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(71) Applicant *(for all designated States except US)*: **DREXEL UNIVERSITY** [US/US]; 3201 Arch Street, Philadelphia, PA 19104 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **KO, Frank** [US/US]; 5144 Castor Avenue, Philadelphia, PA 19124 (US). **GESHURY, Amotz** [US/US]; 506 Twin Oaks Drive, Wynnewood, PA 19096 (US). **LAM, Hoa** [US/US]; 834 Cantrell Street, Phiadelphia, PA 19148 (US).

(74) Agents: **PACE, Vincent, T.** et al.; Dann, Dorfman, Herrell and Skillman, P.C., 1601 Market Street, Suite 720, Philadelphia, PA 19103-2307 (US).

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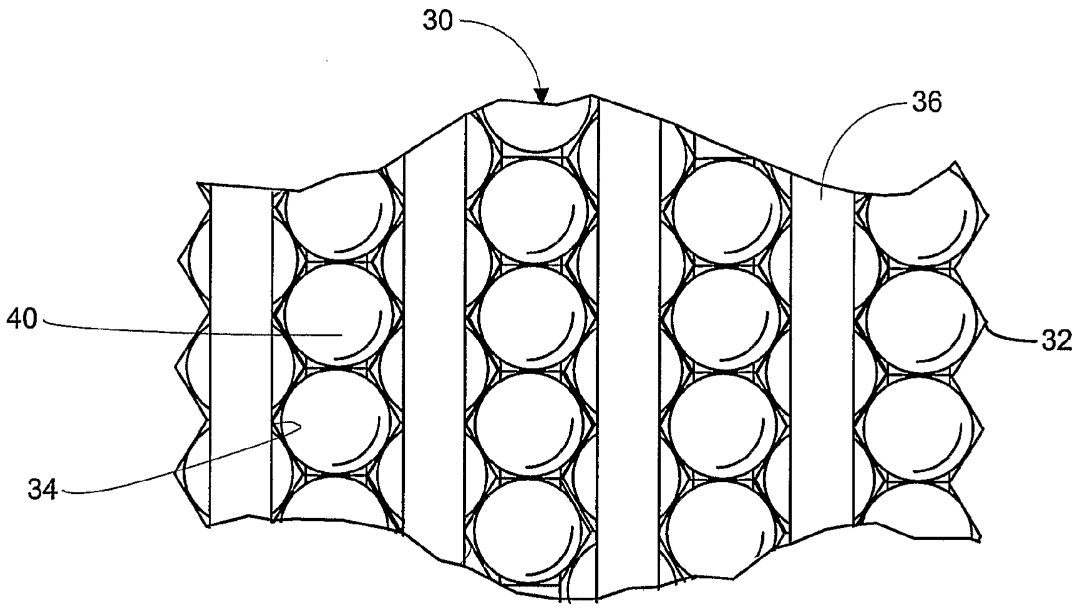
(54) Title: ANTI-BALLISTIC COMPOSITE ARMOR AND ASSOCIATED METHOD



(57) Abstract: A composite armor (20) is provided for protecting a person or object from injury or damage caused by a high velocity projectile (9) that impacts the person or object. The composite armor (20) has an energy absorbing layer (30) containing one or more lattices (32), with each lattice (32) forming a number of cells. The lattice or lattices (32) are formed of a flexible fabric. Each lattice cell (32) contains one or more particles (40) formed of a hard material. The particles (40) may be formed of a variety of materials, including but not limited to a ceramic material. In one embodiment of the invention, a sheet formed of a flexible antiballistic fabric (50) is placed over the energy absorbing layer (30).

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ANTI-BALLISTIC COMPOSITE ARMOR AND ASSOCIATED METHOD

Field of the Invention

[0001] The present invention relates to protective armor, and more specifically to flexible composite armor layers having a gradient design containing particles arranged in an organized layer.

Background

[0002] A variety of materials have been used to construct armor layers used in ballistic protection. One objective in designing armor layers is to develop a barrier capable of partially or completely destroying the ballistic projectile. Another objective is to minimize back plate deflection that can injure the person or damage an object covered by the armor. These objectives often conflict with engineering standards, such as maximum limits on the density of material and weight of the armor. Density and weight limitations are frequently specified for armor worn by military personnel.

[0003] Composite structures have been developed to satisfy performance objectives while complying with strict engineering standards. Many composite armor layers have a complex arrangement of metal armor layers and lighter shock absorbing materials. The assembly of these composite armor layers is often costly, and the multitude of layers often adds weight and reduces flexibility in the armor.

[0004] In some composite armors, particles or pellets are used to absorb kinetic energy from a ballistic projectile. Use of pellets can provide a hard face layer that has less weight than monolithic or plate layers. U.S. Patent No.

6,112,635 to Cohen discloses a composite armor panel having a plurality of pellets embedded in a solid matrix material, such as plastic. The pellets and solid material are encased in a hard armor layer made of a rigid material, such as a metallic alloy. Although the panel is intended to be lighter in weight than earlier armor panels, the composite structure does not provide a mechanism for ensuring uniform arrangement of the pellets. In addition, the hard armor layer provides a relatively rigid structure. Rigid armor layers have limited utility and can not be adapted for use on irregular surfaces. As a result, the capabilities of the known composite armors fall short of the needs of applications that require a combination of ballistic protection and flexibility.

Summary of the Invention

[0005] In light of the foregoing, the present invention provides a composite layer for protecting a person or object from penetration by a ballistic projectile. The composite layer has a flexible lattice that forms a number of cells. Particles formed of a hard material are placed in each of the cells. The lattice is made of a flexible material that conforms to the geometric contours of the person or object to be protected. The particles provide a hard layer that absorbs the impact force of a projectile and redistributes the force into weaker component forces that can be absorbed by the armor.

