



US 20140013492A1

(19) **United States**(12) **Patent Application Publication**
Bottlang et al.(10) **Pub. No.: US 2014/0013492 A1**(43) **Pub. Date: Jan. 16, 2014**(54) **PROTECTIVE HELMET FOR MITIGATION
OF LINEAR AND ROTATIONAL
ACCELERATION****Publication Classification**(51) **Int. Cl.**
A42B 3/12 (2006.01)
(52) **U.S. Cl.**
CPC **A42B 3/125** (2013.01)
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Portland, OR (US)**(21) Appl. No.: **13/803,962**(22) Filed: **Mar. 14, 2013****Related U.S. Application Data**(60) Provisional application No. 61/670,258, filed on Jul.
11, 2012.(57) **ABSTRACT**

Embodiments provide protective helmets configured to protect the head from linear and rotational acceleration in an impact. In various embodiments, the helmets may include an outer layer, an inner layer, and at least one intermediate layer coupled to the outer and inner layers by alternate fixation sites, thereby providing a suspension between the outer and inner layers. In various embodiments, the intermediate layer may be made from a honeycomb material, such as an aluminum honeycomb. In use, in-plane deformation of the honeycomb may allow for translation of the outer layer in a substantially tangential direction relative to the inner layer, thereby mitigating rotational acceleration imparted by the tangential impact component. Additionally, crumpling of the honeycomb in a substantially non-elastic manner may deplete impact energy to minimize the elastic rebound that can contribute to linear and rotational head acceleration, thereby mitigating linear acceleration imparted by the perpendicular impact component.

