

FLEXIBLE MATERIAL FOR USE IN AN INFLATABLE STRUCTURE

BACKGROUND OF THE INVENTION

Field of the Invention

The invention is directed to the field of flexible materials and, in particular, to the field of flexible composite materials. The material has direct application to inflatable structures such as the gas bag for lighter-than-air vehicles.

Description of Related Art

In large non-rigid lighter-than-air vehicles, the material used for the gas bag must meet a large number design requirements such as high strength, provide tear resistance, act as a gas barrier, not be subject to degradation by the environment including ultra violet radiation due to exposure to sunlight. Thus such a material winds up being a multi-layer laminate combining materials with diverse properties. The primary axial loads on any portion of the wall of the gas bag are at 0 degrees to the longitudinal axis of the gas bag and at 90 degrees thereto (circumferential). Thus most laminates include woven filamentary material with the filamentary material orientated at the 0 and 90 degree angles. Additionally, to carry shear loads, filamentary material is sometimes included with orientations at plus or minus 45 degrees to those carrying the axial loads.

In early designs, where stress levels were low, several layers of woven cotton cloth impregnated with rubber to provide the gas seal were often used. Later, artificial fibers such as RAYONTM or DACRON^{AM} were used, manufactured by the E. I. duPont de Nemours & Company (hereinafter referred to as "DuPont"). The layers of cotton cloth were at 0 and 90 degrees (axial or strength plies) for the tension loads and plus and

1 minus 45 degrees (bias plies) for the shear loads. However, this approach
2 did not always result in an optimal strength design for the strength required
3 to carry the shear loading was typically, much less than the capability of the
4 bias plies. Using the same material for both the axial tension loads as well
5 as the bias (shear) loads often resulted in a weight penalty.

6
7 Some modern designs use a woven polyester fiber such as
8 DACRONTM for the 0 and 90 degrees axial load carrying material. A film of
9 material that is impervious to Helium such as a polyester terephthalate that
10 serves as the gas barrier is also carries some shear load. A typical
11 polyester terephthalate is sold by DuPont under the trade name MYLARTM.

12 Woven polyester fiber such as DACRONTM has a very large strain to
13 failure value, about 20 percent. However, in large non-rigid airships, the
14 strength requirements have dictated the use of very high strength materials
15 such as a liquid crystal thermotropic (melt spun) polyester polyarylate fiber,
16 for example VECTRANTM manufactured by Hoechst Celanese, Germany to
17 carry the axial loads. Another high strength material is a lyotropic (solvent
18 spun) aromatic polyaramide fiber, such as KEVLARTM, which is
19 manufactured by DuPont. However, both VECTRANTM and KEVLARTM
20 have a very small value of strain to failure value, on the order of 4 percent.

21 If the bias layers were made of the same material, biaxial loading in the 0
22 and 90 degree fibers will transfer significant load to the 45 degree bias
23 layers. Requiring these layers to work as hard as the 0 and 90° plies,
24 introduces a potential failure mode, or a weakening of the system. In fact
25 having a bias layer with higher elongation than the 0 and 90 degree
26 (strength fibers) precludes premature failure in the bias ply at ultimate load
27 in the strength fibers.

28 Some of the prior art teaches away from the use of such a concept,
29 for example, German Patent No. DE 3702936 "Fiber Composite Material-
30 With high Tensile And High Modulus Fiber In different Orientations by S.
31 Roth, et al. Roth, et al. teaches the use of fibers with high strength and
32 elongation at 0 and 90 degrees in conjunction with 45 degree fibers that

1 have a high elastic modulus for use in rigid composite structures. Thus the
2 stain value at failure of the plus or minus 45 degree fibers is less than the 0
3 and 90 fibers.

4
5 In U. S. Patent No. 4,770,918 "Diagram For Producing Sound" by A.
6 Hayashi a flexible diagram for producing sound is disclosed having at least
7 one layer of a first woven fabric having a low elongation and at least two
8 layers of a second woven fabric having a high elongation. The first and
9 second fabrics are disposed in such a fashion that the warps thereof cross
10 each other at between 10 and 80 degrees whereby an elongation of the
11 diaphragm in the direction of the warps of the first fabric is generally equal
12 to the elongation of the diaphragm in a direction inclined at a 45 degree
13 angle relative to the direction of the warps of the first fabric. This allows for
14 ease of tuning of the diaphragm. This invention, of course, would produce
15 an inefficient pressurized structure.

