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CARBON/CARBON
HONEYCOMB

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ABSTRACT

The feasibility was established of fabricating carbon/carbon honeycomb using woven carbon cloth. Initial trials with carbon paper were not successful. A new cell configuration was developed to allow forming the honeycomb to curved surfaces and it does not require that the cell wall material withstand pleating. The impregnation resin was mixed to provide flexibility and hi-char characteristics.

CONTENTS

	Page
INTRODUCTION	1
SUMMARY	1
DISCUSSION	2
Cell Design and Application	2
Processing Procedure	2
Resin Systems	3
Weaving Fixture	4
Carbon Cloth Honeycomb Data	5
Carbon Fiber Paper Honeycomb	6
CONCLUSIONS AND RECOMMENDATIONS	6
APPENDIX A	A-1
1 Honeycomb Strength Before Carbonization	A-2
2 Honeycomb Strength After First Carbonization	A-3
3 Honeycomb Strength After Second Carbonization	A-4
4 Honeycomb Strength After Third Carbonization	A-5
5 Honeycomb Strength After Fourth Carbonization	A-5
APPENDIX B	B-1
1 Figure Eight Honeycomb Cell Configuration	B-2
2 Three Dimensional Drawing of Honeycomb Cell Configuration	B-3
3 Fabrication on Special Weaving Fixture	B-4
4 Conical Frustum Half Section - Not Carbonized	B-5
5 Complete Conical Frustum - Not Carbonized	B-6
6 Comparison of Carbonized Specimen With Uncarbonized Specimen	B-7
7 Layup Fixture Used for Fabrication	B-8
8 Weaving Fixture With Cured Honeycomb	B-9

CONTENTS

Page

APPENDIX B (Continued)

9	Rows of Pins for Weaving Fixture	B-10
10	Forming Strips Into Weaving Fixture	B-11
11	Removing Honeycomb From Weaving Fixture	B-12
12	Honeycomb Panel Recently Removed From Weaving Fixture	B-13
13	Honeycomb Panel 1/4 Inch Cell Wall Height After Grinding	B-14
14	Carbon Paper Honeycomb	B-15

INTRODUCTION

New products require lightweight, high-temperature-resistant structures.

To aid in accomplishment of this requirement, the feasibility of fabricating carbon/carbon honeycomb was undertaken. This would give a material which is lightweight, temperature-resistant, and has insulating capability as well as structural strength.

This project was initiated to:

- Select and develop honeycomb cell configurations which could be formed well over surfaces of revolution.
- Select core materials on a basis of strength-to-density ratio, formation over surfaces of revolution, and processing considerations.
- Investigate and determine methods for obtaining satisfactory carbon bonds in the construction of the honeycomb, and bonding the honeycomb to skins or assemblies.
- Develop flat test panels and models that could determine the optimum strength, density, insulation characteristics, and shrinkage data for improved fabrication of carbon honeycomb.

SUMMARY

Carbon/carbon honeycomb has been fabricated. Continued work should refine the process and provide sufficient data to establish the physical properties of carbon/carbon honeycomb.

Initial effort was directed toward development of a rigid honeycomb having a density of 0.05 to 0.1 g/cc and capable of being applied to a conical surface. This required development of a cell configuration which was flexible. The special cell configuration--designated Offset Herringbone Figure Eight--resulted in a low density flexible honeycomb which may be formed (after fabrication) to a conical frustum or cylinder without creating anti-clastic curvature.

Effort on this project was terminated prior to achievement of all objectives since the anticipated design requirements for this product did not materialize. Feasibility of making carbon honeycomb has been shown so that a process could be refined for fabricating carbon honeycomb.

DISCUSSION

CELL DESIGN AND APPLICATION

The newly developed cell design, Offset Herringbone Figure Eight, is illustrated in Figures 1 and 2 (Appendix B). This cell design provides sufficient flexibility on the X-axis to permit the prefabricated honeycomb sheets to be formed to a radius as small as approximately one and one-half inches (depending upon material, cell size, and impregnating process used). Figure 2 illustrates the cell pattern, showing a three dimensional view of the honeycomb. Figure 3 defines the placement of the strips of material over the weaving pins in a special fixture used to produce the cell pattern shown.

Although the cell pattern might be modified to produce special characteristics, this specific pattern satisfied all present requirements and appeared to provide maximum flexibility on the X-axis (a direction parallel to the material strips).