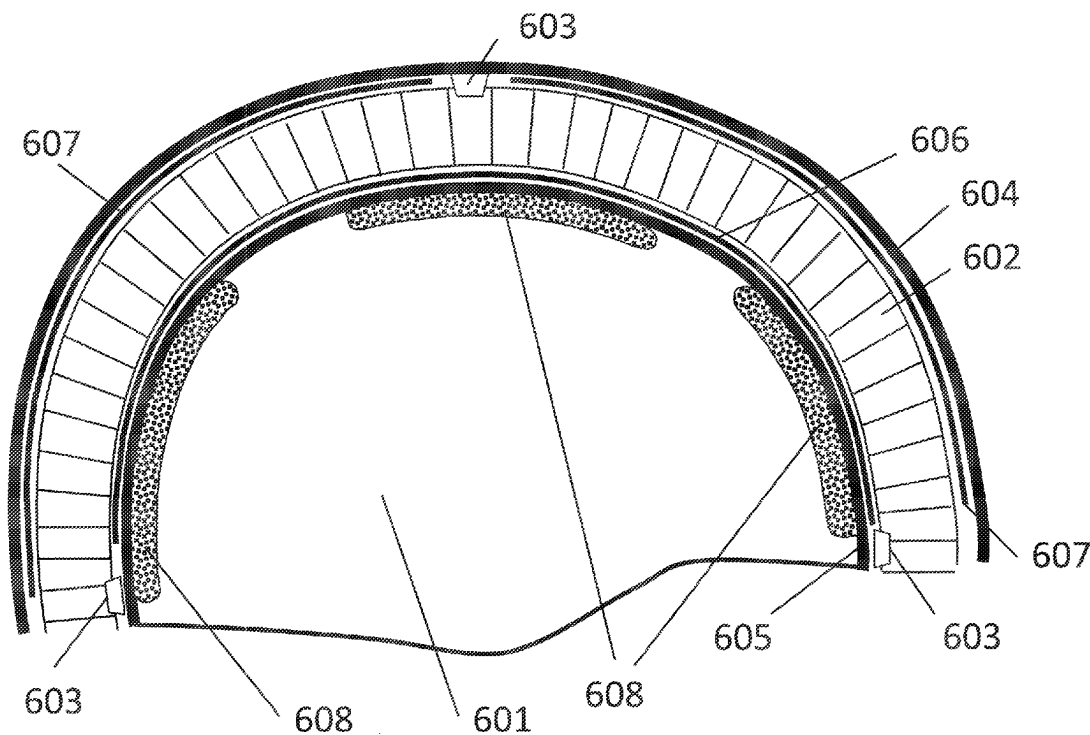
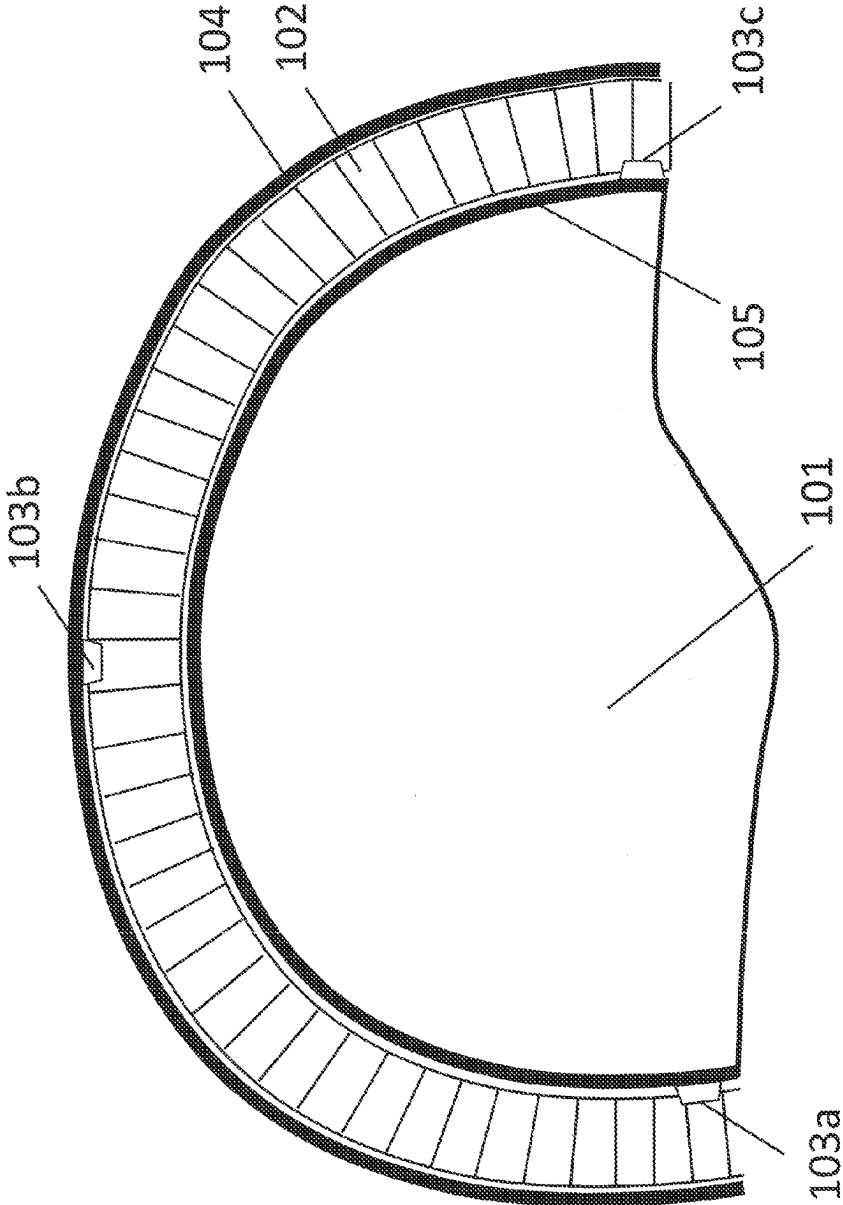