16
17 Other patents of general interest wherein materials of different
18 properties are combined into a single flexible structure are U. S. Patent
19 Nos. 5,189,280 "Three Dimensional Fiber Structures Having Improved
20 Penetration Resistance" by G. A. Harpell, et al., 4,871,598 "Container With
21 Flexible Walls" by E. Potente, et al. and 5,215,795 "Shock-Absorbing Air
22 Bag" by M. Matsumoto, et al.

23
24 Thus it is primary object of the invention to provide a laminate
25 material suitable for the wall of flexible pressurized containers.

26
27 It is a another primary object of the invention to provide a laminate
28 material suitable for the wall of a flexible pressurized containers wherein
29 bias shear load carrying plies have a greater strain to failure value than the
30 axial tension load carrying plies.

1 It is a further object of the invention to provide a laminate material
2 suitable for the flexible wall pressurized containers that is not degraded by
3 ultra violet radiation.

4
5 It is a still further object of the invention to provide a laminate
6 material suitable for the wall of flexible pressurized containers that are
7 suitable for containing Helium gas.

8
9 It is another object of the invention to provide a laminate material
10 suitable for the wall of flexible pressurized containers that can easily be
11 seamed together.

12 13 **SUMMARY OF THE INVENTION**

14
15 The invention is a material suitable for use as the wall of a
16 pressurized container such as the gas bag of a lighter-than-air vehicle. In
17 detail, the invention includes a first flexible layer comprising unidirectional
18 filamentary material at 0 and 90 degrees to each other. The filamentary
19 material of the first layer can be separate unidirectional plies at 0 and 90
20 degrees or woven or weaved cloth. A second flexible layer is included
21 having unidirectional filamentary material at 0 and 90 degrees to each other
22 and at 45 degrees to the filamentary material of the first layer. The
23 filamentary material of the second layer can also consist of separate
24 unidirectional plies at 0 and 90 degrees or woven or weaved cloth. In
25 addition, the filamentary material in both layers can be in the form of single
26 strands or yarns. Also, either or both layers can be divided into a number
27 of thinner layers and mixed together in any fashion.

28
29 Critical to the invention is that the strain value at failure for the
30 filamentary material of the second layer must be greater than the 0 and 90
31 degree filamentary material of the first layer. The first and second layers
32 are bonded together by a resin. The first and second plies can also be

1 knitted or stitched together with or without the resin to add additional
2 strength. Preferably, an additional film of a gas impermeable material and
3 an ultra violet radiation resistant material are bonded to the first two layers.
4

5 The novel features which are believed to be characteristic of the
6 invention, both as to its organization and method of operation, together with
7 further objects and advantages thereof, will be better understood from the
8 following description in connection with the accompanying drawings in
9 which the presently preferred embodiments of the invention are illustrated
10 by way of examples. It is to be expressly understood, however, that the
11 drawings are for purposes of illustration and description only and are not
12 intended as a definition of the limits of the invention.
13

14 **BRIEF DESCRIPTION OF THE DRAWINGS**

15

16 Figure 1 is a perspective view of a lighter-than-air vehicle.
17

18 Figure 2 is a perspective view of a portion of the wall of the gas bag
19 made of flexible fabric laminate illustrating the main axis of filamentary
20 material alignment.

21 Figure 3 is a partial perspective view of a portion of the fabric
22 laminate wherein the first and second layers are woven materials.
23

24 Figure 4 is a partial side view of a second embodiment of the fabric
25 laminate wherein the filamentary material making up both the first and
26 second layers are unidirectional plies that are stitched together.
27

28 Figure 5 view of a third embodiment of the fabric laminate
29 perpendicular thereto wherein the filamentary material making up both the
30 first and second layers are unidirectional plies that are knitted together.
31

1 Figure 6 is a side view of the third embodiment of the fabric laminate
2 illustrated in Figure 5.

3
4 Figure 7 is a graph plotting the strength of the 0 and 90 degree fiber
5 as a function of the ratio of the strain rate at failure of the 0 and 90 degree
6 fiber to the plus or minus 45 degree fiber.