[0006] In one embodiment, the composite armor has a first anti-ballistic layer and a second anti-ballistic layer. The first anti-ballistic layer has a flexible lattice forming a plurality of cells. Each cell contains one or more particles which are packed together and collectively form a hard-face layer. As a projectile collides with the face layer, the particles create a fracture zone adjacent to the projectile that reduces projectile velocity and deforms or destroys the projectile. The particles also disperse the impact force of the projectile and distribute the force into smaller components having insufficient magnitude to inflict injury on a person or damage to an object. The second anti-ballistic layer comprises a sheet formed of an impact resistant material.

The lattice in the first anti-ballistic layer and the sheet in the second anti-ballistic layer are flexible to conform to the geometric contours of the person or object to be protected. The particles may be formed of ceramic spheres that are arranged in the cells of the lattice. One or more lattice layers containing such spheres may be adjoined or stacked to form the armor.

Description of the Drawings

[0007] The foregoing summary as well as the following description will be better understood when read in conjunction with the figures in which:

[0008] Figure 1 is a perspective view of a composite armor layer in accordance with the present invention;

[0009] Figure 2 is a partial plan view of a face layer of the composite armor of Figure 1;

[0010] Figure 3 is a partial plan view of an alternate embodiment of the face layer of Figure 2;

[0011] Figure 4 is a partial plan view of a further embodiment of the face layer of Figure 2;

[0012] Figure 5 is a perspective view of a further embodiment of the composite armor layer in accordance with the present invention; and

[0013] Figure 6 is a block flow diagram of a method of constructing a composite armor layer in accordance with the present invention.

Detailed Description of the Preferred Embodiment

[0014] Referring now to the drawings, and to Figure 1 specifically, a composite armor in accordance with the present invention is shown and designated generally as 20. The composite armor 20 is configured to cover a person or object and absorb energy from the impact of a high velocity projectile, such as a bullet or fragment that strikes the composite armor layer. A high speed projectile 9 is shown approaching the composite layer 20 in a trajectory substantially normal to the armor layer. The composite layer 20 has a gradient design comprising a face layer 30 and a backing layer 50 adjoining the face layer. The gradient design offers ballistic resistance while reducing armor weight and manufacturing costs. The face layer 30 and backing layer 50 are formed of flexible materials that allow the composite layer to bend and conform for a variety of uses, including but not limited to protective vests for law enforcement officers and protective armor for vehicles.

[0015] The composite armor 20 has an interior side 22 and exterior side 24. The interior side 22 of the composite armor 20 faces the object or person when the armor is in use. The exterior side 24 of the composite armor 20 is directed outwardly and receives the initial impact of ballistic projectiles. The face layer 30 is disposed rearwardly from the exterior side 24 and has a flexible lattice structure 32 that forms a plurality of cells 34, as shown in Fig. 2. The cells 34 are arranged in an organized geometry and contain a plurality of particles 40. The particles 40 provide a hard protective layer that destroys the projectile and distributes the kinetic energy from the impacting projectile over a wide area. The backing layer 50 absorbs the dispersed energy to minimize deflection of the interior side 22 of the composite armor 20, thereby reducing blunt force trauma to the person or damage to an object being protected.

[0016] The composite armor 20 will now be described in greater detail with reference to Figs. 1 and 2. The lattice 32 is preferably a honeycomb structure that holds the particles 40 in a uniform distribution within the face layer 30. The lattice 32 may be formed of any flexible dried fabric, such as non-woven, woven, knitted, or braided fabric. The dried fabric provides significant flexibility and conformability over contoured surfaces. In addition to conformability, the dried fabric provides a lighter armor design and a lower material cost than aluminum or glass. Fabrics sold under the name

"SPECTRA SHIELD" by Honeywell have performed well in the construction of the lattice 32. Oriented woven fabrics, such as tri-axial woven carbon fabric, have also performed well.

[0017] The backing layer 50 may be formed of any high strength material that is flexible to allow the composite layer to bend and conform to different surfaces. For example, the backing layer may contain glass fiber, spider silk, nylon, "KEVLAR" brand fiber, or carbon nanotube material.

[0018] In general, the main objectives of composite armor layers include the destruction of the projectile and elimination of back layer deflection that occurs at the interior side of the armor. Even though a particular armor layer may be capable of deforming and deflecting a ballistic projectile that impacts the armor, deformation of the interior side of the armor may still occur, causing serious injury or damage to persons or objects covered by the armor. A uniform arrangement of particles, such as the particles 40 used in the present invention, has proven effective in deforming or destroying projectiles while limiting back layer deflection. To optimize impact energy absorption and minimize the weight of the composite armor 20, the particles 40 are preferably formed of a material with a low to moderate density and high hardness. A variety of ceramic materials provide the desired hardness without adding significant weight to the composite armor 20. Table 1 lists the properties of four ceramic materials or composite materials that may be used to form the particles 40.

Table 1: Properties of ceramic materials

Materials	Density (g/cm^3)	Modulus (GPa)	Hardness (kg/mm^2)
Aluminum Oxide	3.40	227	1800
Boron Carbide	2.48	440	2790
Silicon Carbide	3.2	440	2700
Boron Carbide + Silicon Carbide	2.60	340	2750

[0019] Spherical particles formed of ceramic material have demonstrated significant energy absorption characteristics that are comparable to monolithic or solid ceramic layers. The spherical shape of the particles 40 has been found to alter the trajectory of the projectile and thereby change the incident angle of the projectile as it transfers energy to the face layer 30. By changing the incident angle of the projectile from an angle generally normal to the face layer 30 to an oblique angle, the normal component of force and consequent deflection of the interior side 22 of the armor is reduced. This has been observed during high speed analysis when the projectile tip collides with the face layer 30 at a point between two particles. By altering the direction of the projectile, the residual velocity of the projectile and consequent backplate deflection is decreased.