Various shapes can be produced by forming and bonding smaller sections together to form the desired configuration. Bonding requires the same resin system used to prepare the honeycomb. After the sections have been bonded together to create the desired structural shape and dimensions, further weight reduction (lower density) and greater resistance to high temperatures may be obtained by carbonizing the entire structure. Final carbonization of the resin system often causes dimensional changes unless the material is stabilized or restricted during the carbonizing process.

Photographs in Appendix B illustrate the conical frustum carbon honeycomb structure at various stages of fabrication. Figure 4 shows a formed honeycomb conical frustum half-section. The manner in which two or more sections may be bonded together to form a complete structure is shown in Figure 5. Figure 6 shows Offset Herringbone Figure Eight samples made from impregnated and bonded carbonized fabric which has been subjected to a final carbonization after fabrication.

PROCESSING PROCEDURE

The fabrication of the carbon cloth honeycomb samples shown in Figure 4 and Figure 6 was accomplished by winding carbon cloth prepreg strips around Teflon pins in a special fixture. Such a fixture is shown in Figure 7. The procedure is:

1. Impregnate the carbon cloth with the resin/solvent solution.

2. Allow the impregnated cloth to air dry.
3. Cut the impregnated cloth (prepreg) into strips of the required width.
4. Weave the prepreg strips over the Teflon pins to produce the desired cell configuration.
5. Apply pressure to the stack pins and cloth.
6. Cure the molded honeycomb in the fixture under sustained pressure (4 hours at 200°F + 4 hours at 300°F).
7. Remove the honeycomb from the fixture.
8. Carbonize the honeycomb in a nitrogen atmosphere at 1600°F.
9. Grind honeycomb to desired cell height.

RESIN SYSTEMS

Desired properties of the resin system are:

1. It provides good node bonds in the honeycomb.
2. It isn't too brittle.
3. It has good carbonization properties.

The resin system used is a mixture of Dow Epoxy Novalac 439 and Shell Epon 872, with boron-trifluoride-monoethylamine complex as the catalyst and methylethylketone as the solvent (see number 3 following).

The DEN 439 alone gives a good carbon yield when carbonized, but has no flexibility; Epon 872 is a flexible resin, but does not give a high carbon yield when carbonized.

Resin study summaries are as follows:

1. The first formulation used to impregnate carbon cloth was an equal parts mixture by weight of DEN 439 and Epon 872 with catalyst and solvent added. This system gave good node bonds and a flexible honeycomb structure, but the backing material would not release from the impregnated cloth.

2. The second formulation evaluated was a mixture of DEN 439 catalyst and solvent with no Epon 872. It did not give good node bonds and was very brittle. However, it did release well from the backing material.
3. The next formulation used was a 75/25 percent mixture by weight of DEN 439 and Epon 872 with catalyst and solvent added. This system gave good node bonds and a flexible honeycomb structure as well as not adhering to the backing material. It appears to meet all of the desired properties.

WEAVING FIXTURE

Description -- A weaving fixture was designed to fabricate figure eight honeycomb. The fixture will produce a 9 by 11-1/2 by 1/2-inch-thick honeycomb panel.

The weaving fixture has 45 rows of figure eight shaped pins and one row of cylindrically shaped pins (Figure 8). To get the offset herringbone pattern, the 45 rows of figure eight pins are divided into two groups. One group has 23 rows, and each row has 17 pins. These pins are at an angle of 30 degrees clockwise from a plane perpendicular to the row. The second group has 22 rows with 18 pins per row. These pins are at an angle of 30 degrees counterclockwise from a plane perpendicular to the row (Figure 9). The rows are set in the fixture starting with a row of cylindrical pins, followed by a row of 17 pins, then a row of 18 pins. The rows are then alternated ending with a row of 17 pins. Each row of pins has a lip on each end which fits into the slot on the side plates. These plates keep the rows from sliding in a lateral direction. The front plate, a smooth plate against which the row of cylindrical pins is set, acts as a retainer. The back plate is similar to the front plate except that it has six bolts for applying pressure to the pins during cure.