7 8 DESCRIPTION OF THE PREFERRED EMBODIMENT

9
10 Illustrated in Figure 1 is a perspective view of a lighter-than-air
11 vehicle, generally designated by numeral 10. The vehicle 10 includes a
12 gas bag 12 having a longitudinal axis 13A, lateral axis 13B and a vertical
13 axis 13C. A gondola 14 is suspended from the gas bag and which
14 incorporates a plurality of propulsion systems 16 mounted thereon. As the
15 vehicle increases in size, large stress levels are introduced into the gas bag
16 12. Additionally, the gas bag 12 must be: impervious to Helium gas; not be
17 effected by the environment (including ultra-violet radiation); capable of
18 being seamed; and be damage tolerant. Meeting all these requirements
19 requires a laminated multi-layer flexible cloth made of a different materials
20 having specific mechanical properties.

21
22 In Figure 2, a portion of the flexible wall 20 is illustrated having an
23 inside surface 22 and outside surface 24 and is composed of multiple
24 layers of filamentary material in a manner to be subsequently discussed.
25 The main axial loads are introduced along the 0 degree axis, aligned with
26 the longitudinal axis 13A, and indicated by numeral 26, and 90 degrees
27 thereto indicated by numeral 28. Thus the main load carrying filamentary
28 material is aligned with these axis. Shear loads are carried by filamentary
29 material aligned with the plus and minus 45 degree directions indicated by
30 numerals 30 and 32. The angle of 45 degrees can be adjusted based
31 upon the detail requirements of the specific application.

1 Referring to Figure 3 the flexible wall 20 is made of (starting from
2 interior surface 22) a first layer of resin 40 that is bonded to a first layer 42
3 of woven yarn with individual strands at 0 and 90 degrees. The resin layer
4 40 and subsequent layers of resin are, preferably, a polyurethane. The first
5 layer 42 is made of a high strength yarn such as liquid crystal thermotropic
6 (melt spun) polyester polyarylate fiber (VECTRANTM). A lyotropic (solvent
7 spun) aromatic polyaramide fiber (KEVLARTM) is also suitable. A second
8 layer of resin 44, separates the first layer 42 from a second layer 46 of
9 woven filamentary material with individual strands at plus or minus 45
10 degrees. A third layer of resin separates the second layer 46 from a film of
11 material that is substantially impervious to Helium gas such as polyester
12 terephthalate (MYLARTM) Finally a fourth layer of resin is use to bond an
13 outer layer of a material that is resistant to degradation by ultra violet
14 radiation and also provides protection from wind erosion and the like. Such
15 a material is a polyvinyl fluoride fiber, which is sold under the trade name
16 TEDLARTM by DuPont. As illustrated in Figure 3, the material is illustrated
17 in its "lay up form". An alternative to MYLARTM or TEDLARTM is to increase
18 the resin content of the laminate so as to impregnate the fibers creating a
19 gas impermeable layer.

20

21 The critical factor in the selection of materials for the gas bag wall
22 20, besides being chemically compatible, is that the strain (inch per inch) at
23 failure of the second layer of filamentary material be greater than the strain
24 at failure for the first layer. This will insure that the strains introduced by the
25 0 and 90 degrees axial loads into layer 42 do not create failures when
26 transferred into the layer 46. Furthermore, having a high strain rate
27 material for the second layer 46 is very desirable in that it reduces the
28 possibility of local stress concentrations

29

30 In Figure 4 a second embodiment of the subject material is
31 illustrated and indicated generally by numeral 60. Starting from the bottom
32 up, the material comprises a first layer of resin 61; a first layer 62 having a

1 unidirectional filamentary material ply 64 at 0 degrees and a ply 66 at 90
2 degrees; a second layer 70 having a unidirectional filamentary material ply
3 72 at plus 45 degrees and a second ply 74 at minus 45 degrees. The four
4 plies 62, 64, 72 and 74 are stitched together, with the stitches indicated by
5 numeral 78. A Helium gas barrier layer of material such as MYLARTM
6 layer 79 is bonded there over by the resin layer 76 and a final layer 80 a
7 ultra violet radiation resistant material such as of TEDLARTM is bonded by
8 means of a resin layer 82. As in the first embodiment illustrated in Figure 3,
9 when the individual layers are bonded together, the first and second layers,
10 62 and 70, respectively, become encapsulated in a flexible resin matrix. It
11 should be noted that the woven or weaved first and second layers of
12 material 42 and 46, respectively illustrated in Figure 3 could also be
13 stitched together.

