DEPARTMENT OF MECHANICAL ENGINEERING

Contribution of USC Department of Mechanical Engineering to the Navy CECMT

Technical Report # USC-ME-LAMSS-99-107 of 09/ 30/99
Cooperative Agreement N00140-95-2-J044
Project TDL 95-08, period 6/10/99 – 9/30/99

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SUMMARY

In the period June-September 1999, the Laboratory for Adaptive Materials and Smart Structures (LAMSS) of the Department of Mechanical Engineering, University of South Carolina performed research in support of Department of Chemical Engineering's effort to develop adhesion solutions for the CSI/GLCC space boards project.

The work performed under this contract consisted of mechanical testing of shear lap tension adhesion specimens manufactured from space board material using a variety of adhesive solutions. In this process, (a) a number of adhesion-related ASTM standards were studied and modified to address the specifics of space board material; (b) test fixtures were designed and manufactured; (c) test were conducted in the Mechanical Engineering experimental facilities; (d) data was collected and process; (e) the results were interpreted and discussed with CSI/GLCC representatives. To date, the process is finalized, and no follow up work is envisioned from CSI/GLCC. A detailed Technical Report compiled by Christopher Jenkins follows.

Technical Report

Shear Test of Adhesives on Landfill and OCC Spaceboards

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ABSTRACT

The purpose of this work is to screen various adhesives and identify the best ones to be used on Spaceboard (a product made by an CSI incubator, Conversion Technologies Industries). Spaceboard is made of hot-pressed fibers. The bottom of a Spaceboard panel is flat and it's top is molded during fabrication into elevated square grids. There are two types of Spaceboard. One is made of recycled paper and recycled cardboard (OCC), and the other is made of paper fibers harvested from a landfill. The one made from OCC is mainly comprised of paper fibers, but the one from the landfill contains clay, dirt, metal, and other impurities from the landfill. Spaceboard is an ideal material for packaging because it is strong, biodegradable, cheap, and made of recycled material. The material itself is strong, but experiments have shown that it usually fails at the point where the two panels are glued together. The Spaceboard samples that were being tested are very porous and unglossy. The method chosen to test the adhesive was a shear test, designed to test the strength of the interface between two glued Spaceboard panels. As a result of a number of tests, we have made a table rating the tested adhesive's shear strength and elongation at failure.

1. SHEAR TEST GRID TO GRID

1.1 Items Used

- Twelve screws that are 1 inch long and 1/8 of an inch in diameter
- Twelve nuts that fix the screws
- Two pieces of Spaceboard that are 2 inches wide and 8-1/8 inches long and must be cut as shown below
- Two pieces of steel with an extended piece of 1 inch metal and two without as shown in figure 1 (all of the metal pieces had a thickness of 1/8 of an inch)

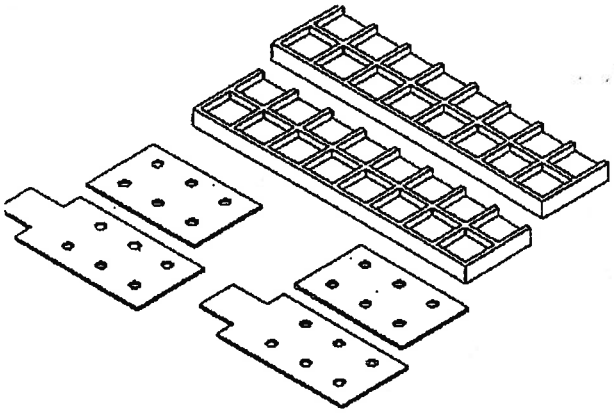

Figure 1

1.2 Sample Preparation

The glue was applied to the two pieces of Spaceboard using a small brush. The shaded areas in figure 2 display where the glue was actually applied. After the glue was applied, the two pieces of Spaceboard were aligned grid to grid as shown in figure 2.

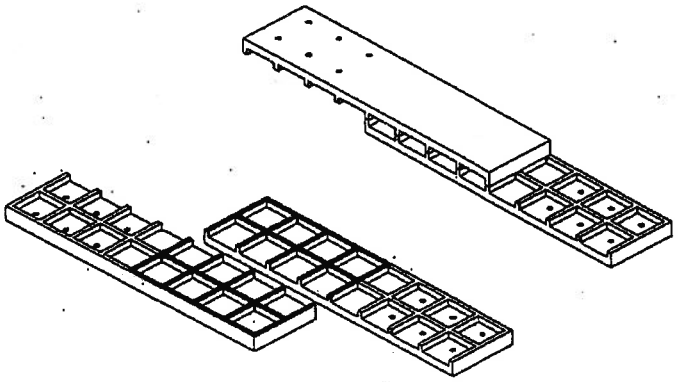

Figure 2

The glued pieces of Spaceboard were placed on a two feet by two feet board of wood. A two-inch by 2 feet piece of Spaceboard was placed on the top of the wooden board to support it and prevent the piece of glued Spaceboard from bending when placed in the vacuumed bag as shown in figure 3.

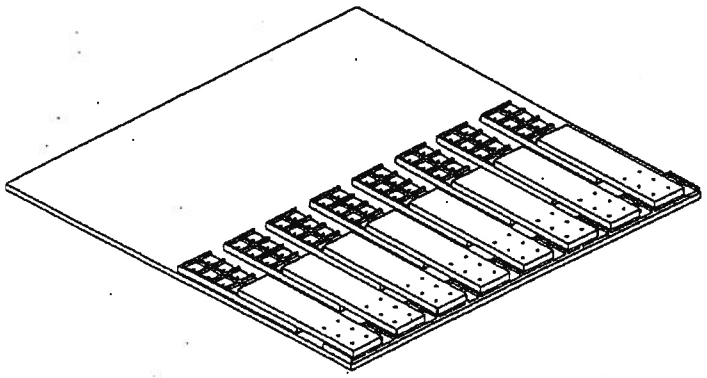

Figure 3

Then the glued Spaceboard and wooden board were placed in a large plastic bag that was attached to a vacuum pump. The wooden board was placed in the bag so the bag would keep its shape and not crush the Spaceboard when the vacuum pump is turned on. The glued pieces of Spaceboard were pressed in the bag for ten minutes then removed and the glue was allowed to cure for two days. (Note: BEFORE the Spaceboard was glued together, the holes for the screws were drilled in the Spaceboard. If the holes are drilled after the Spaceboard is glue together, the drilling will weaken the bond of the glue.)

1.3 Testing

The glued specimens were tested on a Tinius Olsen tensile testing machine. This machine is designed to perform a tensile test. However, because of the way the test specimen was fabricated, the stress state at the glued interface is pure shear and thus the test is a shear test. The metal holder plates were attached to the glued Spaceboard as shown.

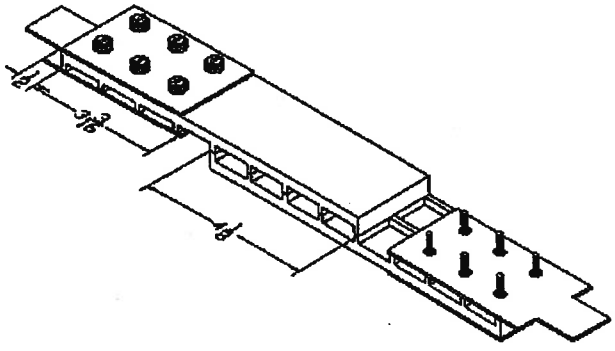

Figure 4

It is important that the metal holder plates are always placed on the side of the Spaceboard with the grid as shown above because if the metal holder plates are not properly aligned, the machine will pull the Spaceboard apart unevenly. The rate at which the machine pulled the glued

Spaceboard apart was .40 inches per minute. During a test, the machine displays the maximum force obtained and the maximum elongation experienced by the Spaceboard. Figure 5 is a schematic of the Spaceboard in the process of being pulled.