[0020] As illustrated in Fig. 2, the ceramic spheres 40 are arranged in a packed geometry to transfer kinetic energy from a high velocity projectile. More specifically, the individual spheres 40 in the lattice engage one another. A packed arrangement of spheres 40 has been found to exhibit ballistic resistant properties comparable to that of solid ceramic tile, while providing a lighter weight armor by virtue of void spaces between the spheres.

[0021] Thus far, the composite armor 20 has been described and illustrated with a single face layer 30 and a backing layer 50. It is understood, however, that a variety of configurations can be used without deviating from the scope of the invention. For example, it may be desirable to place multiple lattices together in a stacked arrangement in the face layer. As shown in Fig. 5, a composite armor 120 has a face layer 130 and a backing layer 150. The face layer 130 has three lattice layers 132A, 132B, and 132C in a stacked arrangement. The lattices are stacked adjacent to one another to form multiple layers of spheres that engage one another in a three dimensional matrix. Preferably, the matrix is arranged so that cells in adjacent layers are axially offset from one another. In this way, spheres in adjacent layers are staggered so that they can be packed tightly to distribute ballistic impact forces efficiently. The front side of the composite armor 20 may be covered by a covering layer similar to the backing layer.

[0022] The interaction of ceramic spheres 40 in the face layer will now be described. After a projectile impacts the exterior side 24 of the composite layer 20, the ceramic spheres 40 disposed at the point of impact (i.e. the "impact sphere or spheres") transfer stresses from the impact location to adjacent spheres that engage the impact spheres. Stresses disperse through the lattice layer or layers as kinetic energy is transferred through individual spheres. In the case of multiple lattice layers, the sphere layers incur a conical fracture pattern that originates at the impact point and propagates towards the interface between the face layer 30 and backing layer 50. Tensile fracture develops at the interface as the result of the reflection of the initial compressive wave as a tensile one. A conical zone of fully fragmented material develops in front of the projectile, forming a mass of ceramic fragments or powder. As a consequence of the interaction between the projectile and the ceramic powder, the projectile body is broken into fragments, stopping further penetration of the projectile.

[0023] Referring again to Fig. 2, the lattice 32 will be described in more detail. The lattice 32 may be formed using a variety of known methods in the art. In the preferred embodiment, the lattice 32 is manufactured using a folded sheet process as disclosed in U.S. Patent No. 6,183,836. The folded sheet process forms a plurality of cells 34 and a plurality of transverse bands 36 that span across the cells 34 on both sides of the lattice 32. The bands 36 provide surface area which may be bonded or fastened to the backing layer 50 to connect the face layer 30 to the backing layer. Preferably, the spheres are bound together in the lattice using a resin. Any of a variety of resins may be used, including but not limited to a vinyl ester, a toughened epoxy, or a "KAPTON" brand film.

[0024] The lattice structure may be formed with various cell sizes and shapes to accept different sized spheres. Although honeycomb shaped cells have been described thus far, a variety of cell shapes may be formed in the lattice without departing from the scope of the invention. Alternatively, the lattice may be formed from a variety of commercially available lattice structures, such as commercially available honeycomb lattices. Where a folded sheet process is used, holes may be cut in the fabric to accommodate a particular sphere diameter. As stated earlier, the lattice 32 may hold a plurality of particles of uniform size. The chosen sphere size depends on a variety of factors, including the size of the projectile that is anticipated to strike the composite armor 20. In general, spheres with diameters smaller than the cross section of the projectile provide greater velocity reduction and less deflection of the interior side. Referring to Fig. 2, the face layer 30 is shown with cells 34 each containing a single sphere 40. Fig. 3 shows a second embodiment of the face layer 30 in which each cell 34 contains a plurality of small spheres 40′. The small spheres 40′ in each cell 34 are encased in a solid material, such as an epoxy. The cells 34 may also contain a plurality of spheres having non-uniform sizes. Fig. 4 shows a third embodiment of the face layer 30 in which each cell 34 contains a primary sphere 40A and a plurality of smaller secondary spheres 40B that surround the primary sphere. In this embodiment, the primary sphere 40A and secondary spheres 40B in each cell 34 are encased in a solid material, such as an epoxy.

[0025] Although the composite armor 20 has been described with ceramic spheres, a variety of shapes may be used within the scope of the invention. For example, the flexible lattice or lattices may contain a plurality of cylindrical shaped particles, or rectangular tiles, or other polygonal objects.

[0026] Referring now to Fig. 6, a method for constructing a composite armor according to this invention is shown and designated generally as 100. Individual steps of the method are represented in block diagram form, designated generally by reference numbers 200-1200. The composite armor is formed by first selecting an appropriate fabric sheet for the face layer in step 200. The fabric sheet is processed to form a lattice that contains the particles in the face layer. In the preferred embodiment, the lattice is manufactured using the folded sheet process described in U.S. Patent No. 6,183,836, the contents of which is incorporated herein by reference. In step 300, a cutting template is fabricated and placed over the fabric. The template is fabricated with openings that correspond to the desired dimensions for the cells in the lattice. Once the template is placed over the fabric, the fabric sheet is cut to form a plurality of rectangular openings in step 400. The sheet may be cut using a hot knife, heated stamping, laser cutting or other cutting procedure.

