TO: KSI/Scientific & Technical Information Division
   Attn: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General
      Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code
KSI, the attached NASA-owned U.S. Patent is being forwarded for
abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No.: 4,052,523

Government or Corporate Employee: U.S. Government

Supplementary Corporate Source (if applicable):

NASA Patent Case No.: LAR-11,898-1

NOTE - If this patent covers an invention made by a corporate employee
of a NASA Contractor, the following is applicable:

YES ☐ NO ☒

Pursuant to Section 305(a) of the National Aeronautics and Space Act,
the name of the Administrator of NASA appears on the first page of the
patent; however, the name of the actual inventor (author) appears at
the heading of column No. 1 of the Specification, following the words
"...with respect to an invention of ..."

Bonnie L. Henderson

Enclosure

(NASA-Case-LAR-11898-1) COMPOSITE SANDWICH  N78-10214
LATTICE STRUCTURE Patent (NASA) 13 p
CSCL 11D

Unclas
00/24  51205
This invention relates to a lattice type structural panel utilizing the unidirectional character of filamentary epoxy impregnated composites to produce stiff lightweight structural panels for use in constructing large area panels for space satellites and the like.

17 Claims, 9 Drawing Figures
COMPOSITE SANDWICH LATTICE STRUCTURE

ORIGIN OF THE INVENTION

The invention described herein was made by employees of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

Contemporary and future aerospace vehicle requirements continue to provide challenges to the structural designer for reducing structural weight. In the interest of fuel economy, a premium is placed on structural weight in the design aircraft. Similarly, the anticipated needs for very large area space structures will tax the load carrying capability of any conceivable booster system. Relative recent advances in filamentary composite materials have provided the structural design improvements of a factor of two to four in strength-to-density ratios and a factor of three to eight in modulus-to-density ratios when compared with the normally used metal structures. To fully exploit this potential, structural designs must be developed wherein the unidirectional nature of the advanced composite materials is considered from the outset.

Accordingly, it is an object of the present invention to provide a new and improved lightweight structural panel.

Another object of the present invention is the provision of a novel panel construction.

A further object of the present invention is the provision of a lattice type structural panel wherein the unidirectional characteristics of filamentary compositions are exploited.

An additional object of the present invention is the provisions of composite material panel structure wherein the geometry of the panel lattice network is tailored to provide the appropriate stiffness and loading requirements.

A further object of the present invention is a novel method of making a composite lattice panel structure.

BRIEF DESCRIPTION OF THE INVENTION

According to the present invention, the foregoing and other objects are attained by providing a lightweight honeycomb core sheet having a plurality of symmetrical angular openings extending through the core sheet to leave a lattice network or rows of honeycomb cells divided by the plurality of angular openings. Strips of prepreg composite tape of the exact width of the network are individually extended and this composite material temperature cured to bond the individual strips or tapes into a unitary panel structure with the honeycomb core. Where additional strength or stiffness of the panel is desired more than one ply or strip of tape may be bonded to one or more rows of the honeycomb cells. Also, the total mass of the lattice panel may be increased by varying the width of the structural rows of honeycomb cells making up the lattice network.

A more complete appreciation of the invention and many of the attendant advantages thereof will be readily apparent as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. 1 is a perspective view of a lightweight sandwich lattice panel according to the present invention;

FIG. 2 is an enlarged sectional view taken along lines 2-2 of FIG. 1;

FIG. 3 is a perspective view of a panel similar to FIG. 1 and showing different angular network and face sheets for the panel;

FIGS. 4-6 show various modifications of the panel of the present invention;

FIG. 7 is a graphic representation showing variations in mass relative to various lattice spacing in panels of the present invention;

FIG. 8 is a graphic representation showing bending stiffness relative to the lattice spacing in panels according to the present and invention; and

FIG. 9 is a graphic representation showing panel mass as a function of bending stiffness for panels according to the present invention.

Referring now more particularly to the drawings and specifically to FIG. 1, there is shown one embodiment of the lightweight sandwich panel and designated by reference numeral 20. As shown therein, panel 20 is formed of a lattice network of honeycomb core cells as designated by reference numeral 21. The lattice is formed of rows of honeycomb cells extending transversely to inner and outer skin members as designated respectively by reference numerals 24 and 25. The lattice network of panel 20 is provided with 0° ± 60° angular facesheets.