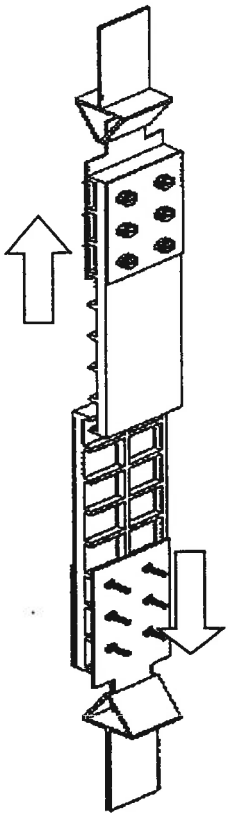

Figure 5

2. SHEAR TEST GRID TO BACK

2.1 Items Used

- Twelve screws that are 1 inch long and 1/8 of an inch in diameter
- Twelve nuts that fix the screws
- Two pieces of Spaceboard that are 2 inches wide and 8-1/8 inches long and must be cut as shown below
- Two pieces of steel with an extended piece of 1 inch metal and two without as shown in figure 6 (all of the metal pieces had a thickness of 1/8 of an inch)

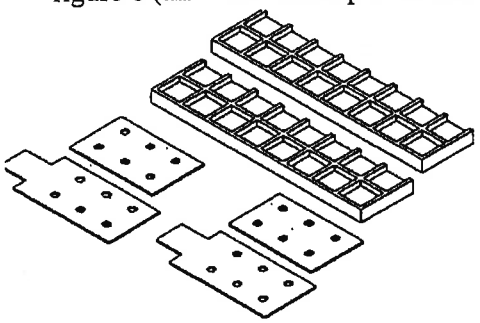

Figure 6

2.2 Sample Preparation

The glue was applied to the two pieces of Spaceboard using a small brush. The shaded areas in figure 7 displays where the glue was actually applied. The glue on the back of the Spaceboard covered an area of 2 in x 4-1/8 in. After the glue was applied, the two sections of Spaceboard were put together grid to back as shown in figure 7.

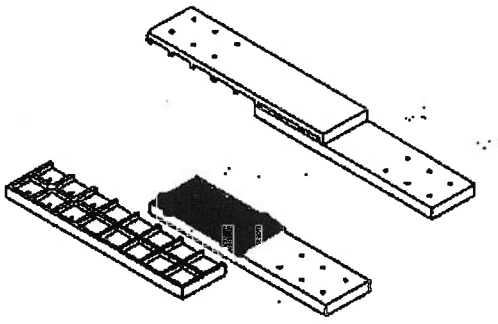

Figure 7

The glued pieces of Spaceboard were placed on a two feet by two feet board of wood. A two-inch by 2 feet piece of Spaceboard was placed on the top of the wooden board to support it and prevent the piece of glued Spaceboard from bending when placed in the vacuumed bag as shown in figure 8.

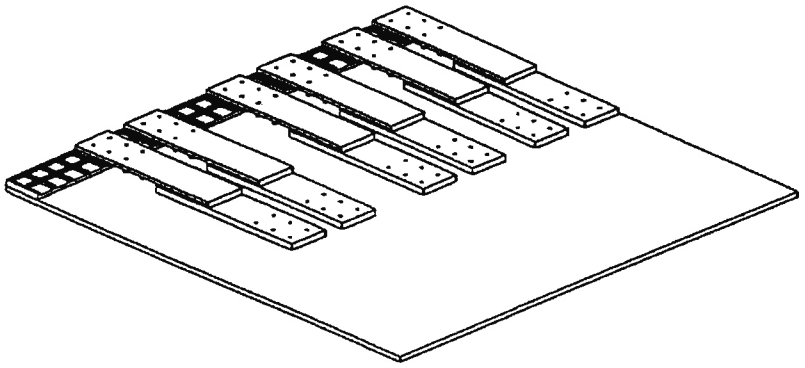

Figure 8

Then the glued Spaceboard and wooden board were placed in a large plastic bag that was attached to a vacuum pump. The wooden board was placed in the bag so the bag would keep its shape and not crush the Spaceboard when the vacuum pump is turned on. The glued pieces of Spaceboard were pressed in the bag for ten minutes then removed and the glue was allowed to cure for two days. (Note: BEFORE the Spaceboard was glued together, the holes for the screws were drilled in the Spaceboard. If the holes are drilled after the Spaceboard is glue together, the drilling will weaken the bond of the glue.)

2.3 Testing

The glued Spaceboard was tested on a Tinius Olsen tensile testing machine (the same machine used in Section 1.3). The metal plates were attached to the glued Spaceboard as shown. (**Note:** the metal holder plates and Spaceboard are not in the same position as in Section 1.3)

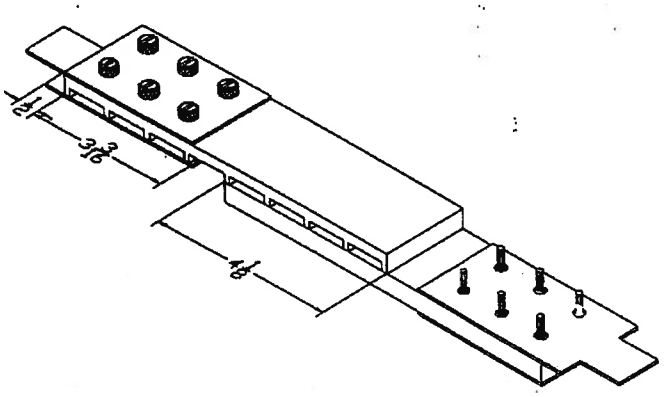

Figure 9

It is important that the metal holder plates are always placed on the side of the Spaceboard were the bond is and so it is parallel to the bond as shown above because if the metal holder plates are

not properly aligned, the machine will pull the Spaceboard apart unevenly. The rate at which the machine pulled the glued Spaceboard apart was .40 inches per minute. During a test, the machine displays the maximum force obtained and the maximum elongation experienced by the Spaceboard. Figure 10 is the Spaceboard in the process of being pulled apart. (**Note:** the Spaceboard is not in the same position as in Section 1.3)