[0027] Once the fabric sheet is cut, the process proceeds to step 500 wherein the sheet is folded along first edges of each rectangular opening to form alternating channels in the sheet. In step 600 the sheet is then folded in a direction perpendicular to the first direction along second edges of each rectangular opening. Once folded in the first and second directions, the fabric sheet is compressed in directions parallel to the first and second fold directions in step 700. As the sheet is compressed, strips between the cut sections converge at intermittent locations to form hexagonal cells. In step 800, sections that contact each other, i.e. “contact points”, are bonded together to hold the shape of the hexagonal cells. Construction of the lattice structure is essentially completed at this point.

[0028] In step 900, the backing layer is cut from one or more layers of fabric, placed into a mold cavity and consolidated in a hot press. The lattice is then spread out, and particles are placed in the cells to form an organized face layer in step 1000. As mentioned earlier, each cell may contain one or more particles of uniform or non-uniform size. Once particles are placed in the cells, the particles are bonded in place in the cells by filling the cells with a binding compound in step 1100. In the preferred embodiment, the binding compound is an epoxy resin. Once the cells are filled with particles, the face layer is placed on top of the backing layer in the mold cavity and bonded to the backing layer in step 1200. As with step 1100, the binding compound is preferably an epoxy resin. Once the face layer and backing layer are bound together, a finished composite armor is formed. The finished composite armor may then be cut and shaped to a desired configuration in step 1300.

[0029] The terms and expressions which have been employed are used as terms of description and not of limitation. There is no intention in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof. It is recognized, therefore, that various modifications are possible within the scope and spirit of the invention. Accordingly, the invention incorporates variations that fall within the scope of the following claims.

Claims

I claim:

1. An energy absorbing layer for a composite antiballistic armor comprising a flexible lattice having a plurality of cells, said lattice being formed of a flexible fabric, and a plurality of particles formed of a hard ceramic material, wherein each of the cells in the flexible lattice contains at least one of said particles.

2. An energy absorbing layer as set forth in claim 1 wherein each of the cells of the flexible lattice contains a plurality of said particles.

3. An energy absorbing layer as set forth in claim 1 wherein the plurality of particles have a substantially uniform size.

4. An energy absorbing layer as set forth in claim 1 wherein the plurality of particles comprise primary particles having a first size and secondary particles having a second size smaller than said primary particles.

5. An energy absorbing layer as set forth in claim 4 wherein each of the cells of the flexible lattice contains a primary particle and a plurality of secondary particles.

6. An energy absorbing layer as set forth in claim 5 wherein the primary and secondary particles are encased in a solid matrix material.

7. An energy absorbing layer as set forth in claim 1 wherein each of the cells of the flexible lattice contains a single ceramic particle.

8. A flexible composite armor comprising:

an energy absorbing layer having a flexible lattice that includes a plurality of cells, said lattice being formed of a flexible fabric, and said energy absorbing layer having a plurality of particles formed of a hard ceramic material, wherein each of the cells in the flexible lattice contains at least one of said particles; and

a sheet formed of a flexible antiballistic fabric positioned over a face portion of said energy absorbing layer.

9. A flexible composite armor as set forth in claim 8 further comprising a second sheet formed of the flexible antiballistic fabric, said second sheet being positioned over a second face portion of said energy absorbing layer.

10. A flexible composite armor as set forth in claim 8 further comprising a second energy absorbing layer having a flexible lattice that includes a plurality of cells, said lattice being formed of the flexible fabric, and said second energy absorbing layer having a plurality of particles formed of a hard ceramic material, wherein each of the cells in the flexible lattice contains at least one of said particles, said second energy absorbing layer being sandwiched between said energy absorbing layer and said sheet of flexible antiballistic fabric.

11. A composite layer for protecting a person or object from penetration by a ballistic projectile, said composite layer comprising:

A. a flexible lattice forming a plurality of cells; and

B. a plurality of particles disposed in the cells in engagement with one another,

wherein the flexible lattice is configured to conform to the geometric contour of the person or body to be protected, and said particles are operable to absorb an impact force and distribute said force into a plurality of weaker component forces having insufficient magnitude to penetrate into the person or object.

12. The composite layer of claim 11, wherein the lattice is formed of one of a woven, non-woven, knitted and braided fabric.

13. The composite layer of claim 11, wherein the lattice is formed of one of a polyethylene fiber and a carbon fabric.

14. The composite layer of claim 11, wherein the particles are formed of a ceramic material.

15. The composite layer of claim 11, wherein the particles comprise a plurality of spherical members.

16. The composite layer of claim 11, wherein the particles comprise a plurality of rectangular tiles.

17. The composite layer of claim 11, wherein each cell contains a plurality of particles having a uniform dimension.

18. The composite layer of claim 11, wherein each cell contains a plurality of particles having non-uniform dimensions.

19. The composite layer of claim 18, wherein each cell contains a primary particle and a plurality of secondary particles surrounding the primary particle, said secondary particles having smaller dimensions than the primary particle.

20. The composite layer of claim 11, wherein the particles are bonded to one or more interior surfaces in the cells.

21. The composite layer of claim 11, comprising one or more backing panels configured to attach the lattice to an adjacent surface.

22. A composite armor, comprising:

A. a first anti-ballistic layer, comprising:

(1) a flexible lattice forming a plurality of cells; and

(2) a plurality of particles disposed in the cells in engagement with one another; and

B. a second anti-ballistic layer, comprising a flexible sheet,

wherein the flexible lattice and flexible sheet are configured to conform to the geometric contour of the person or body to be protected, and said particles are operable to absorb an impact force and distribute said force into a plurality of weaker component forces having insufficient magnitude to penetrate into the person or object.

23. The composite armor layer of claim 22, wherein the second anti-ballistic layer is formed of one of polyethylene, glass fiber, spider silk, nylon, "KEVLAR" brand fiber and carbon nanotube.

24. The composite layer of claim 22, wherein the lattice is formed of one of a woven, non-woven, knitted and braided fabric.