As shown more particularly in FIG. 2 each portion of the lattice network of panel 20 includes inner skin 24, outer skin 25, and intermediate core 21 adhesively bonded to the inner and outer skin respectively by adhesive layers, 27 and 28. Inner skin 24 and outer skin 25 are of identical construction and provide a single skin for covering honeycomb core 21 and are formed of graphite/epoxy composite tapes. As shown in FIG. 2, skins 24 and 25, respectively, are made up of graphite fibers 29, 29' impregnated or embedded in a thermosetting epoxy matrix 30 and 30' as will be further explained hereinafter. These tapes are fabricated from unidirectional prepreged/tape that are cut into strips of the desired width and are available commercially, for example, from the Whittaker Corporation, Narmco Materials Division, 600 Victoria Street, Costa Mesa, California 92627, under the tradename RIGIDITE 5208. This tradename material is a thermosetting epoxy resin curing at 355°±10° F for a period of 120 ± 5 minutes and employed as the matrix system with a variety of carbon fibers to produce RIGIDITE prepreg. The term "prepreg" is a term of art that denotes prepreged fiber materials that may be temperature cured to provide a rigid composite structure. The impregnation of the carbon fibers is accomplished by a hot melt process that is free of solvents to provide outstanding handling characteristics, tack, long out time, and essentially void-free laminates. After impregnation with the epoxy, the resulting prepreg is cut into the desired width and rolled for storage under refrigeration in the temperature range of 0° or below and in a sealed container. The storage life of the prepreg at these temperatures is at least six months although the manufacturer only provides a warranty period of ninety days. If maintained at room temperature i.e., 70° ± 5° F. the storage life is approximately 14 days. The graphite or carbon fibers utilized in making the prepreg are available in various diameters from numerous commercial sources, for example, Hercules, Morgenite, Stackpole, Union Carbide and others.
In the specific example described herein, the prepreg was RIGIDITE 5208-T-300 wherein the T-300 refers to Union Carbide's tradename Thornel 300 graphite fibers. These and all other graphite fibers contemplated in use of the present invention are continuous type fibers that extend the length of the prepreg tapes. Other prepreg tapes that are suitable in practice of the present invention are commercially available from the 3-M Company, Hercules, FibeRite Company and others. Although the prepreg tapes are sold commercially in various widths, from slit widths as narrow as 0.376 inch to 12 inch widths, the most commonly used width is 3 inches. These widths may be cut when ready for use to that desired for the particular application. Also, the thickness of the prepreg tapes that are commercially available vary from those providing a cured ply thickness in the range of 0.0015 inch to 0.0025 inch for ultra-thin applications to the standard range of 0.005 inch to 0.006 inch as employed in the specifically described application herein. The cured thickness is primarily dependent upon the graphite fiber diameter with the prepreg tapes having a fiber content of 58 ± 3% by volume and an epoxy content of 42 ± 3% and with a 60-40% graphite/epoxy being preferred. In one specific example the panel had a strip width of 0.25 inch and a lattice spacing of 1.5 inches.

The honeycomb core 21 for panel 20 in one specific embodiment was a high temperature nylon sold under the tradename NOMEX by the Hexcel Company. This specific material had hexagonal cells ⅛ inch in diameter and the sheet material had a density of three pounds per cubic foot. Other densities and cell shape and size are equally useful in practice of the construction of the panels of the present invention. In another specific example constructed, the honeycomb core 21 was constructed of American Cyanamid's aluminum core having 3/32 inch hexagonal cells and a density of 4 pounds per cubic foot. The adhesive layers 27 and 28 are formed by a suitable epoxy resin adhesive, such for example, Epon Resin 828/ Epon Curing Agent V-40 manufactured by The Shell Chemical Company of Pittsburgh, California.

Referring now to FIG. 3 lattice composite panel 32 is shown wherein the openings in the face sheets are 0° 45°, 90°. Otherwise the construction of panel 32 is identical with that described hereinabove for panel 20 and a single ply inner face skin 34 and single ply outer face skin 35 is bonded to honeycomb element 36.