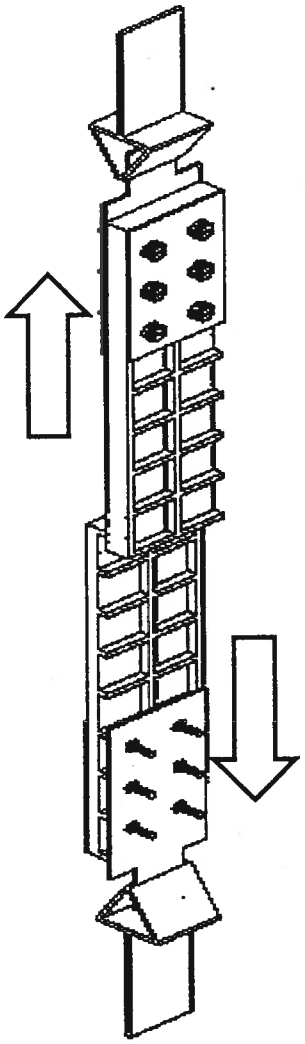

Figure 10

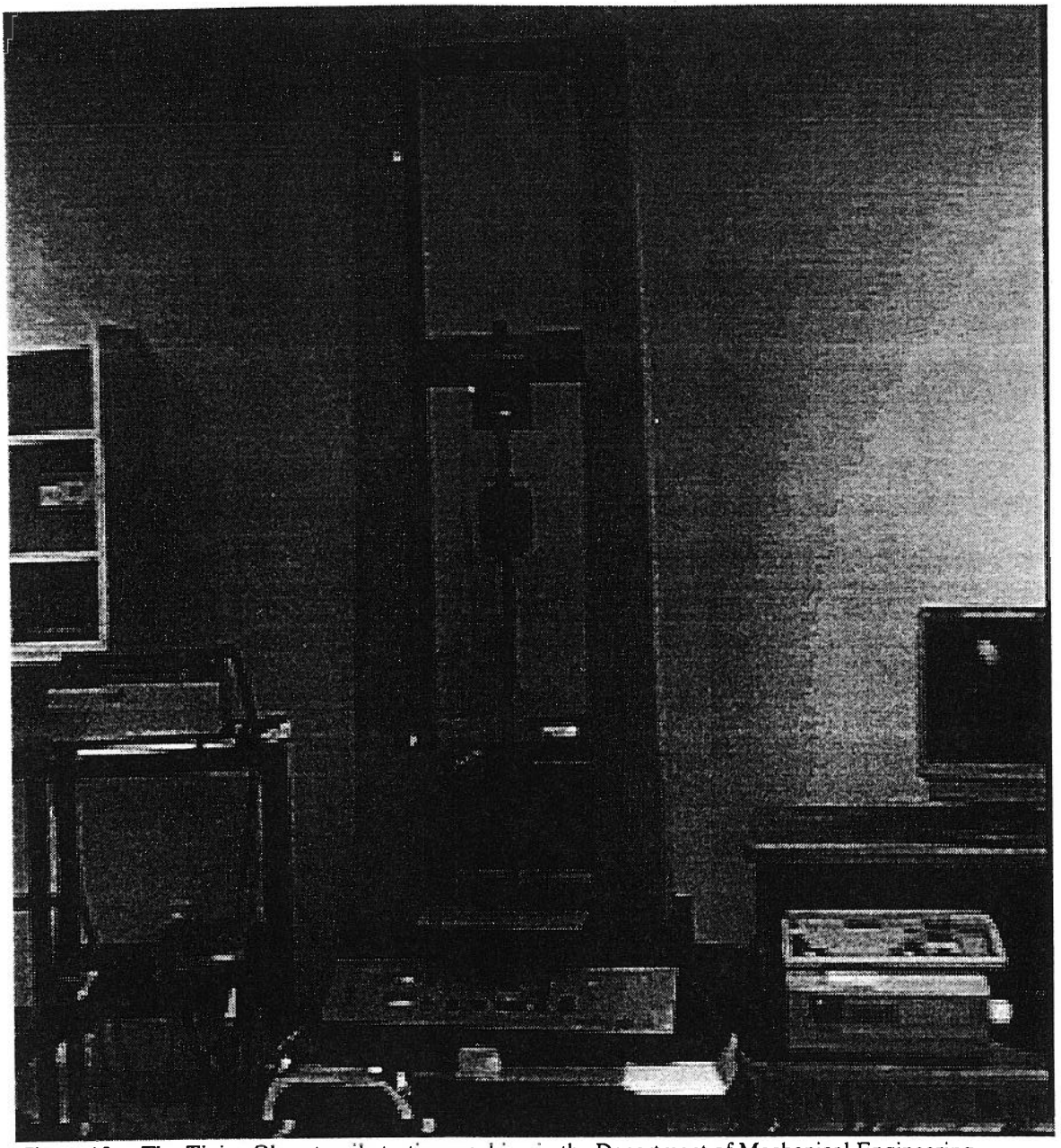

Figure 10a –The Tinius Olsen tensile testing machine in the Department of Mechanical Engineering Testing Laboratory

3. RESULTS AND COMPARISONS

The results of these tests are summarized on Tables 1-4 on the following pages. The tables has ten columns with the following titles:

1) *Name of Adhesives* – shows the name of the adhesives that were tested
2) *Name of Company* – shows the name of the company that makes the adhesive
3) *Base*- shows the base of the adhesive
4) *Viscosity* – shows the measure of the resistance of a fluid to flow usually expressed in poise (or centipoise). A higher reading indicates more viscous material.
5) *Area of Bond (in^2)* – shows the area (in squared inches) of the bond between the two pieces of Spaceboard
6) *Max. Force Applied (lbs.)* – shows the highest amount of force (measured in pounds) on the bond
7) *Shear Strength of Adhesive (lbs. /in^2)* – shows the *Max. Force Applied* divided by the *Area of Bond*
8) *Elongation at Max. Force (in)* – shows the measured elongation of the specimen at the instant the *Max. Force was Applied*
9) *Elongation at zero force* – shows the measured elongation of the specimen when the bond between the two pieces of Spaceboard was completely broken
10) *Observations* – qualitative observations on how the bond broke.

Table 5 shows the comparisons of the four tests. The table has 7 columns with the following titles:

1) *Name of Adhesives* – shows the name of the adhesives that were tested
2) *Max. Force Applied for Landfill Spaceboard* – shows the highest amount of force (measured in pounds) on the Landfill Spaceboard bonds for grid to grid and grid to back
3) *Change in Max. Force from Landfill GG to Landfill GB* – shows how much the max. force changed from the Landfill Grid to Grid to the Landfill Grid to Back
4) *Max. Force Applied for OCC Spaceboard* – shows the highest amount of force (measured in pounds) on the OCC Spaceboard bonds for grid to grid and grid to back
5) *Change in Max. Force from OCC GG to OCC GB* – shows how much the max force changed from the OCC Grid to Grid to the OCC Grid to Back
6) *Change in Max. Force from Landfill GG to OCC GG* – shows how much the max force changed from the Landfill Grid to Grid to the OCC Grid to Grid
7) *Change in Max. Force from Landfill GB to OCC GB* – shows how much the max force changed from the Landfill Grid to Back to the OCC Grid to Back

Table 1: Results of Shear Test of Adhesives on Landfill Spaceboard Grid to Grid (GG)