Figure 1



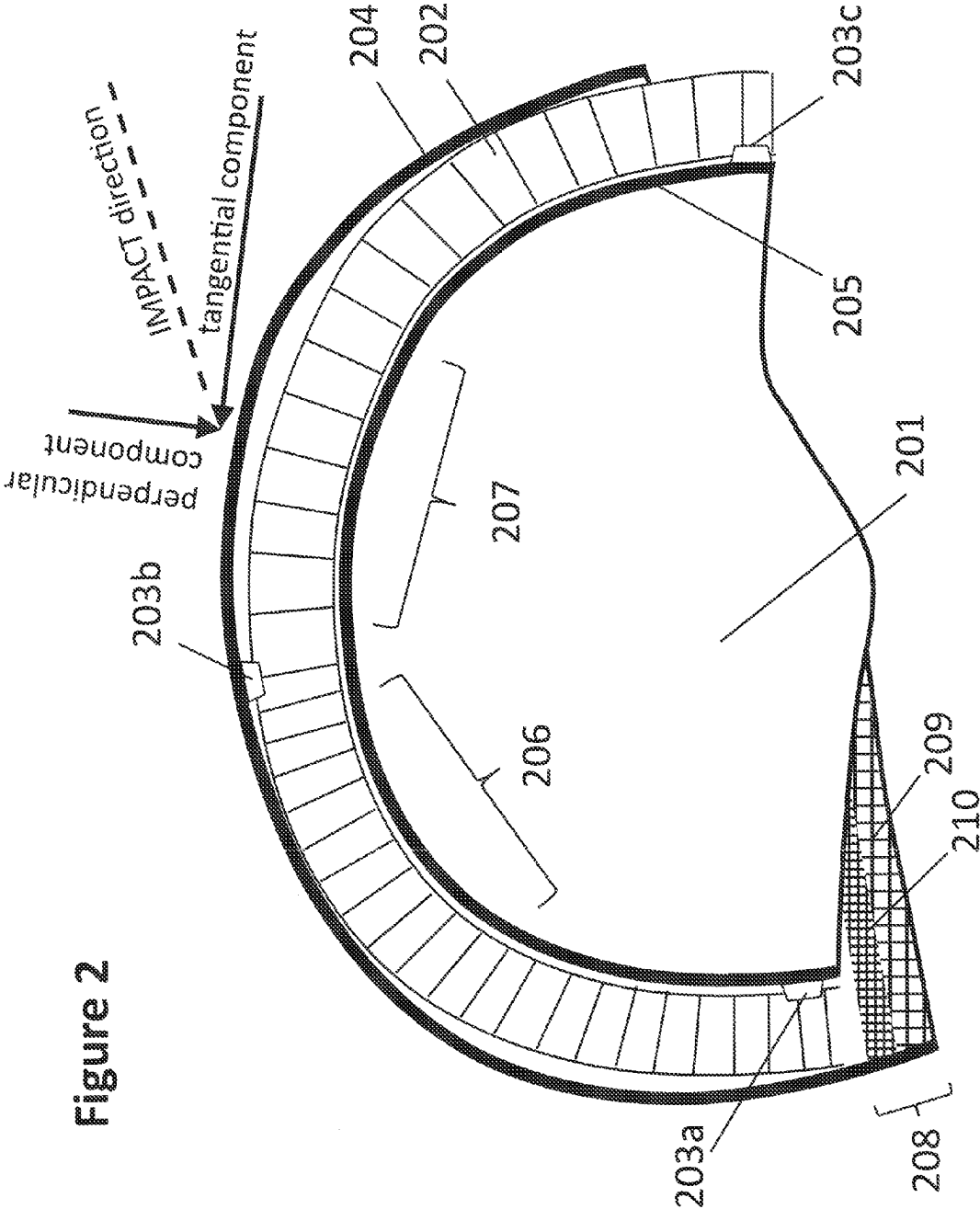


Figure 2

Figure 3B

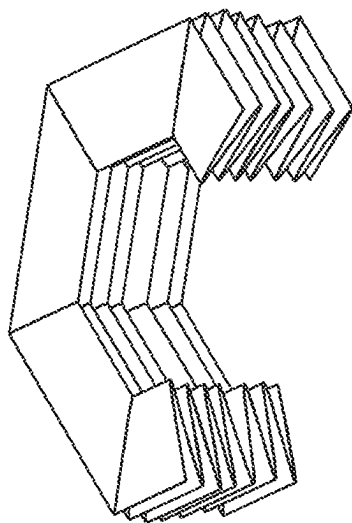


Figure 3A

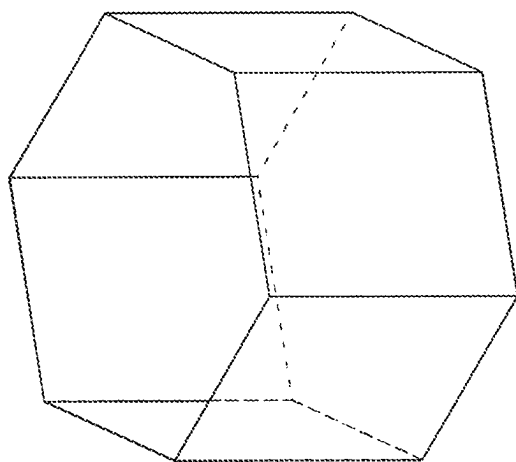


Figure 4B

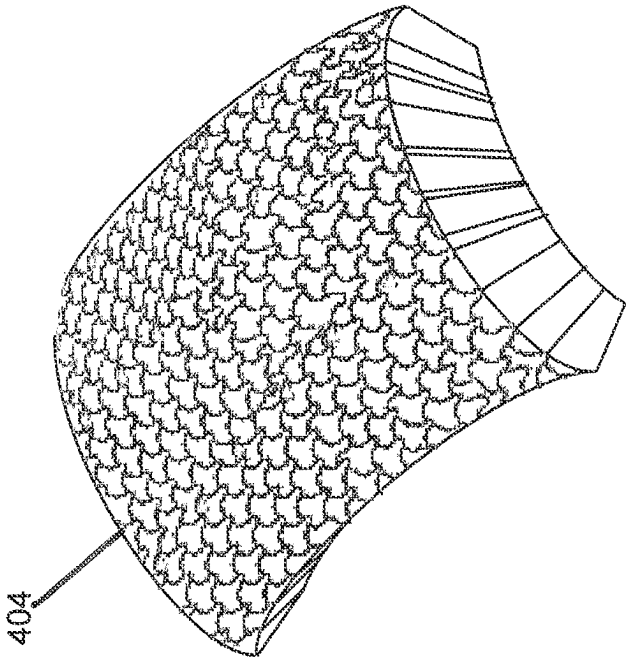


Figure 4A

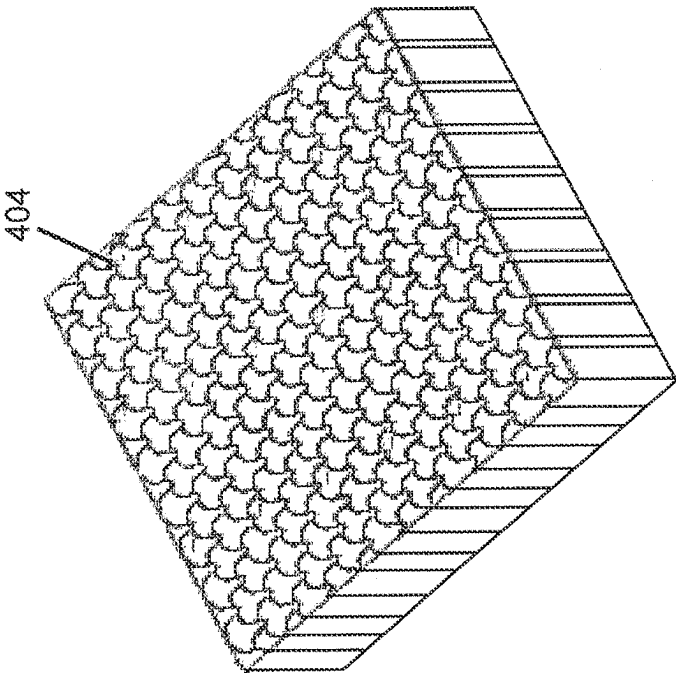


Figure 5C

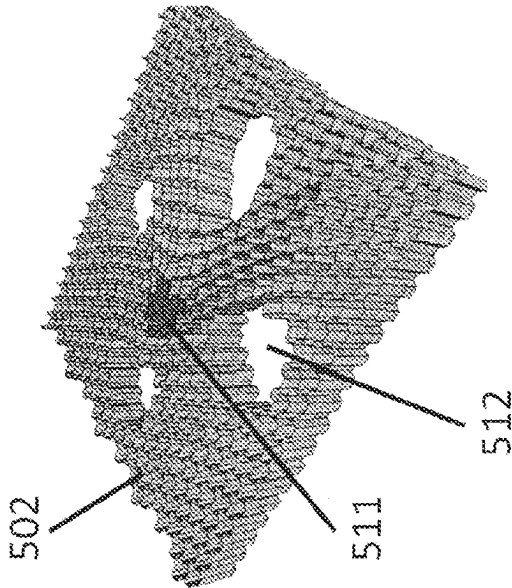


Figure 5B

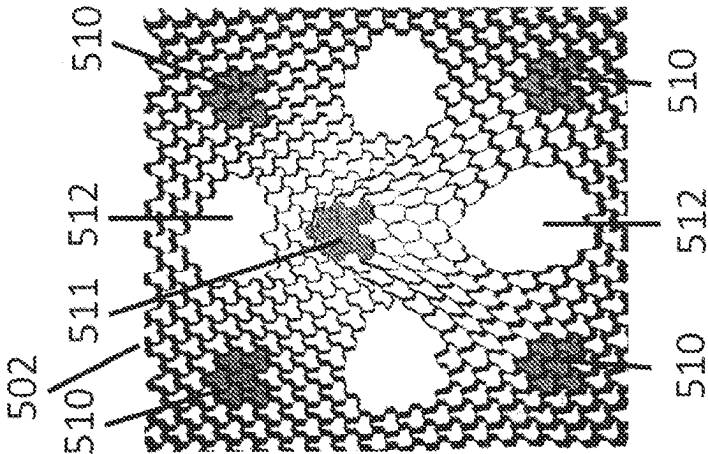


Figure 5A

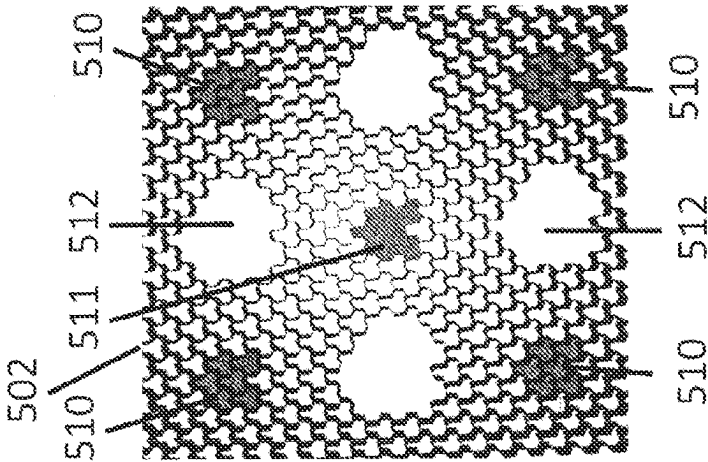


Figure 6

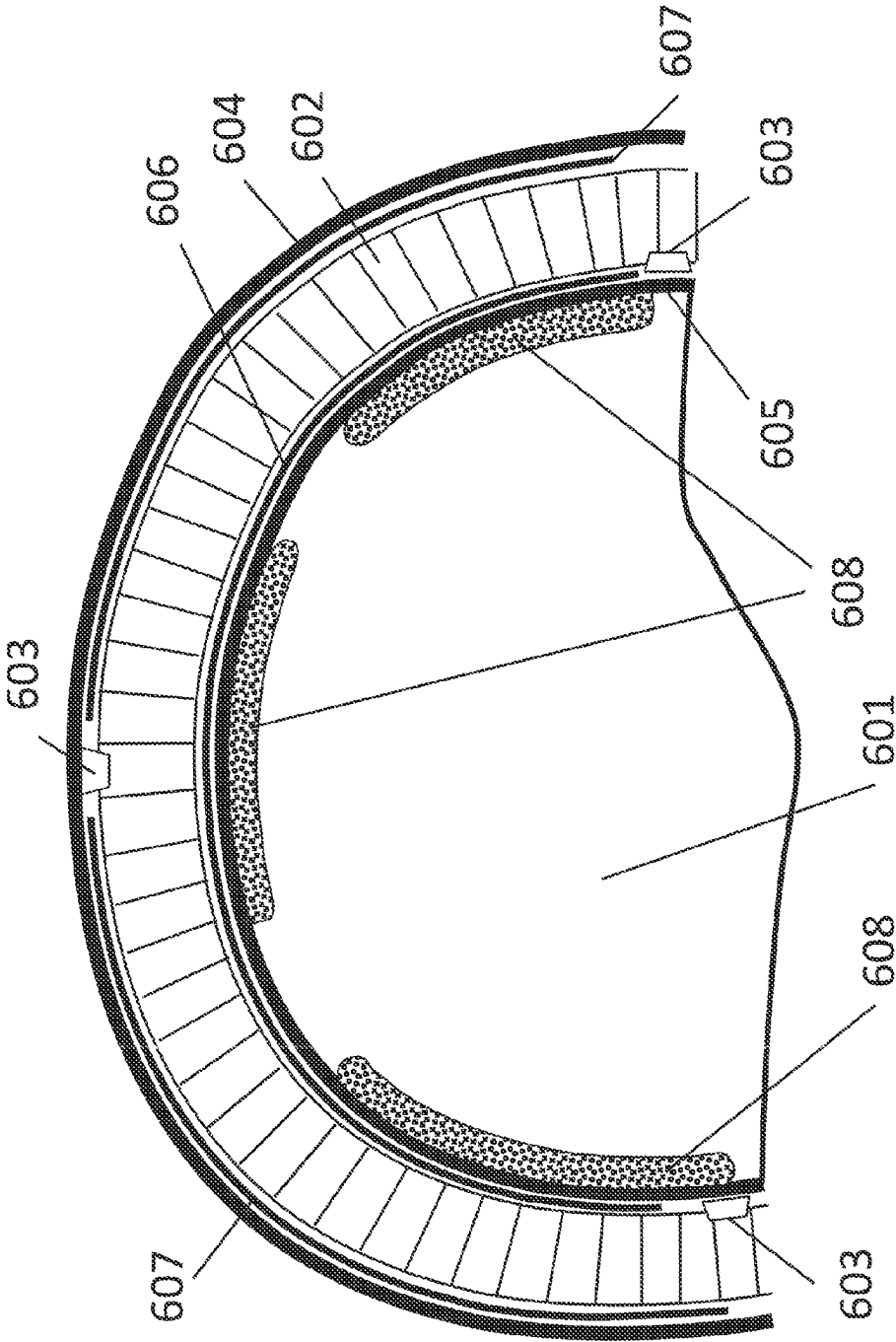


Figure 7

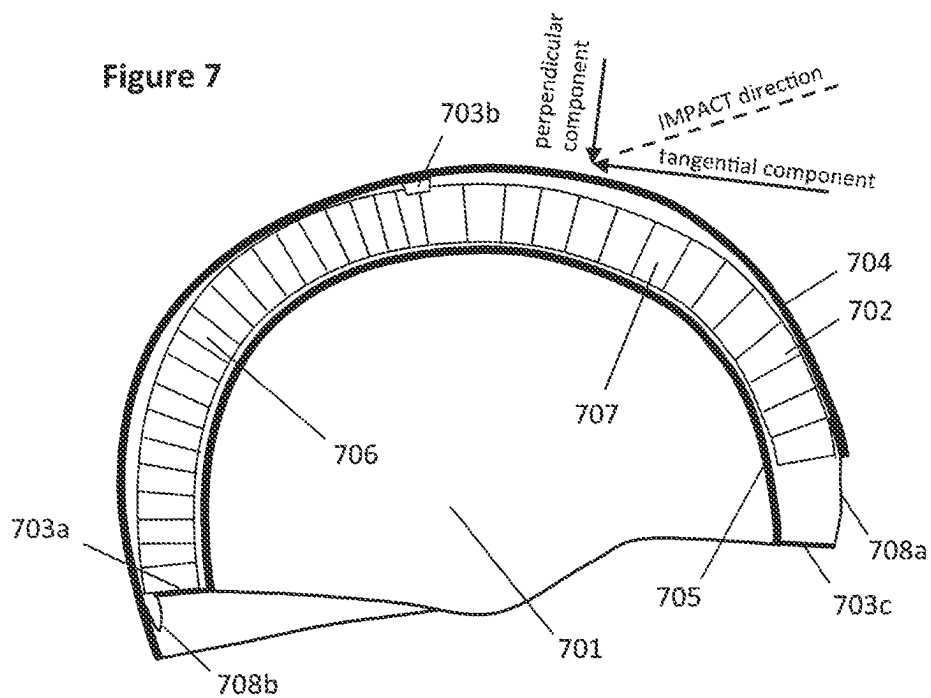
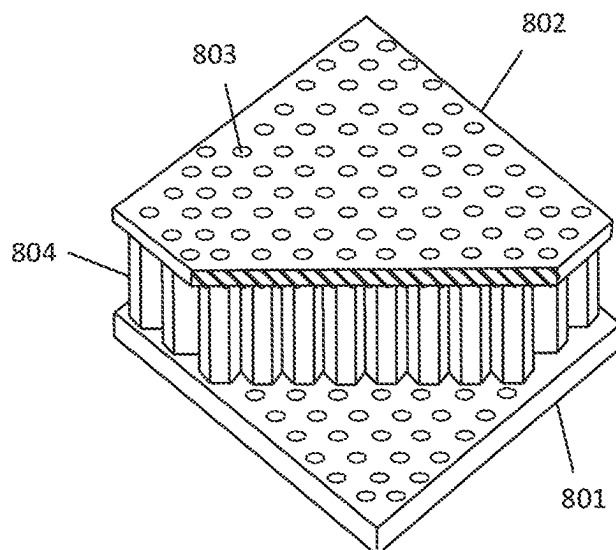


Figure 8