FIG. 4 a panel configuration 40 is shown having multiple plies 41 for selected strips of outer skin 45 thereof. Honeycomb core 46 and inner skin 44 are of identical construction to the described hereinabove for the embodiments of FIGS. 1-3. Although only selected strips of the lattice network of panel 40 are shown as being provided with multiple skin plies, it is to be understood that in each of the embodiments of invention described herein, the entire outer and inner skins or any number of the lattice strips thereof may be provided with multiple plies as so desired for increased panel stiffness and strength properties. As used herein, multiple plies is meant to include 2, 3, or 4 plies of prepreg tape.

In FIG. 5 a composite lattice panel 50 is shown wherein selected diagonal strips or rows of the honeycomb cells in honeycomb core 51 are omitted. Structural panels of this type may be employed where the stiffness requirements are not as great as that required for the preceding embodiments, or where it is necessary to reduce the weight. Other embodiments that include additional strips and ply combinations will be readily apparent to those skilled in the art and are not included herein in the interest of clarity.

As shown in FIG. 6, as inner and outer face sheet of thin bonded plastic film, and designated respectively by reference numerals 58 and 59, may be bonded to lattice panel 60. Panels of this construction are desirable in some instances to support pressure or other distributed panel loads and the plastic film face sheets 58 and 59 bonded, by respective layers 62 and 63 of a suitable adhesive to the respective inner and outer skins 64 and 65 covering the honeycomb core 66 of panel 60. Face sheets 58 and 59 are constructed of a suitable plastic such for example, DuPont's Mylar, a polyester film, or Kapton, a polyimide film.

FIG. 7 shows a graphic representation of the mass of several lattice panels constructed according to the present invention relative to the lattice network spacing. The solid lines represent prepreg tape thickness of 0.0055 inch while the dashed lines are for prepreg tapes of 0.003 inch.

FIG. 8 shows a graphic representative of plate bending stiffness for several lattice panels of the present invention relative to lattice network spacing and the solid and dashed lines are for tapes as described in FIG. 7.

FIG. 9 is a plot illustrating typical panel mass as a function of bending stiffness. Bending stiffness decreases as the lattice spacing increases as would be expected.

**PANEL FABRICATION**

In the preferred process for fabricating the panels of the present invention, the triangular patterns in the honeycomb core were removed before bonding of the inner and outer face skins. Although these triangular segments could be removed after bonding of the tape skin surfaces, this would require extreme care to avoid damage to the individual strips of tape as the core is being cut. A template and a cutter designed to remove the individual triangular sections were employed in fabricating the panels described herein. This template was made from aluminum stock and the grid pattern therein was cut on a numerical controlled milling machine. Silicon rubber blankets were also cut with the template and placed in the grooves provided in the base and top halves of an aluminum mold. These silicon rubber blankets permitted the overlapping tapes at the intersecting areas of the grid to be cushioned during pressure curing to avoid undue compression mold forces at these points. The mold grooves and silicon blankets were coated with a suitable conventional release agent, such for example, Frekote 33, a product of Frekote, Inc. of Boca Roton, Florida, or MS-122, a fluorocarbon release agent containing tetrafluoroethylene polymer solids and manufactured by Miller Stephens Chemical Company, Inc. The release agent serves to prevent sticking of the prepreg to the mold and silicon blankets. The composite material face sheets were then placed in the top and bottom halves of the mold. The grooves in the mold halves are cut slightly wider than that of the tapes to be employed to prevent binding of the cured panel after fabrication. Also the depth of the grooves are adequate to permit the use of multiple layers or plies of tapes with the silicon rubber blankets providing uniform forces to the tapes during bonding. After the tapes are positioned in the mold halves, the faces of the precut honeycomb are brush
Patent of the United States is appended claims.

ings without departing from the spirit and scope of the
teachings to those skilled in the art in the light of the above teach-
other features of the invention will be readily apparent
invention is not so limited and changes in these and 55
lattice structural components have been illustrated, the
fications of the angular openings and the width of the
may be practiced otherwise than as specifically de-
examples'shown and herein described are to be taken as
preferred embodiments only, and that the invention 50
invention and the specific materials used in the specific
prepregs are available in various widths, strengths and
thicknesses and may be selected and cut to suit the 45
Fiber and Epoxy Resin prepreg system that is useful in 40
Material Division of the Whittaker Corporation, Costa
America, Broad Brook, Connecticut. Also, Narmco
Borsic Aluminum prepreg from Composite Materials 35
have been constructed utilizing continuous filament
process described herein are concerned with graphite
3Q
Mesa, California manufactures a KEVLAR 49 Aramid
proximately 40 percent by volume.
 Thermal expansion characteristics such as graphite or a
thermal expansion between the aluminum and the graphite com-
was necessary to cure the graphite prepreg outside of 10
15 minutes to cure the bonding resin. This low tempera-
ture cure also permitted the resin matrix in the graphite
10° F for 120 ± 5 minutes finally cure the resin in the