Name of Adhesive	Name of company	Base	Viscosity	Area of Bond (in^2)	Max. Force Applied (lbs.)	Shear Strength of Adhesive (lbs/in^2)	Elongation at Max. Force (in)	Elongation at zero force (in)	Observations
4224-NF Pressure Sensitive Adhesive	3M	Water-Based; Acrylate	9000-12000 cps	2.125	57	26.82	0.20	2.10	glue stretched and the top part of the grid tore
003	Chembond Adhesives, Inc	w ater-based	1500 cps	2.125	66	31.06	0.22	0.82	only the top part of the grid tore
BestBond	Abatron, Inc	?	100-400 cps	2.125	67	31.53	0.17	0.54	only the top part of the grid tore
Water Based Contact Cement	CP Adhesives, Inc	w ater-based, compounded Neoprene	2250 cps	2.125	71	33.41	0.20	3.01	glue stretched and only the top part of the grid tore
4268-NF Industrial Adhesive	3M	Water-Based	2500 cps	2.125	75	35.29	0.16	0.92	only the top part of the grid tore
HPL700	Chembond Adhesives, Inc	w ater-based	3500 cps	2.125	78	36.71	0.18	1.34	top part of grid and the sides of the grid tore
Wisdom	Wisdom	?	low	2.125	82	38.59	0.24	1.98	glue stretched and only the top part of the grid tore
4213-NF Industrial Adhesive	3M	w ater dispersed; Synthetic Resin	2000 cps	2.125	88	41.41	0.20	1.70	glue stretched and only the top part of the grid tore
S3855	AFCO	?	1200-1400 cps	2.125	88	41.41	0.20	1.06	only the top part of the grid tore
CB1465 White	Chembond Adhesives, Inc	w ater-based	1000-3000 cps	2.125	96	45.18	0.22	1.26	glue stretched and only the top part of the grid tore
S3920P	AFCO	?	350-400 cps	2.125	96	45.18	0.20	1.30	only the top part of the grid tore
Elmer's Glue-All	Elmer's	polyvinyl acrylate, w ater-soluble	high	2.125	98	46.12	0.20	0.70	only the top part of the grid tore
30-NF Neutral Contact Adhesive	3M	w ater dispersed; Polychloroprene	200-600 cps	2.125	101	47.53	0.22	3.48	glue stretched and only the top part of the grid tore
Carpenter's Wood Glue	Elmer's	?	high	2.125	108	50.82	0.24	0.76	top part of grid tore but mostly grid sides tore; 6 square grids stayed together
CA122	Chembond Adhesives, Inc	w ater-based	7500 cps	2.125	111	52.24	0.26	1.12	sides of the grid tore but mostly the top part of the grid tore
MPA White	CP Adhesives, Inc	w ater-based	6000 cps	2.125	113	53.18	0.22	3.04	only tw o grid squares tore completely; the other grid squares tore a little

Table 2: Results of Shear Test of Adhesives on Landfill Spaceboard Grid to Back (GB)

Name of Adhesive	Name of company	Base	Viscosity	Area of Bond (in^2)	Max. Force Applied (lbs.)	Shear Strength of Adhesive (lbs/in^2)	Elongation at Max. Force (in)	Elongation at zero force (in)	Observations
Wisdom	Wisdom	?	low	2.125	78	36.71	0.12	0.48	top of grid tore
4224-NF Pressure Sensitive Adhesive	3M	Water-Based; Acrylate	9000-12000 cps	2.125	85	40.00	0.12	0.76	top of grid tore
4268-NF Industrial Adhesive	3M	Water-Based	2500 cps	2.125	86	40.47	0.18	0.34	top of grid tore
Water Based Contact Cement	CP Adhesives, Inc	water-based, compounded Neoprene	2250 cps	2.125	86	40.47	0.12	2.42	glue stretched; top and sides of the grid tore
BestBond	Abatron, Inc	?	100-400 cps	2.125	90	42.35	0.16	1.4	top of grid tore
CB1465 White	Chembond Adhesives, Inc	water-based	1000-3000 cps	2.125	98	46.12	0.18	1.14	top of grid tore and the grid bent
30-NF Neutral Contact Adhesive	3M	water dispersed; Polychloroprene	200-600 cps	2.125	100	47.06	0.14	1.3	top of grid tore and the grid bent
S3920P	AFCO	?	350-400 cps	2.125	106	49.88	0.12	0.50	top of grid tore
S3855	AFCO	?	1200-1400 cps	2.125	107	50.35	0.14	0.56	top and sides of the grid tore
HPL700	Chembond Adhesives, Inc	water-based	3500 cps	2.125	108	50.82	0.14	0.92	top and sides of the grid tore
4213-NF Industrial Adhesive	3M	water dispersed; Synthetic Resin	2000 cps	2.125	111	52.24	0.14	1.08	top of grid tore and the grid bent
CA122	Chembond Adhesives, Inc	water-based	7500 cps	2.125	111	52.24	0.16	0.44	top and sides of the grid tore
Carpenter's Wood Glue	Elmer's	?	high	2.125	118	55.53	0.18	0.5	top and sides of the grid tore; grid bent
003	Chembond Adhesives, Inc	water-based	1500 cps	2.125	120	56.47	0.18	0.66	top of grid tore
Elmer's Glue-All	Elmer's	polyvinyl acrylate, water-soluble	high	2.125	131	61.65	0.14	0.56	top of grid tore and the grid bent
MPA White	CP Adhesives, Inc	water-based	6000 cps	2.125	132	62.12	0.18	0.44	top and sides of the grid tore; grid bent

Table 3: Results of Shear Test of Adhesives on OCC Spaceboard Grid to Grid (GG)

Name of Adhesive	Name of company	Base	Viscosity	Area of Bond (in^2)	Max. Force Applied (lbs.)	Shear Strength of Adhesive (lbs/in^2)	Elongation at Max. Force (in)	Elongation at zero force (in)	Observations
Water Based Contact Cement	CP Adhesives, Inc	water-based, compounded Neoprene	2250 cps	2.125	47	22.12	0.24	2.24	top of grid tore only; glue stretched
MPA White	CP Adhesives, Inc	water-based	6000 cps	2.125	60	28.24	0.24	1.34	top and side of grid tore
4213-NF Industrial Adhesive	3M	water dispersed; Synthetic Resin	2000 cps	2.125	65	30.59	0.20	1.38	top of grid tore only; glue stretched
Wisdom	Wisdom	?	low	2.125	66	31.06	0.18	1.55	top of grid tore only
S3855	AFCO	?	1200-1400 cps	2.125	67	31.53	0.22	1.00	top and side of grid tore
003	Chembond Adhesives, Inc	water-based	1500 cps	2.125	68	32.00	0.20	1.40	top of grid tore only; glue stretched
HPL700	Chembond Adhesives, Inc	water-based	3500 cps	2.125	68	32.00	0.20	1.60	top of grid tore only
BestBond	Abatron, Inc	?	100-400 cps	2.125	69	32.47	0.20	0.98	top of grid tore only
4268-NF Industrial Adhesive	3M	Water-Based	2500 cps	2.125	71	33.41	0.22	1.52	top of grid tore only
CB1465 White	Chembond Adhesives, Inc	water-based	1000-3000 cps	2.125	73	34.35	0.20	0.78	top of grid tore only
S3920P	AFCO	?	350-400 cps	2.125	73	34.35	0.20	1.30	top of grid tore only
Elmer's Glue-All	Elmer's	polyvinyl acrylate, water-soluble	high	2.125	74	34.82	0.14	1.12	top of grid tore only
4224-NF Pressure Sensitive Adhesive	3M	Water-Based; Acrylate	9000-12000 cps	2.125	76	35.76	0.22	3.00	top of grid tore only; glue stretched
Carpenter's Wood Glue	Elmer's	?	high	2.125	81	38.12	0.22	0.62	top of grid tore only
CA122	Chembond Adhesives, Inc	water-based	7500 cps	2.125	81	38.12	0.22	3.00	top of grid tore only
30-NF Neutral Contact Adhesive	3M	water dispersed; Polychloroprene	200-600 cps	2.125	84	39.53	0.24	2.26	top of grid tore only

Table 4: Results of Shear Test of Adhesives on OCC Spaceboard Grid to Back (GB)