14
15 In Figures 5 and 6 a third embodiment is illustrated, generally
16 indicated numeral 90 wherein the first and second layers 62 and 70 shown
17 in Figure 4 are knitted together as indicated by numeral 92. The remainder
18 of the material 90 would be similar to Figure 4. Again, it should be noted
19 that the woven or weaved first and second layers of material 42 and 46,
20 respectively illustrated in Figure 3 could also be knitted together to improve
21 strength.

22
23 As previously mentioned it is critical to the invention that the strain
24 value at failure for the filamentary material in the second plus or minus 45
25 layer must be greater than the 0 and 90 degree filamentary material for the
26 first layer. Figure 7 demonstrates the importance of this feature. The
27 strength of the material under both uniaxial and biaxial loading conditions is
28 shown with a series of different strain values for the biaxial material. The
29 biaxial material strain to failure is divided by the 0 and 90 degree material
30 strain to failure to produce a strain ratio. If the ratio is less than one the
31 plus or minus 45 degree bias layer will fail first, a ratio greater than one

1 means the 0 and 90 degree layer will fail first. The severe penalty for low
2 ratio's is obvious.

3

4 While the invention has been described with reference to a particular
5 embodiments, it should be understood that the embodiments are merely
6 illustrative as there are numerous variations and modifications which may
7 be made by those skilled in the art. Thus, the invention is to be construed
8 as being limited only by the spirit and scope of the appended claims.

9

10 **INDUSTRIAL APPLICABILITY**

11

12 The invention has applicability to the composites industry and also
13 to the aircraft industry.

CLAIMS

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- 1 1. A material for a pressurized container comprising:
2 at least one first flexible layer comprising unidirectional filamentary
3 material at 0 and 90 degrees to each other;
4 at least one second flexible layer comprising unidirectional
5 filamentary material at 0 and 90 degrees to each other and at 45 degrees
6 to and having a strain value at failure greater than said 0 and 90 degree
7 filamentary material of said at least one first layer; and
8 said at least one first and second layers joined together.
- 1 2. The material as set forth in Claim 1 wherein said at least one first
2 and second layers are joined together.
- 1 3. The material as set forth in Claim 2 wherein said at least one first
2 and second layer are joined together by bonding
- 1 4. The material as set forth in Claim 2 wherein said 0 and 90 degree
2 filamentary material of said at least one first layer are woven together.
- 1 5. The material as set forth in Claim 4 wherein said 0 and 90 degree
2 filamentary material of said at least one second layer are woven together.
- 1 6. The material as set forth in Claim 5 wherein said unidirectional
2 filamentary material of said at least one first and second layers are in the
3 form of yarns.
- 1 7. The material as set forth in Claim wherein said at least one first layer
2 is selected from the group consisting of liquid crystal thermotropic (melt
3 spun) polyester polyarylate and lyotropic (solvent spun) aromatic
4 polyaramide fibers.

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1 8. The material as set forth in Claim 4 wherein said filamentary material
2 of said second layer is a polyester fiber.

1 9. The material as set forth in Claim 1, or 2, or 3, or 4, or 5, or 6, or 7,
2 or 8 wherein said at least one first and second layers are knitted together.

1 10. The material as set forth in Claim 1, or 2, or 3, or 4, or 5, or 6, or 7,
2 or 8 wherein said at least one first and second layers are stitched together.

1 11. The material as set forth in Claims 1, or 2, or 3, or 4, or 5, or 6, or 7,
2 or 8 further comprising a flexible gas impermeable sheet of material
3 bonded to said at least one first and second layers.

1 12. The material as set forth in claims 11 wherein said gas impermeable
2 sheet is a polyester terephthalate.

3
4 13. The material as set forth in Claim 10 further comprising a sheet of
5 ultra violet radiation protection sheet of material bonded to said at least one
6 first and second layers.