Use -- To make a honeycomb panel, the pressure end plate and all the rows of pins are first removed from the fixture. The side plates are loosened but not removed. The row of cylindrical pins is put into the fixture. Impregnated cloth, with polyethylene backing, is cut into strips 1/2-inch wide. The polyethylene backing is removed from one side of the impregnated cloth and the carbon cloth is formed around the pins using a 1/4-inch metal rod. Next, the polyethylene backing is removed from the other side of the material and another row of pins is put into the fixture. This process is continued until all the rows have been put into the fixture. Figure 10 shows how the strips are formed around the pins. After all the side plates are tightened down, the bolts in the pressure plate are tightened to apply pressure to the bars. After the pressure is

applied, the fixture is placed in an oven for curing. When the curing cycle is complete, the fixture is removed from the oven and allowed to cool. The fixture with cured honeycomb is shown in Figure 8. The two side plates are loosened and the front end plate is removed to release the honeycomb from the fixture. The rows of pins and honeycomb are pushed forward so that the first row of pins clears the base, then the Teflon rods are turned to release them from the honeycomb and the bar is removed from the fixture. Figure 11 shows the bars being removed. The procedure is continued until all the bars have been removed. The fixture is then re-assembled and ready for use in making another honeycomb panel.

A honeycomb panel that has just been removed from the fixture is shown in Figure 12. The panel usually has a cell wall height of approximately 1/2 inch after removal from the weaving fixture. Because the honeycomb panel does not have a uniform thickness after cure, some cleanup grinding is needed. A finished piece of honeycomb after grinding has a maximum cell height of around 0.400 inch. A honeycomb panel with a cell height of 1/4 inch is shown in Figure 13.

CARBON CLOTH HONEYCOMB DATA

A limited amount of testing has been conducted on carbon/carbon honeycomb fabricated with woven materials. Uncarbonized honeycomb efficiency (strength-to-weight ratio) appears comparable to that of other types of honeycomb.

The characteristics of four different cloth materials were evaluated after successive resin impregnation and carbonization cycles. The test samples were 2 by 2 by 1/4-inch-thick made from Hitco Square Weave Carbon Tape, Hitco Square Weave Graphite Tape, Hitco 8 Harness Carbon Cloth, and National Carbon VCK8 Harness Carbon Cloth. Table 1 lists the densities and strengths of samples after cure. The remainder of the samples were carbonized at 1600°F. Table 2 lists the samples that were tested after the first carbonization. The loss in strength and density seem to be dependent on basic material and weave pattern. Samples were then reimpregnated and carbonized until a total of four carbonization cycles had been run. Two samples of each material were removed and tested after each cycle. Tables 3 through 5 represent the data that was obtained after the various cycles.

The data shows that reimpregnation and carbonization increases the compressive strength of the material. From the tables it is apparent that the 8 Harness weaves produce the strongest honeycomb.

CARBON FIBER PAPER HONEYCOMB

The carbon fiber paper, a 90 percent carbon fiber with a 2 percent polyvinylacetate binder, was evaluated and found to be difficult to handle because of the low fiber-to-fiber bond strength. Attempts to pleat the carbon paper were unsuccessful. The paper does not hold a pleat due to the spring-back of the fibers (Figure 14).

Additional work was done using the carbon fiber paper and impregnating it with a resin system. During the first attempt, weakness of the resin wetted paper caused problems in removing the paper from the resin bath. Carbon paper honeycomb panels were very brittle after cure and were easily damaged during removal from the fixture.

CONCLUSIONS AND RECOMMENDATIONS

Effort was terminated prior to achievement of all objectives since anticipated design requirements did not materialize.

Feasibility of making carbon honeycomb has been shown so that if a requirement does develop, a process could be further refined to fabricate carbon honeycomb.

It does not seem practical to consider using the carbon fiber paper as a material of construction. The use of woven-cloth honeycomb has promise and it should be possible to improve the characteristics that have been reported.

There are other manufactured cloth materials that could be investigated. Specially woven tape might increase compressive strength. This tape would contain a large percentage of high modulus material in the fill direction of the weave. The weave would be such that a minimum crimp is obtained in the fill yarns. Other resin systems might yield better properties in the carbon/carbon condition. The reimpregnation and carbonization of the honeycomb could be studied further.

The thermal properties of carbon/carbon honeycomb when filled with an insulating material need to be evaluated. A possible application of this material would be as a support structure for high temperature insulation.