Name of Adhesive	Name of company	Base	Viscosity	Area of Bond (in^2)	Max. Force Applied (lbs.)	Shear Strength of Adhesive (lbs/in^2)	Elongation at Max. Force (in)	Elongation at zero force (in)	Observations
Wisdom	Wisdom	?	low	2.125	63	29.65	0.08	0.62	top of grid tore only
003	Chembond Adhesives, Inc	water-based	1500 cps	2.125	75	35.29	0.12	0.68	top of grid tore only
4213-NF Industrial Adhesive	3M	water dispersed; Synthetic Resin	2000 cps	2.125	82	38.59	0.16	1.32	top of grid tore only
4268-NF Industrial Adhesive	3M	Water-Based	2500 cps	2.125	83	39.06	0.16	0.70	top of grid tore only; glue stretched
4224-NF Pressure Sensitive Adhesive	3M	Water-Based; Acrylate	9000-12000 cps	2.125	89	41.88	0.14	3.96	top of grid tore only; glue stretched
BestBond	Abatron, Inc	?	100-400 cps	2.125	94	44.24	0.14	3.16	top of grid tore only; glue stretched
S3855	AFCO	?	1200-1400 cps	2.125	94	44.24	0.12	0.60	top of grid tore only
30-NF Neutral Contact Adhesive	3M	water dispersed; Polychloroprene	200-600 cps	2.125	104	48.94	0.16	1.66	top of grid tore only
Water Based Contact Cement	CP Adhesives, Inc	water-based, compounded Neoprene	2250 cps	2.125	105	49.41	0.16	1.40	top of grid and three sides of the grid tore
CB1465 White	Chembond Adhesives, Inc	water-based	1000-3000 cps	2.125	107	50.35	0.14	1.72	top of grid tore only
S3920P	AFCO	?	350-400 cps	2.125	116	54.59	0.16	1.14	top of grid tore only
CA122	Chembond Adhesives, Inc	water-based	7500 cps	2.125	122	57.41	0.18	0.50	top of grid tore only
Elmer's Glue-All	Elmer's	polyvinyl acrylate, water-soluble	high	2.125	125	58.82	0.20	1.08	top of grid tore only
HPL700	Chembond Adhesives, Inc	water-based	3500 cps	2.125	145	68.24	0.20	1.14	top of grid tore only
Carpenter's Wood Glue	Elmer's	?	high	2.125	146	68.71	0.18	0.86	top of grid tore only
MPA White	CP Adhesives, Inc	water-based	6000 cps	2.125	151	71.06	0.18	1.02	top of grid tore only

Table 5: Comparisons of Results

Name of Adhesive	Max. Force Applied for Landfill Spaceboard		Change in Max. Force from Landfill GG to Landfill GB	Max. Force Applied for OOC Spaceboard		Change in Max. Force from OOC GG to OOC GB	Change in Max. Force from Landfill GG to OOC GG	Change in Max. Force from Landfill GB to OOC GB
	GG	GB		GG	GB			
003	66	120	54	68	75	7	2	-45
30-NF Neutral Contact Adhesive	101	100	-1	84	104	20	-17	4
4213-NF Industrial Adhesive	88	111	23	65	82	17	-23	-29
4224-NF Pressure Sensitive Adhesive	57	85	28	76	89	13	19	4
4268-NF Industrial Adhesive	75	86	11	71	83	12	-4	-3
BestBond	67	90	23	69	94	25	2	4
CA122	111	111	0	81	122	41	-30	11
Carpenter's Wood Glue	108	118	10	81	146	65	-27	28
CB1465 White	96	98	2	73	107	34	-23	9
Elmer's Glue-All	98	131	33	74	125	51	-24	-6
HPL700	78	108	30	68	145	77	-10	37
MPA White	113	132	19	60	151	91	-53	19
S3855	88	107	19	67	94	27	-21	-13
S3920P	96	106	10	73	116	43	-23	10
Water Based Contact Cement	71	86	15	47	105	58	-24	19
Wisdom	82	78	-4	66	63	-3	-16	-15

NOTE: GG is short for Grid to Grid and GB is short for Grid to Back. A negative number means that the Max. Force decreased from one test to the other and a positive number means that the Max. Force increased from one test to the other test.

4. HOW THE SPACEBOARD TORE

For both types of Spaceboard, the Spaceboard tore on the top of the grid or the bottom of the grid. This may suggest that the middle of the grid is the strongest part of the grid. For the most part, the only thing that tore on the OCC Spaceboard was the top of the grid as shown in figure 11. The landfill Spaceboard was completely different. When the landfill Spaceboard tore, the some of the sides of the grid tore or all of the sides tore from the bottom as shown in figure 12.

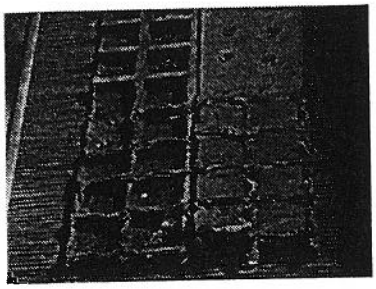

Figure 11

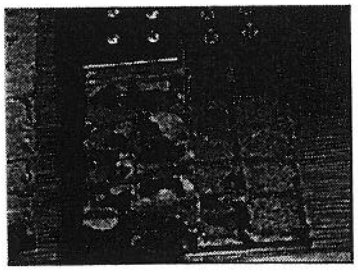

Figure 12

The reason for the OCC Spaceboard tearing the way that it tears maybe because the top part of the grid is the weakest part of the grid. The landfill Spaceboard probably bonds better at the top because of the impurities in the Spaceboard. Figure 13 shows the landfill Spaceboard coming apart; notice how the top part of the grid remains bonded to the back of the Spaceboard.

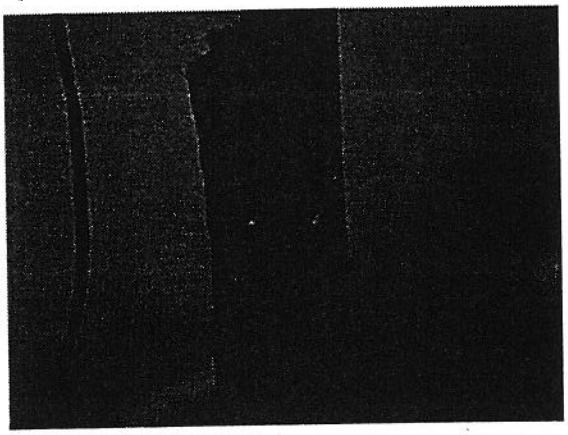

Figure 13

Many of the landfill Spaceboard came apart in a similar way. Since some of the Spaceboard tore as shown in figure 13, the machine was not measuring the strength of the adhesive, it is measuring the inconsistent strengths of the landfill Spaceboard.