7
8 14. The material as set forth in Claim 13 wherein said sheet of ultra
9 violet radiation protection material is polyvinyl fluoride.

10
11 15. A material for a pressurized container comprising:
12 a first flexible cloth comprising yarns of filamentary material weaved
13 together in a 90 degree pattern;

14 a second flexible cloth comprising yarns of filamentary material at a
15 plus and minus 45 degrees to and having a strain value at failure greater
16 than said 0 and 90 degree filamentary material of said first cloth; and
17 said first and second cloths bonded together by a resin matrix.

18 16. The material as set forth in Claim 15 wherein a film of gas
19 impermeable material on the opposite side of said first flexible cloth.



- 1 17. The material as set forth in claim 16 wherein a fourth cloth of a
2 ultra-violet radiation resistant material is bonded over said film.
3
- 4 18. The material as set forth in Claim 15, or 16, or, 17 wherein said first
5 and second cloths are knitted together.
6
- 7 19. The material as set forth in Claim, or 15, or 16, or 17, wherein said
8 first and second cloths are stitched together.

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AMENDED CLAIMS

[received by the International Bureau on 7 August 1995 (07.08.1995); original claims 1, 3, 4, 7, 9-13, 15 and 16 amended; original claim 2 cancelled; remaining claims unchanged (2 pages)]

1 1. A material for a wall of a pressurized container, said material
2 comprising:
3 at least one first flexible layer comprising unidirectional
4 filamentary material at 0 and 90 degrees to each other;
5 at least one second flexible layer comprising unidirectional
6 filamentary material at 0 and 90 degrees to each other and at 45
7 degrees to and having a strain value at failure greater than said
8 0 and 90 degree filamentary material of said at least one first layer;
9 and
10 said at least one first and second layers joined together.

1 3. The material as set forth in Claim 1 wherein said at least one
2 first and second layer are joined together by bonding.

1 4. The material as set forth in Claim 1 wherein said 0 and 90 degree
2 filamentary material of said at least one first layer are woven
3 together.

1 5. The material as set forth in Claim 4 wherein said 0 and 90 degree
2 filamentary material of said at least one second layer are woven
3 together.

1 6. The material as set forth in Claim 5 wherein said unidirectional
2 filamentary material of said at least one first and second layers
3 are in the form of yarns.

1 7. The material as set forth in Claim 6 wherein said at least one
2 first layer is selected from the group consisting of liquid crystal
3 thermotropic (melt spun) polyester polyarylate and lyotropic (solvent
4 spun) aromatic polyaramide fibers.

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1 8. The material as set forth in Claim 4 wherein said filamentary
2 material of said second layer is a polyester fiber.

1 9. The material as set forth in Claim 1, or 3, or 4, or 5, or 6,
2 or 7, or 8 wherein said at least one first and second layers are
3 knitted together.

1 10. The material as set forth in Claim 1, or 3, or 4, or 5, or 6,
2 or 7, or 8 wherein said at least one first and second layers are
3 stitched together.

1 11. The material as set forth in Claims 1, or 3, or 4, or 5, or 6,
2 or 7, or 8 further comprising a flexible gas impermeable sheet of
3 material bonded to said at least one first and second layers.

1 12. The material as set forth in Claim 11 wherein said gas impermeable
2 sheet is a polyester terephthalate.

1 13. The material as set forth in Claim 10 further comprising a sheet
2 of ultra violet radiation protection material bonded to said at least
3 one first or second layers.

1 14. The material as set forth in Claim 13 wherein said sheet of
2 ultra violet radiation protection material is polyvinyl fluoride.

1 15. A material for a wall of a pressurized container, the material
2 comprising:
3 a first flexible cloth comprising yarns of filamentary material
4 weaved together in a 90 degree pattern;
5 a second flexible cloth comprising yarns of filamentary material
6 at a plus and minus 45 degrees to and having a strain value of failure
7 greater than said 0 and 90 degree filamentary material of said first
8 cloth; and
9 said first and second cloths completely bonded together by a resin
10 matrix.

1 16. The material as set forth in Claim 15 wherein a film of gas
2 impermeable material is bonded on the opposite side of said first
3 flexible cloth to which the second flexible cloth is bonded.

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