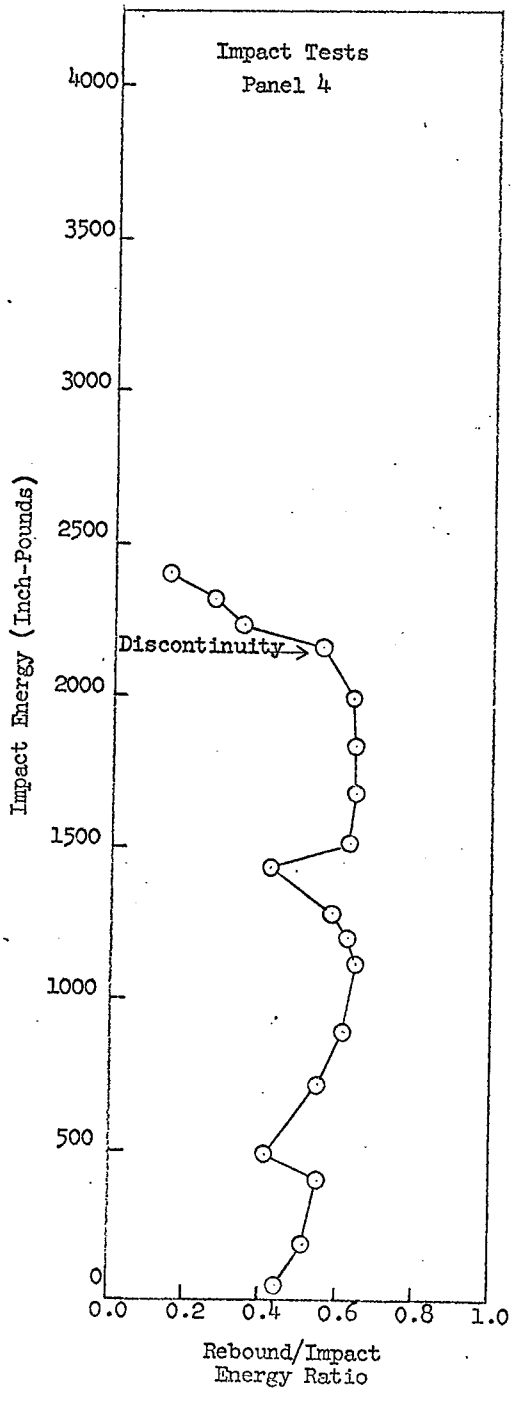


Figure 5

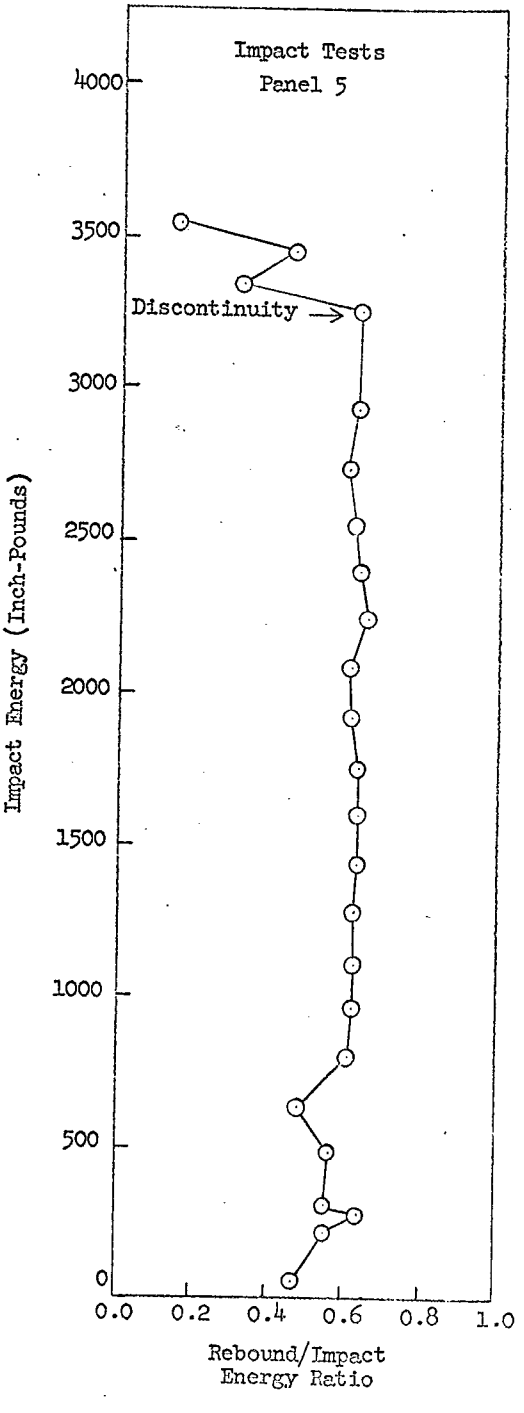
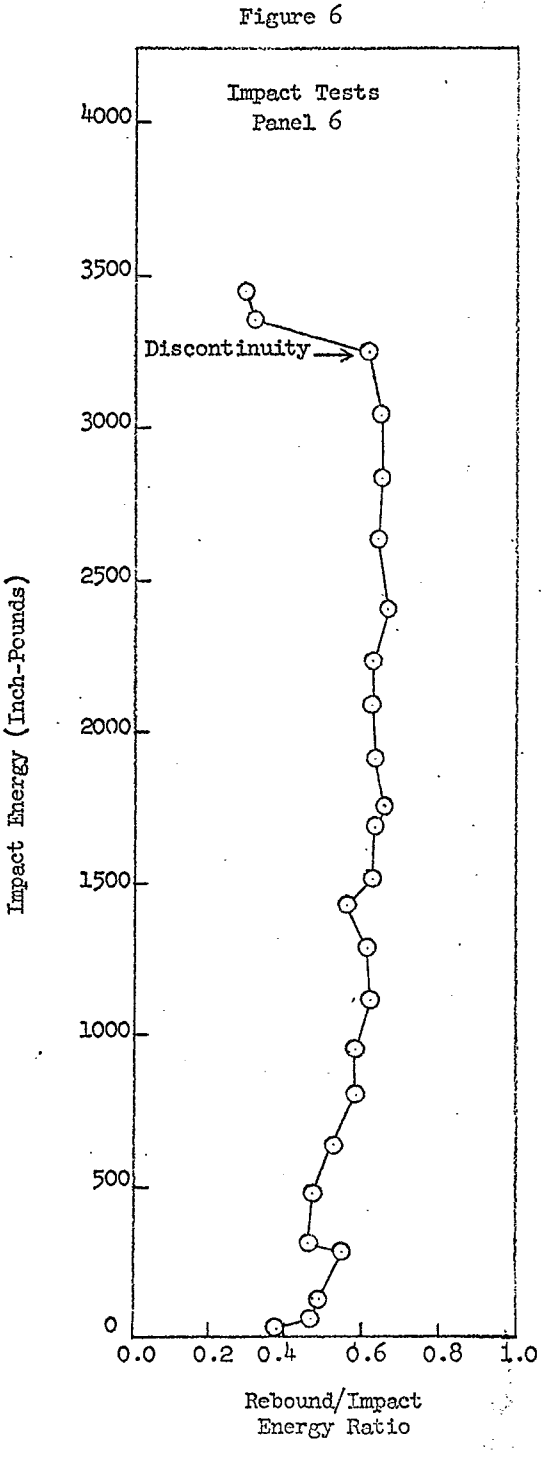


Figure 6


Impact Tests
Panel 6
Discontinuity
Impact Energy (Inch-Pounds)
4000
3500
3000
2500
2000
1500
1000
500
0
0.0
0.2
0.4
0.6
0.8
1.0
Rebound/Impact
Energy Ratio

APPENDIX A
TABLE A-I

Sandwich Panel #1--Polyurethane Foam Core

Impact Test: Ram Drop Height, Impact Energy and Rebound/Impact Energy Ratio

Drop Number	Drop Height, Inches	Impact Energy Inch-Pounds	Rebound/Impact Energy Ratio
1	2	32	- -
2	4	64	0.594
3	6	96	0.657
4	8	128	0.689
5	10	160	0.625
6	12	192	0.688
7	14	224	0.678
8	16	256	0.648
9	18	288	0.430
10	20	320	0.500
11	25	400	- -
12	30	480	0.555
13	35	560	0.336
14	40	640	0.097

REMARKS:

Drop Number:
1. through 11 - No visible damage
12. Upper skin crazed in impact area.
13. Forty-five degree shear in core, partial delamination of lower skin.
14. Partial delamination of upper skin.