5. FAILED TESTING METHODS

A major problem that was associated with testing the shear strength of the Spaceboard was the size of the cross section. The cross section is the area were the two Spaceboard panels are joined together. The first test that was preformed was gluing two OCC Spaceboard panels back to back using Elmer's Glue-All. With a cross section of 2-in by 2-in, the cardboard tore at 553 lbs., but the bond of the glue didn't. This caused a problem because the machine was only testing the strength of the Spaceboard and not the bond. The cross section had to be reduced so that the bond would break before the Spaceboard. The cross section was calculated down to 6.36-mm by 2-in. The problem with this is it is difficult to make the glue have a width as small as 6.36-mm on both OCC Spaceboard panels and align the Spaceboard panels perfectly. One method that was used was gluing the Spaceboard panels together with a cross section of 2-in by 2-in and reducing the cross section with a band saw. The cuts were made perpendicular to the bond, not parallel. Since the cuts were made perpendicular to the bond, the saw had to go through the Spaceboard. Then samples were tested in the pulling machine and the following results were obtained:

Adhesive	Force (lbs)	Elongation (in)	Comments
Water Cement	114.2	0.3	glue Stretched with the cardboard and cardboard tore
MPA	205	0.12	cardboard tore where the glue was
OO3	285	0.22	cardboard tore where the glue was
30 NF	40	0.3	Inconclusive: sawed to deep with saw
Best Bond	76	0.12	error: sample was weaken before test
4268	297	0.32	cardboard tore where the glue was
Wisdom	153	0.22	cardboard tore where the glue was
CB-1465	193	0.18	cardboard tore where the glue was
Elmer's Carpenter's Glue	276	0.18	cardboard tore where the glue was
Elmer's Glue	417	0.26	cardboard tore where the glue was
HPL	none	none	none
4224	97	0.33	glue Stretched with the cardboard and cardboard didn't tear
CA-122	302	0.18	cardboard tore where the glue was
4213	298	0.18	cardboard tore where the glue was

Note: ONLY OCC SPACEBOARD WAS USED. The cardboard is 2' X 8' and the cross section was reduced from 2' X 2' to 2' X 1/4' using a band saw. This entire test has error in it because the test was used for estimation and not for accuracy.

This test had a lot of error in it because sometimes the saw would cut pass the bond or it would not cut the bond at all. If it cut pass the bond, the results from the pulling machine would be less than it actually is. If it did not cut the bond at all, the results from the pulling machine would be more than it actually is. This test idea was abandoned.

Another test that was done was mixing sawdust in the Elmer's Carpenter's Glue. The test was done grid to back using an OCC specimen with and without the sawdust, and a landfill specimen with and without the sawdust. The

specimens had the same dimensions as in the grid to back the in Section 2. The maximum force of the OCC specimen with the sawdust was 94 lbs. and the maximum force of the OCC specimen without the sawdust was 128 lbs. The sawdust didn't increase the performance of the adhesive. The maximum force of the landfill specimen with the sawdust was 138 lbs. and the maximum force of the landfill specimen without the sawdust was 130 lbs. The landfill specimen with the sawdust was higher than the landfill specimen without the sawdust, but the test was inconclusive because of the way the landfill Spaceboard tore. Both of the landfill specimens tore at the bottom of the grid as shown in figure 13 on page 14. The bonds on both of the specimens were not broken, therefore the machine only measured the strength of the Spaceboard and not the strength of the bond.

6. CONCLUSIONS AND RECOMMENDATIONS

Although MPA White was best in all but the OCC GG test (see Table 3), it can be concluded that MPA White is the best adhesive to use on Spaceboard. MPA White is also better than Elmer's Carpenter's Wood Glue (the glue that CSI is currently using). The reason why the shear strength of MPA White was so low on the OCC grid to grid test was because the grid sides on the Spaceboard were weak. As the Spaceboards were being pulled apart, the grid sides tore before the max. force could be obtained. Because the Spaceboards used for the MPA White were weak, a false max. force was obtained.

When the results for the grid to grid test and grid to back tests are compared for the same Spaceboard, it can be noted that the ranking of the various adhesives is not the same. This is probably because the texture and composition on the back of the Spaceboard is different from that of the Spaceboard grid surfaces.

It is expected that the measured shear strength of the adhesive should be higher in the grid to back than in the grid to grid configuration, all of the adhesives did this except for four in the landfill Spaceboard test and one in the OCC Spaceboard test. There are several reasons for this: the way that the glue was applied, the temperature of the room (most glue cure faster at a certain temperature), and the inconsistencies in the strength of the Spaceboards.

When the max. forces of the landfill Spaceboard grid to grid test was compared with the max. forces of the OCC Spaceboard, 13 of the measured max. forces decreased from landfill Spaceboard to OCC Spaceboard (see Table 5). In the corresponding grid to back tests, six of the adhesive's max. forces decreased from landfill Spaceboard to OCC Spaceboard. Theses results show that certain adhesives are stronger and work better on the landfill Spaceboard than the OCC Spaceboard. There are two possible reasons for this: some adhesives might bond better to impurities than paper and some adhesives might absorb better in landfill Spaceboard than in OCC Spaceboard.

An important issue was bought up in section 4 (See second and third paragraph in the section named How the Spaceboard Tore). Through these observations, the accuracy of the results from the tests must be questioned. It is possible that a false measurement of the adhesives true strength may have been obtained, and that only the strength of the cardboard was tested, not the strength of the adhesive.

Although the MPA White adhesive is the best adhesive, Elmer's Carpenter's Wood Glue should also be considered. On the landfill Spaceboard grid to grid test, Elmer's Wood Glue failed 5-lbs before the highest; on the landfill Spaceboard grid to back it failed 14-lbs before the highest; on the OCC Spaceboard grid to grid it failed 3-lbs before the highest; and on the OCC landfill Spaceboard grid to back it failed 5-lbs before the highest. Elmer's Carpenter's Wood Glue is also easier to clean up because it is non-toxic and has no hazardous chemicals,

unlike MPA White that has kaolin in it. Elmer's Carpenter's Wood Glue is also recommended because it is cheaper than MPA White.

It is also recommended that more tests be done on the Spaceboard because of the inconsistencies in the properties of the Spaceboard. The test that is recommended is pick the top 5 adhesives and do each one of the tests three times. For example, do three tests with the OCC Spaceboard glued grid to grid with MPA White adhesive then take the average of the three max. forces to obtain the final max. force.

7. ACKNOWLEDGEMENTS

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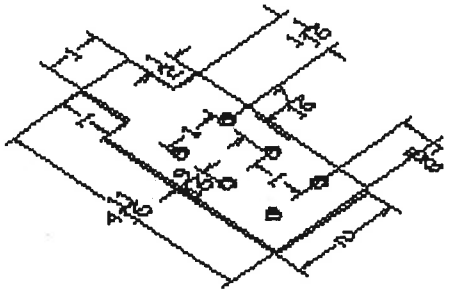
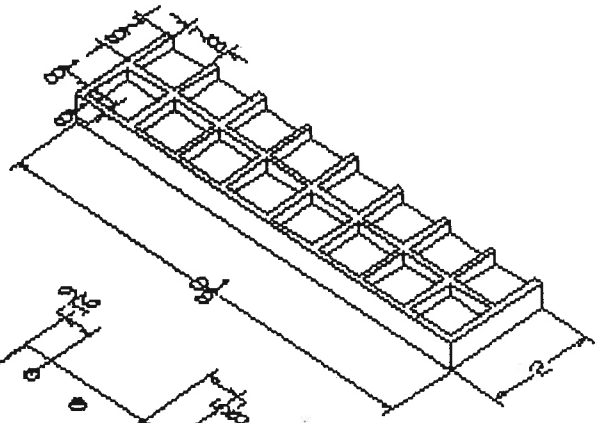
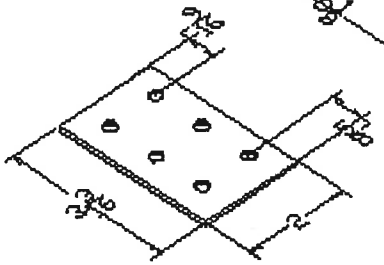
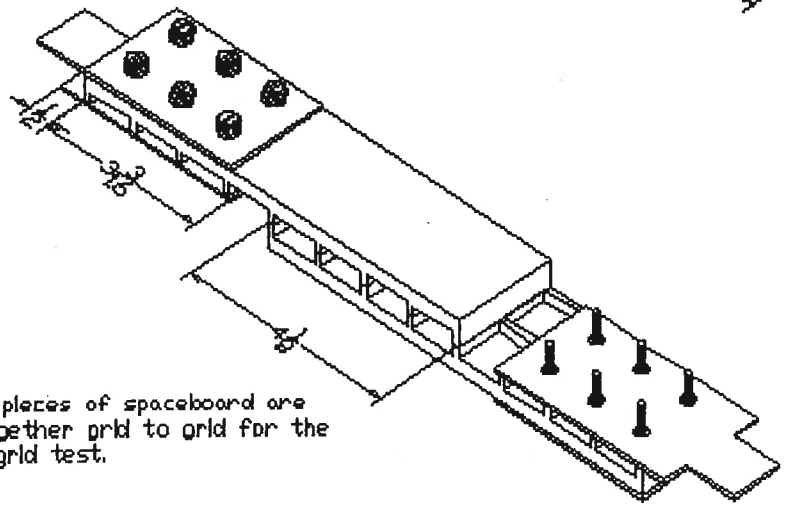
5) Dan Wilhelm – USC Mechanical Engineering Laboratory Technician