25. The composite layer of claim 22, wherein the lattice is formed of one of a polyethylene fiber and a carbon fabric.

26. The composite layer of claim 22, wherein the particles are formed of a ceramic material.

27. The composite layer of claim 22, wherein the particles comprise a plurality of spherical members.

28. The composite layer of claim 22, wherein the particles comprise a plurality of rectangular tiles.

29. The composite layer of claim 22, wherein each cell contains a plurality of particles having a uniform dimension.

30. The composite layer of claim 22, wherein each cell contains a plurality of particles having non-uniform dimensions.

31. The composite layer of claim 30, wherein each cell contains a primary particle and a plurality of secondary particles surrounding the primary particle, said secondary particles having smaller dimensions than the primary particle.

32. The composite layer of claim 22, wherein the particles are bonded to one or more interior surfaces in the cells.

33. The composite layer of claim 22, comprising one or more panels configured to attach the lattice to the flexible sheet.

34. The composite layer of claim 22, wherein the first anti-ballistic layer comprises a plurality of adjacent flexible lattices forming a plurality of cells in a stacked arrangement, wherein cells of adjacent lattices are axially offset from one another.

35. A method of constructing a composite armor layer, said method comprising the steps of:

A. selecting a flexible fabric;

B. forming a honeycomb shaped lattice from the fabric, said lattice having a plurality of cells;

C. filling the cells in the lattice with a plurality of spherical ceramic particles;

D. placing the lattice and ceramic particles on top of a flexible backing layer; and

E. binding the lattice, ceramic particles and backing layer together with a resin.

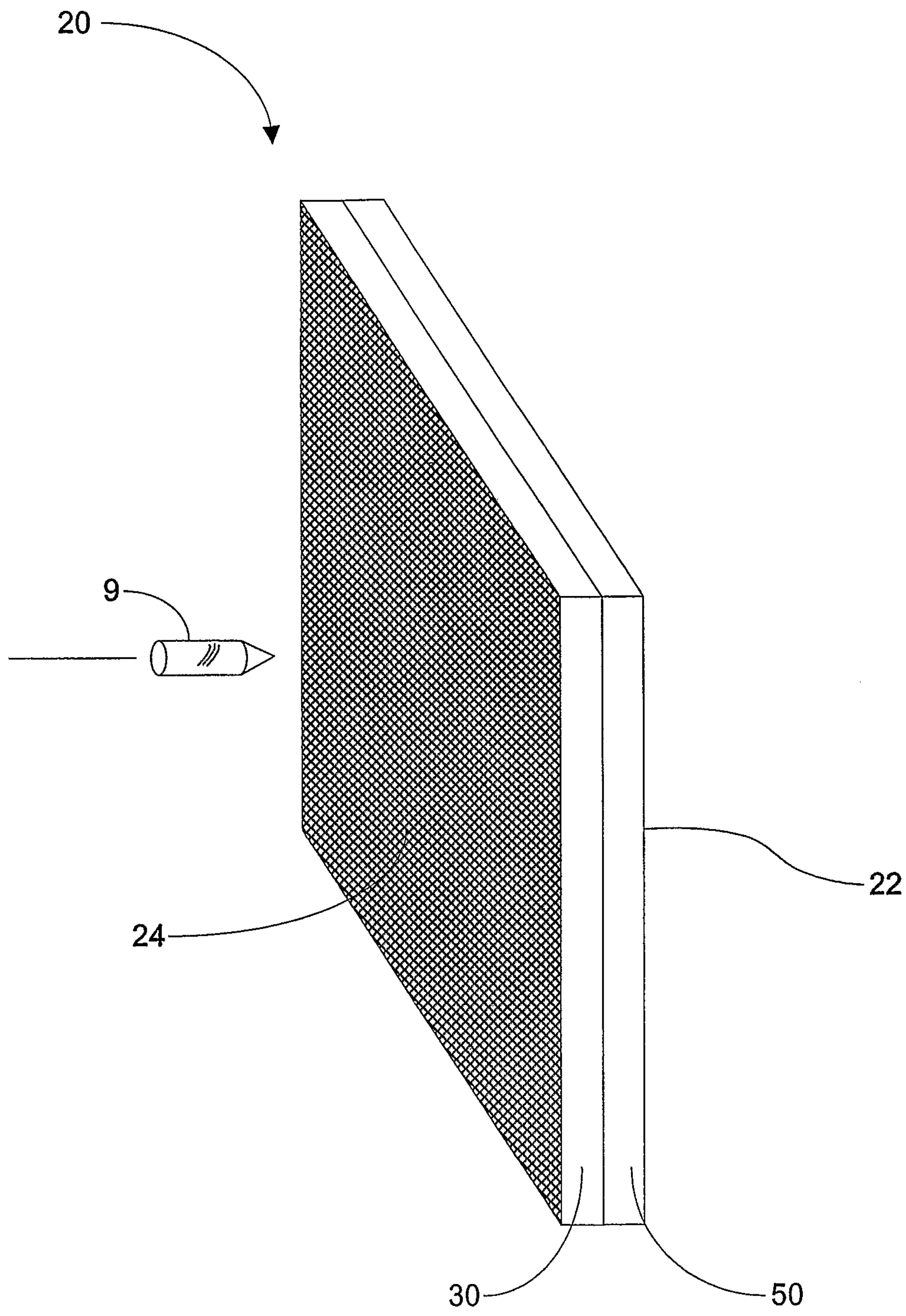