APPENDIX A
TABLE A-II

Sandwich Panel #2--Polyurethane Foam Core

Impact Test: Ram Drop Height, Impact Energy and Rebound/Impact Energy Ratio

Drop Number	Drop Height, Inches	Impact Energy Inch-Pounds	Rebound/Impact Energy Ratio
1	2	32	0.562
2	4	64	0.657
3	6	96	0.688
4	8	128	0.688
5	10	160	0.688
6	12	192	0.687
7	14	224	0.642
8	16	256	0.665
9	18	288	0.674
10	20	320	0.387
11	25	400	0.430
12	30	480	0.162

REMARKS:

Drop Number: 1 thru 8--No visible damage
9. Slight crazing in upper facing.
10 and 11--More crazing of plastic facing.
12 Forty-five degree shear in core, partial delamination of upper and lower skins.

APPENDIX A
TABLE A-III

Sandwich Panel #3--Polyurethane Foam Core

Impact Test: Ram Drop Height, Impact Energy and Rebound/Impact Energy Ratio

Drop Number	Drop Height, Inches	Impact Energy Inch-Pounds	Rebound/Impact Energy Ratio
1	2	32	0.313
2	4	64	0.625
3	6	96	0.670
4	8	128	0.672
5	10	160	0.706
6	12	192	0.710
7	14	224	0.678
8	16	256	0.679
9	18	288	0.687
10	20	320	0.676
11	25	400	0.330
12	30	480	0.430
13	35	560	0.335
14	40	640	0.225
15	45	720	0.278
16	50	800	0.275

REMARKS:

Drop Number: 1 thru 12--No visible damage.
13 Forty-five degree shear in core. Bottom skin partially delaminated.
14 More separation of core and bottom facing.
15 Partial separation of upper facing and core.
16 More separation of upper facing and core.

APPENDIX A
TABLE A-IV

Sandwich Panel #4--Balsa Wood Core

Impact Test: Ram Drop Height, Impact Energy, and Rebound/Impact Energy Ratio

Drop Number	Drop Height, Inches	Impact Energy Inch Pounds	Rebound/Impact Energy Ratio
1	2	32	0.407
2	4	64	0.438
3	6	96	0.480
4	8	128	0.493
5	10	160	0.550
6	12	192	0.506
7	14	224	0.506
8	16	256	0.539
9	18	288	0.548
10	20	320	0.563
11	25	400	0.554
12	30	480	0.404
13	35	560	0.425
14	40	640	0.551
15	45	720	0.550
16	50	800	0.581
17	55	880	0.605
18	60	960	- - -
19	65	1040	- - -
20	70	1120	0.618
21	75	1200	0.616
22	80	1280	0.584
23	85	1360	0.635
24	90	1440	0.422
25	95	1520	0.630
26	100	1600	0.630
27	105	1600	0.643
28	110	1760	0.637
29	115	1840	0.637
30	120	1920	0.636
31	125	2000	0.627
32	130	2080	0.608
33	135	2160	0.546
34	140	2240	0.343
35	145	2320	0.261
36	150	2400	0.148

REMARKS: Drop Number-
1 thru 11--No visible damage
12 Separation of both the upper and lower facing in impact area.
13 thru 32--Extension of core-facing delamination towards edges of panel.
33 Core-facing delamination reached edges of panel.
34, 35 Vertical shearing of wood core.