Dimensions

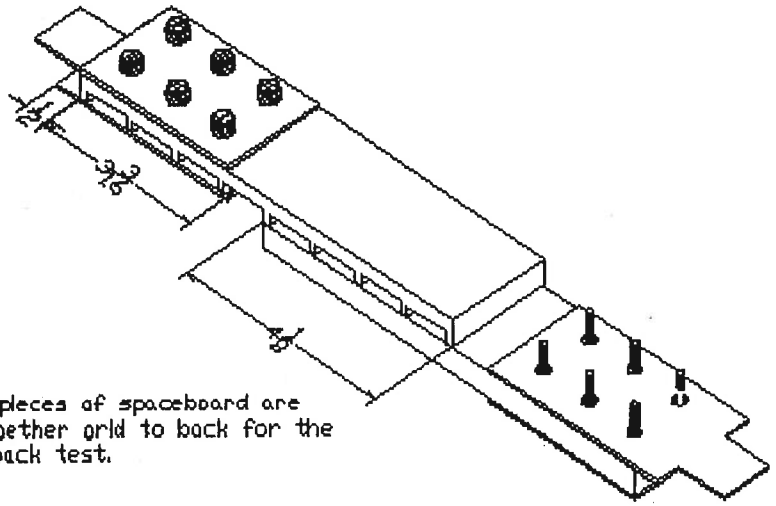








The two pieces of spaceboard are glued together grid to grid for the grid to grid test.



The two pieces of spaceboard are glued together grid to back for the grid to back test.

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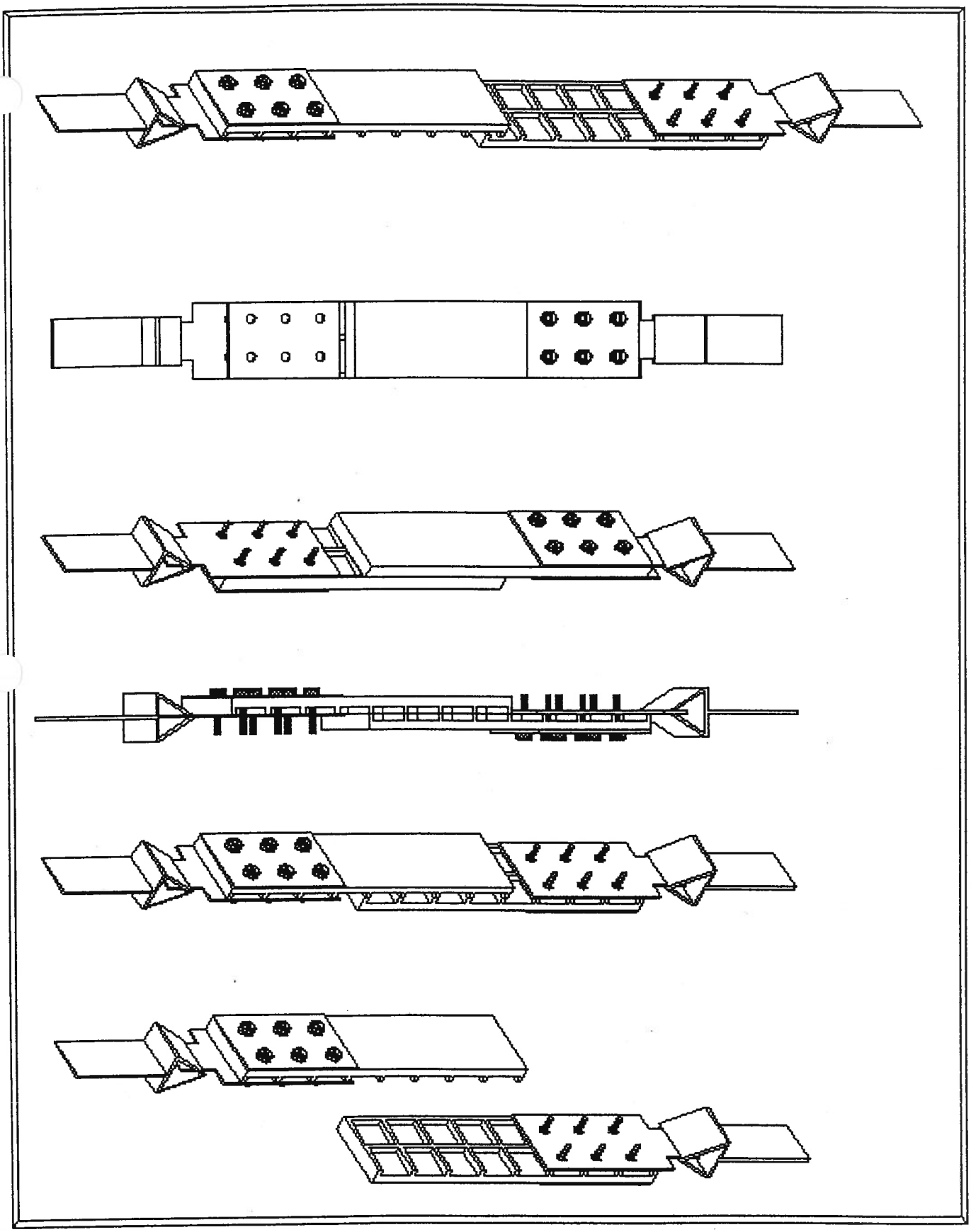
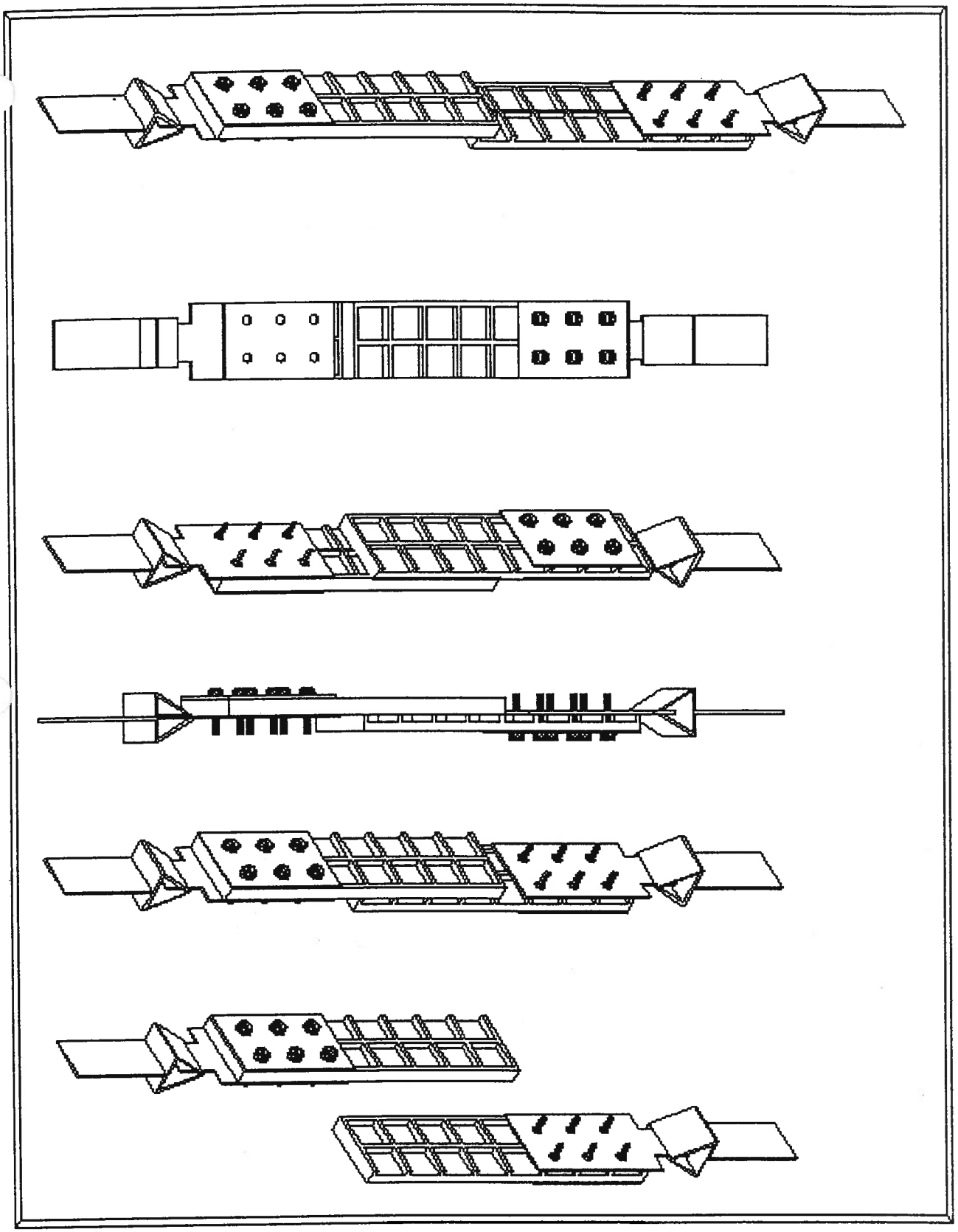
grid to grid