an intermediate core further having said honeycomb
cells disposed in a plurality of rows with said rows
forming a lattice structural configuration to provide
a plurality of triangular openings between adjacent
rows of honeycomb cells, 6
said internal and said external skins being formed of
individual tape strips of material; and wherein said individual tapes of material secured to said rows of
honeycomb cells are constructed of a graphite-
epoxy composite.
2. The sandwich panel of claim 1 wherein said graph-
epoxy composite is constructed of unidirectional
graphite filaments extending the length of said tapes and
embedded in a thermostating epoxy.
3. The sandwich panel of claim 2 wherein said graph-
epoxy composite consists of a 60-40 percent by vol-
ume graphite-epoxy composite.
4. The sandwich panel of claim 1 wherein said honey-
comb core is constructed of high temperature resistant
nylon.
5. The sandwich panel of claim 4 wherein said honey-
comb core has a cell size of one-eighth inch and a den-
ity of three pounds per cubic foot.
6. The sandwich panel of claim 1 wherein said honey-
comb core is constructed of aluminum.
7. The sandwich panel of claim 6 wherein said honey-
comb core has a cell size of 3/32 inch and a density of
four pounds per cubic foot.
8. The sandwich panel of claim 1 wherein said internal
and said external skins are constructed of prepreg
tapes having a thickness in the range of 0.005 inch to
0.008 inch and formed of continuous length graphite
fibers impregnated with an epoxy resin.
9. The sandwich panel of claim 8 wherein the graph-
ite fibers comprise approximately 60 percent by volume
of the total tape weight and the epoxy comprises ap-
proximately 40 percent by volume.
10. A lightweight lattice panel comprising:
 an inner skin, an outer skin and a core element dis-
posed between and bonded to said inner and outer
skins,
said core being formed of a honeycomb material and
provided with multiple angular openings trans-
versely therethrough to provide a lattice structure
for the remaining honeycomb cells;
a first group of elongated strips of graphite/epoxy
tape disposed along one side of said core so as to
completely cover the area of honeycomb cells on
one side of said core thereby form an inner skin
for said panel;
a second group of elongated strips of graphite/epoxy
tape disposed along the other side of said core so as
to completely cover the area of honeycomb cells on
the other side of said core and thereby form an
outer skin for said panel.
11. The lightweight lattice panel of claim 10 wherein
the angular openings in said honeycomb core material
are 60° equiangular triangular openings.
12. The lightweight lattice panel of claim 10 wherein
the angular openings in said honeycomb core material
are formed of 45° and 90° angular openings.
13. The lightweight lattice panel of claim 10 wherein
said first and said second group of tapes form a single ply
inner and outer skin for said panel and further including
at least one additional strip of graphite/epoxy tape on
posed toward and closed by said internal skin and
said external skin,
said intermediate core further having said honeycomb
cells disposed in a plurality of rows with said rows
forming a lattice structural configuration to provide
a plurality of triangular openings between adjacent
rows of honeycomb cells,
selected ones of said first group of tapes to form multiple ply inner skin areas on said panel.

14. The lightweight lattice panel of claim 10 wherein said first and said second group of tapes form a single ply inner and outer skin for said panel and further including at least one additional strip of graphite/epoxy tape on selected ones of said second group of tapes to form multiple ply outer skin areas on said panel.

15. The lightweight lattice panel of claim 10 wherein said first and second group of tapes form a single ply inner and outer skin for said panel and further including at least one additional strip of graphite/epoxy tape on selected ones of said first and second group of tapes to form multiple ply inner and outer skin areas on said panel.

16. The lightweight lattice panel of claim 10 and further including a solid plastics face sheet bonded to and completely covering said inner skin of said panel and the openings therein to provide additional stiffness properties to said panel and to serve as an attachment surface for securing said panel to other structures.

17. The lightweight lattice panel of claim 10 and further including a solid plastics face sheet bonded to and completely covering each of said inner and outer skins of said panel and the angular openings therein to provide additional structural support for said panel.