APPENDIX A
TABLE A-V

Sandwich Panel #5 - Balsa Wood Core

Impact Test: Ram Drop Height, Impact Energy and Rebound/Impact Energy Ratio

Drop Number	Drop Height, Inches	Impact Energy Inch-Pounds	Rebound/Impact Energy Ratio
1	2	32	
2	4	64	0.469
3	6	96	0.500
4	8	128	0.531
5	10	160	0.538
6	12	192	0.542
7	14	224	0.554
8	16	256	0.547
9	18	288	0.641
10	20	320	0.550
11	25	400	0.565
12	30	480	0.572
13	35	560	- - -
14	40	640	0.475
15	45	720	0.556
16	50	800	0.605
17	55	880	0.596
18	60	960	0.613
19	65	1040	0.629
20	70	1120	0.622
21	75	1200	0.600
22	80	1280	0.619
23	85	1360	0.630
24	90	1440	0.628
25	95	1520	0.615
26	100	1600	0.626
27	105	1680	0.627
28	110	1760	0.627
29	115	1840	0.606
30	120	1920	0.613
31	125	2000	0.610
32	130	2080	0.612
33	135	2160	0.618
34	140	2240	0.629
35	145	2320	0.636
36	150	2400	0.628
37	150	2400	0.625
38	150	2400	0.627

APPENDIX A
TABLE A-V (Cont'd)

Drop Number	Drop Height, Inches	Impact Energy, Inch-Pounds	Rebound/Impact Energy Ratio
39	150	2400	0.622
40	150	2400	0.648
41	150	2400	0.648
42	150	2400	0.635
43	150	2400	0.635
44	150	2400	0.635
45	150	2400	0.641
46	50	2540	0.606
47	52	2640	- - -
48	54	2740	0.597
49	56	2840	0.597
50	58	2940	0.624
51	60	3040	0.637
52	62	3150	0.631
53	64	3250	0.625
54	66	3350	0.307
55	68	3450	0.450
56	70	3550	0.152

REMARKS:

Drop Number:
1 thru 7--No visible damage.
8 Separation of top and bottom facings from core in impact area.
9 thru 53 Extension of core-facing separation towards edges of panel.
54 Upper facing buckled half way across panel.
55 No further damage.
56 Vertical shear in core and upper face buckled all of the way across panel.

APPENDIX A
TABLE A-VI

Sandwich Panel #6--Balsa Wood Core

Impact Test: Ram Drop Height, Impact Energy and Rebound/Impact Energy Ratio

Drop Number	Drop Height, Inches	Impact Energy Inch-Pounds	Rebound/Impact Energy Ratio
1	2	32	0.375
2	4	64	0.469
3	6	96	0.459
4	8	128	0.485
5	10	160	0.488
6	12	192	0.520
7	14	224	0.491
8	16	256	0.554
9	18	288	0.550
10	20	320	0.463
11	25	400	0.454
12	30	480	0.466
13	35	560	0.490
14	40	640	0.525
15	45	720	0.563
16	50	800	0.579
17	55	880	0.584
18	60	960	0.580
19	65	1040	0.604
20	70	1120	0.617
21	75	1200	0.603
22	80	1280	0.614
23	85	1360	0.587
24	90	1440	0.565
25	95	1520	0.623
26	100	1600	0.645
27	105	1680	0.631
28	110	1760	0.650
29	115	1840	0.639
30	120	1920	0.634
31	125	2000	0.649
32	130	2080	0.620
33	135	2160	0.628
34	140	2240	0.637
35	145	2320	0.654
36	150	2400	0.655

APPENDIX A
TABLE A-VI (Cont'd)

Drop Number	Drop Height Inches	Impact Energy Inch-Pounds	Rebound/Impact Energy Ratio
37	150	2400	0.655
38	150	2400	0.661
39	150	2400	0.661
40	150	2400	0.647
41	150	2400	0.595
42	150	2400	0.670
43	150	2400	0.657
44	150	2400	0.646
45	150	2400	0.665
46	50	2540	- - -
47	52	2640	0.634
48	54	2740	0.654
49	56	2840	0.645
50	58	2940	0.647
51	60	3040	0.639
52	62	3150	0.643
53	64	3250	0.615
54	66	3350	0.307
55	68	3450	0.289

REMARKS:

Drop Number:
1 through 7--No visible damage.
8 Separation of both top and bottom facing from core in impact area.
9 through 53--Extension of core-facing separation towards edges of panel.
54 Upper facing buckled half way across panel.
55 Upper facing buckled all the way across panel, vertical shear in panel core.

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