Grid to Back



Adhesive Characteristics

Names of Adhesives	Name of company	Phone #	Base	Clean-up	Viscosity	Method to Apply	Features	Cure time	Hazardous	Surface Preparation	Information on toxic chemicals
4213-NF Industrial Adhesive	3M	1-800-362-3553	water dispersed; Synthetic Resin	soap and water	2000 cps	knife, roller, spray, brush	resistance to staining and discoloration	30-45 minutes	Health: 1; Fire: 1; Reactivity:0	clean, dry, temp. at least 65 F	
30-NF Neutral Contact Adhesive	3M		water dispersed; Polychloropr ene	soap and water	200-600 cps	knife, roller, spray, brush	needs two coats	30 minutes	Health: 1; Fire: 0; Reactivity:0	clean, dry, temp. at least 65 F	Toluene, methyl alcohol, Zinc oxide
4268-NF Industrial Adhesive	3M		Water-Based	soap and water	2500 cps	knife, roller, spray, brush	moderate tack to allow for repositioning	Within 20 hours	Health: 1; Fire: 1; Reactivity:1	clean, dry, temp. at least 65 F	Toluene, methyl alcohol
4224-NF Pressure Sensitive Adhesive	3M		Water-Based; Acrylate	soap and water	9000-12000 cps	knife, roller, spray, brush	Excellent initial tack and good bond strength	depends on thickness	Health: 1; Fire: 0; Reactivity:0	clean, dry, temp. at least 65 F	
Carpenter's Wood Glue	Elmer's	Elmer's Products, Inc., 180 East Broad Street, Columbus, Ohio 43215, attn: Consumer Response	?	soap and water		roller, spray, brush, squeeze bottle	grabs and sets fast to reduce clamp time	dry over-night	non-toxic	clean,dry	
Elmer's Glue-All	Elmer's		polyvinyl acrylate, water-soluble	soap and water		roller, spray, brush, squeeze bottle	for all porous materials	30-45 minutes	non-toxic	clean,dry, temp. at least 60 F	
Wisdom	Wisdom		?								
S3920P	AFCO	617-884-6060	?	soap and water	350-400 cps	roller, spray, brush	used commercially in the folding box industries	over night	Health: 1; Fire: 0; Reactivity:0	clean, dry	?
S3855	AFCO		?	soap and water	1200-1400 cps	roller, spray, brush	used commercially in the folding box industries	over night	Health: 1; Fire: 0; Reactivity:0	clean, dry	?
BestBond	Abatron, Inc	414-653-2000	?	soap and water	100-400 cps	roller, spray, brush	water resistant, can be used on porous materials	tacks in 20 minutes	non-toxic	clean, dry	none

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Names of Adhesives	Name of company	Phone #	Base	Clean-up	Viscosity	Method to Apply	Features	Cure time	Hazardous	Surface Preparation	portation or toxic Chemicals
CB1465 White	Chembond Adhesives, Inc	(800) 367-2141 FAX: (419) 447-3502	water-based	soap and water	1000-3000 cps	Roll Coater - Spray - Hand Roller - Bottle	water resistance, stable dispersion of very small polymer particles in water	24 hours		clean, dry	
CA122	Chembond Adhesives, Inc		water-based	soap and water	7500 cps	Roll Coater - Spray - Hand Roller - Bottle	carton adhesive,	fast	Health: 1; Fire: 0; Reactivity:0	clean, dry	
CCC3	Chembond Adhesives, Inc		water-based	soap and water	1500 cps	Roll Coater - Spray - Hand Roller - Bottle	especially effective on difficult to bond substrates when good specific adhesion	24 hours	Health: 1; Fire: 0; Reactivity:0	clean, dry	
HPL700	Chembond Adhesives, Inc		water-based	soap and water	3500 cps	Roll Coater - Spray - Hand Roller - Bottle	water clean up, Non staining	24 hours or less	Health: 1; Fire: 0; Reactivity:0	clean, dry	
MPA White	CP Adhesives, Inc	1-800-454-4583	water-based	soap and water	6000 cps	knife, roller, spray, brush	white glue, creeps under stress	Open Time: 10 min; Clamp time:30 min; full cure: 24 hrs	Health: 1; Fire: 0; Reactivity:0 non-toxic	clean, dry	kaolin
Water Based Contact Cement	CP Adhesives, Inc		water-based, compounded Neoprene	soap and water	2250 cps	knife, roller, spray, brush	easy clean up, heat resistant, open tack for 3 hours	allow to dry for 30-45 min before combining both pieces	Health: 2; Fire: 1; Reactivity:0 non-toxic	clean, dry	2-chloro, 1,3-Butadiene; V M&P