FIGURE 1

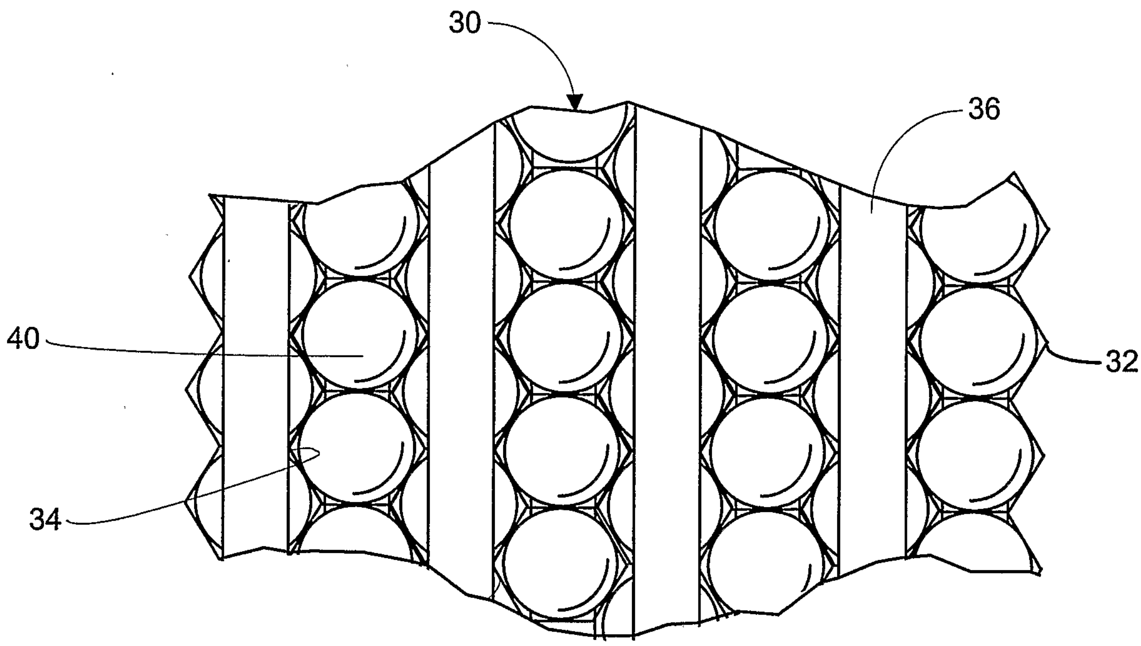

FIGURE 2

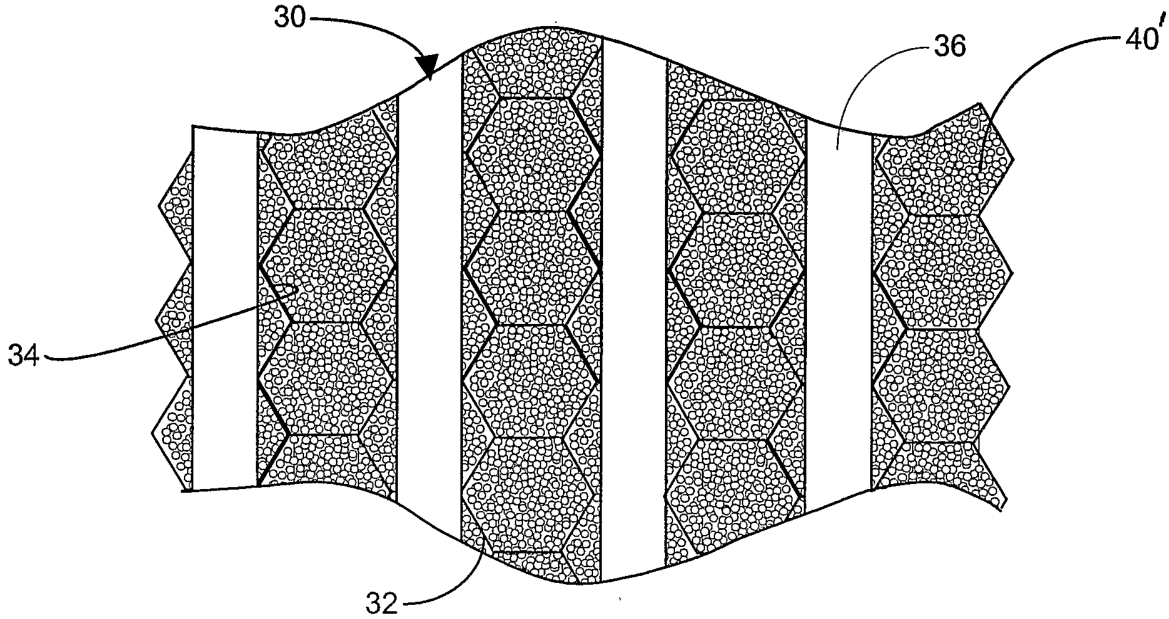

FIGURE 3

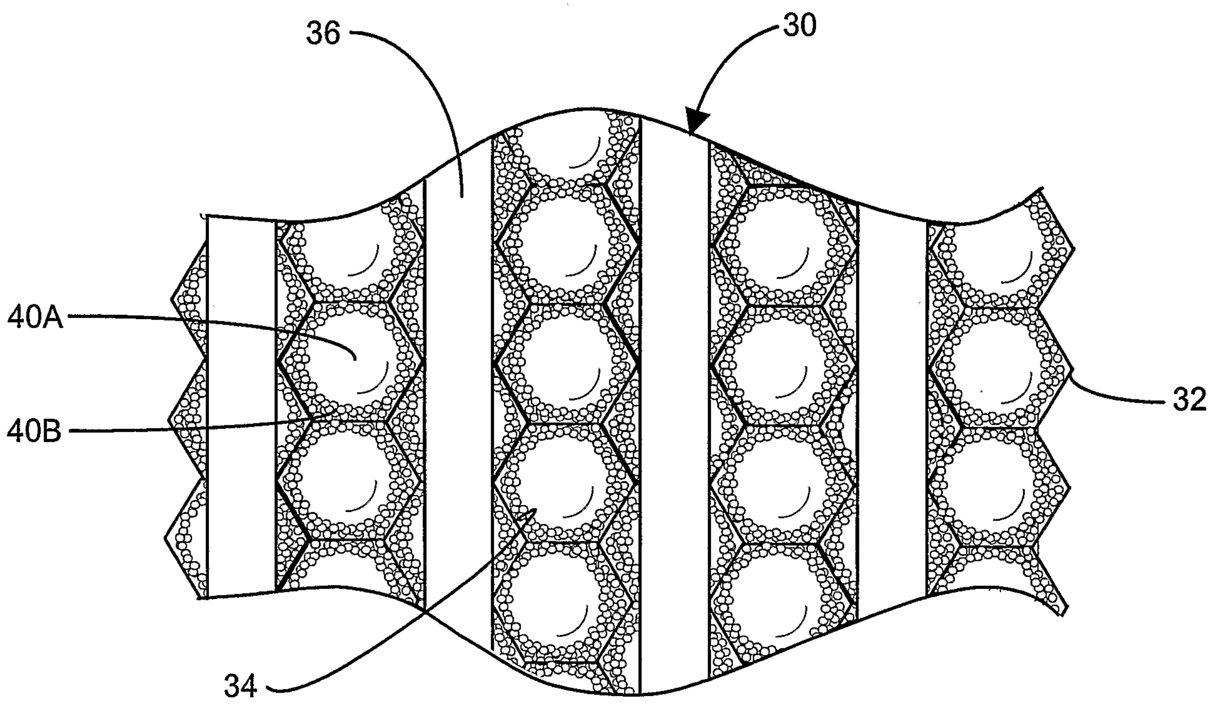

FIGURE 4

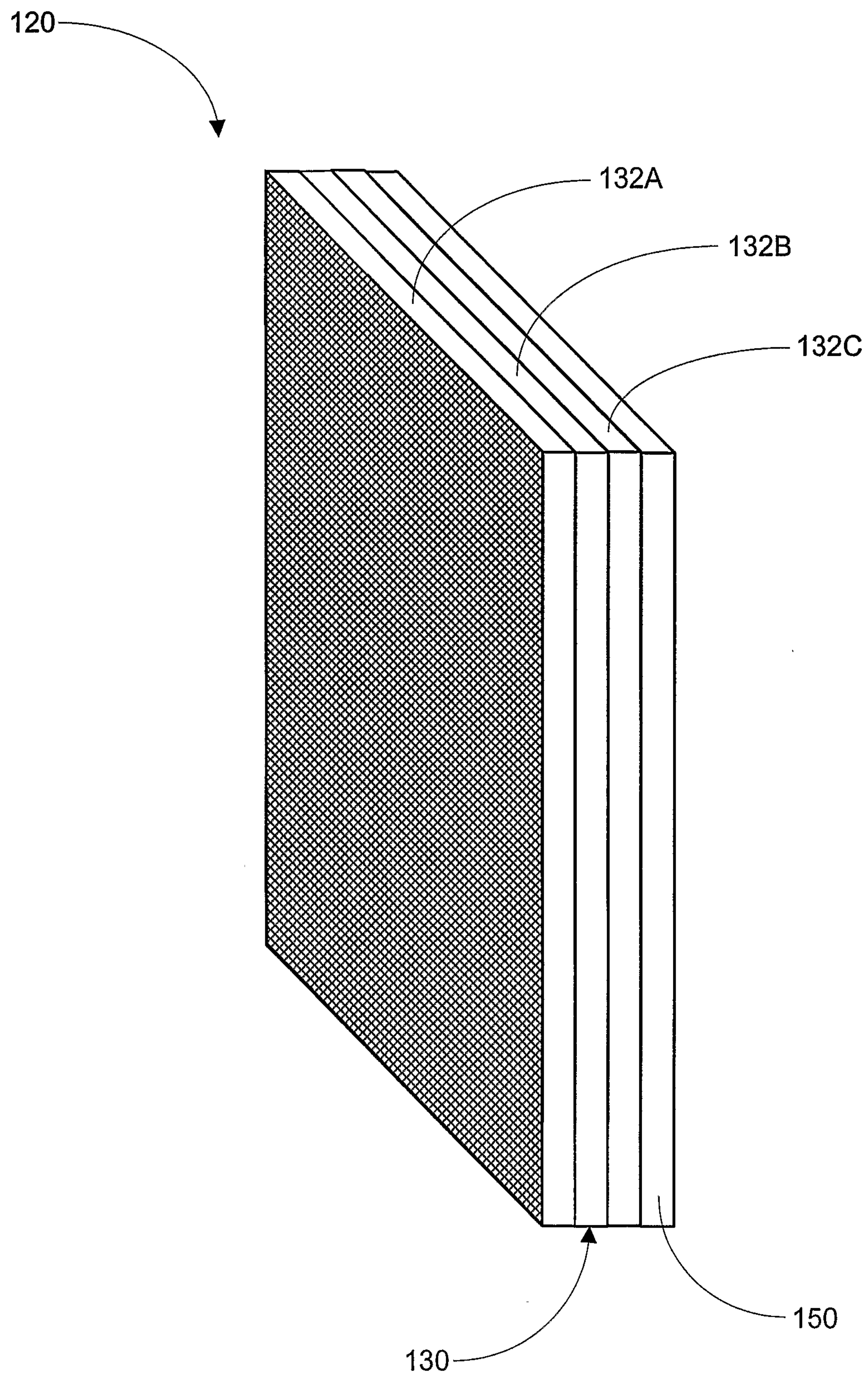

FIGURE 5

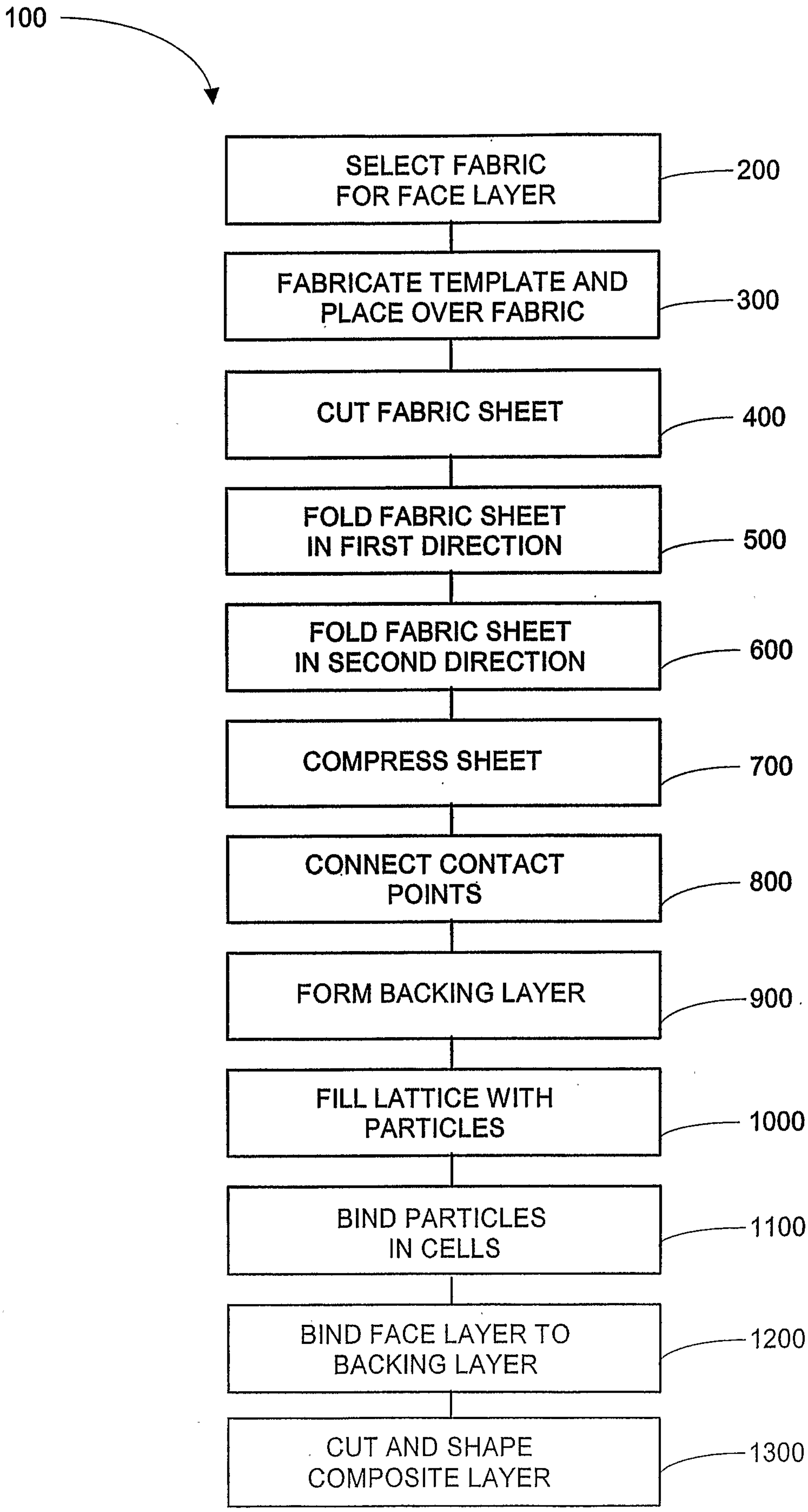
100
SELECT FABRIC FOR FACE LAYER
200
FABRICATE TEMPLATE AND PLACE OVER FABRIC
300
CUT FABRIC SHEET
400
FOLD FABRIC SHEET IN FIRST DIRECTION
500
FOLD FABRIC SHEET IN SECOND DIRECTION
600
COMPRESS SHEET
700
CONNECT CONTACT POINTS
800
FORM BACKING LAYER
900
FILL LATTICE WITH PARTICLES
1000
BIND PARTICLES IN CELLS
1100
BIND FACE LAYER TO BACKING LAYER
1200
CUT AND SHAPE COMPOSITE LAYER
1300

FIGURE 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US03/10664

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : F41H 5/04
US CL : 89/36.02, 36.05; 2/2.5
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 89/36.02, 36.05; 2/2.5

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EU 611943 A1 (DAVEY) 24 August 1994 (24.08.1994) see entire disclosure	1 and 7-10
X	US 5,110,661 A (GROVES) 05 May 1992 (05.05.1992) see entire disclosure	1-3, 7-12, 14-15, 17-18, 20-24, 26-27, 29-30, and 32-34
X	US 5,349,893 A (DUNN) 27 September 1994 (27.09,1994) see entire disclosure	1-3, 7-15, 17-18, 20-26, 29-30, and 32-33
X	GB 2,149,482 A (APPRICH) 12 June 1985 (12.06.1985) see entire disclosure	1-5, 7-12, 14, 16, 18-24, 26, 28, and 30-34

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* *Special categories of cited documents:*

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Date of the actual completion of the international search	Date of mailing of the international search report
28 July 2003 (28.07.2003)	22 APR 2004

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Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450
Facsimile No. (703)305-3230

Authorized officer
Stephen M. Johnson
Telephone No. (703) 306-4158