APPENDIX A

Table 1. Honeycomb Strength Before Carbonization

Material	Sample	Density (g/cc)	Compressive Strength (psi)
Hitco Carbon Tape	1	0.126	276
	2	0.126	299
Hitco Graphite Tape	1	0.118	413
	2	0.124	423
Hitco 8 Harness	1	0.129	1297
	2	0.130	1417
National Carbon 8 Harness	1	0.131	784
	2	0.129	735

Impregnated with DEN 439 50 PBW
 EPON 872 50 PBW
 BF₃-MEA 2.5 PBW

Cure Cycle 8 hours at 200°F + 4 hours at 300°F

Table 2. Honeycomb Strength After First Carbonization

Material	Sample	Density (g/cc)	Compressive Strength (psi)	Approximate Loss in Strength (%)	Approximate Loss in Density (%)
Hitco Carbon Tape	3	0.077	53.3	81	40
	4	0.079	53.3	82	41
Hitco Graphite Tape	3	0.074	31.1	92	41
	4	0.075	31.8	92	42
Hitco 8 Harness	3	0.089	115.3	91	35
	4	0.081	100.4	93	36
National 8 Harness	3	0.090	86.9	89	30
	4	0.083	97.8	87	40

Table 3. Honeycomb Strength After Second Carbonization

Material	Sample	Density (g/cc)	Compressive Strength (psi)
Hitco Carbon Tape	5	0.091	98
	6	0.082	64
Hitco Graphite Tape	5	0.085	50
	6	0.088	57
Hitco 8 Harness	5	0.093	109
	6	0.102	229
National Carbon 8 Harness	5	0.095	136
	6	0.090	123

Reimpregnated with

DEN 439
BF₃ MEA

100 PBW
3 PBW

Diluted 4 to 1 with Methylethylketone

Cure Cycle 6 hours at 200°F + 4 hours at 300°F

Carbonized at 1600°F

Table 4. Honeycomb Strength After Third Carbonization

Material	Sample	Density (g/cc)	Compressive Strength (psi)
Hitco Carbon Tape	7	0.101	90
	8	0.106	118
Hitco Graphite Tape	7	0.095	66
	8	0.096	72
Hitco 8 Harness	7	0.107	124
	8	0.112	273
National Carbon 8 Harness	7	0.104	201

Table 5. Honeycomb Strength After Fourth Carbonization

Material	Sample	Density (g/cc)	Compressive Strength (psi)
Hitco Carbon Tape	9	0.119	131
	10	0.108	124
Hitco Graphite Tape	9	0.119	108
	10	0.108	87
Hitco 8 Harness	9	0.109	261
	10	0.110	322
National Carbon 8 Harness	9	0.122	201
	10	0.117	317

APPENDIX B

Figure 1. Enlarged Drawing of Typical Offset Herringbone Figure
Eight Honeycomb Cell Configuration

A honeycomb cell pattern specifically designed for conical
frustums. It is also applicable to various other forms.

Figure 2. Three Dimensional Drawing of Typical Offset Herringbone Figure Eight Honeycomb Cell Configuration

Figure 3. Fabrication of Offset Herringbone Figure Eight Honeycomb On Special Weaving Fixture

* Orientation of opposing cells (such as C1 and C2) is approximately 30 degrees displaced from the Y axis of the honeycomb for the A=25 percent of B adjacent layer placement shown. The direction of maximum honeycomb flexibility is on the X axis.

Figure 4. Resin Impregnated
Carbon Cloth Honeycomb
Formed Into Conical Half-
Section--Not Carbonized

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Figure 5. Complete Conical
Frustum Assembled From Three
Preformed Prefab Sections--
Not Carbonized

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Figure 6. Comparison of
Carbonized Specimen (Top)
With Uncarbonized Specimen

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Figure 7. Layup Fixture
Used to Fabricate Round
Cell Honeycomb During
Initial Development Phase

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Figure 8. Weaving Fixture
With Cured Honeycomb

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Figure 9. Rows of Pins
for Weaving Fixture

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Figure 10. Forming Strips
Into Weaving Fixture

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Figure 11. Removing
Honeycomb From Weaving
Fixture

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6-18-68

Figure 12. Honeycomb Panel
Recently Removed From
Weaving Fixture

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Figure 13. Honeycomb Panel
--1/4-Inch Cell Wall Height
After Grinding

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Figure 14. Carbon Paper
Honeycomb

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