PROTECTIVE HELMET FOR MITIGATION OF LINEAR AND ROTATIONAL ACCELERATION

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to U.S. Patent Application No. 61/670,258, filed Jul. 11, 2012, entitled “PROTECTIVE HELMET FOR MITIGATION OF LINEAR AND ROTATIONAL ACCELERATION,” the entire disclosure of which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] Embodiments herein relate to the field of protective helmets and, more specifically, to helmets designed to protect the head from linear and rotational acceleration

BACKGROUND

[0003] Helmets protect the head from injury during a direct impact. An impact to the head can cause skull fracture and/or traumatic brain injury (TBI), and TBI is the leading cause of death and long-term disability in the US among people under 45. 90% of traumatic brain injuries occur without the presence of a skull fracture, and TBI can be induced by rotational acceleration alone. Despite the vulnerability of the brain to rotational acceleration, contemporary bicycle helmets are primarily designed and tested to mitigate linear acceleration. Most contemporary helmets have two principal shortcomings: first, they have limited means to absorb rotational acceleration, and second, elastic helmet liners may store energy during impact, and release of the stored energy may induce a rebound after impact that may contribute to the severity and duration of rotational head acceleration.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Embodiments will be readily understood by the following detailed description in conjunction with the accompanying drawings. Embodiments are illustrated by way of example and not by way of limitation in the figures of the accompanying drawings.

[0005] FIG. 1 illustrates a cross-sectional mid-sagittal view of an example of a helmet, shown in an unloaded, non-deformed configuration, in accordance with various embodiments;

[0006] FIG. 2 illustrates a cross-sectional mid-sagittal view of a helmet shown during impact in a loaded, partially deformed configuration, and depicting relative translation between the outer and inner layers, accommodated by in-plane compression and tension of the intermediate layer, in accordance with various embodiments;

[0007] FIGS. 3A and 3B illustrate non-elastic, plastic deformation of an example of a honeycomb membrane, shown in non-deformed (FIG. 3A) and deformed (FIG. 3B, with cut-away) states, in accordance with various embodiments;

[0008] FIGS. 4A and 4B illustrate schematic drawings of a planar segment (FIG. 4A) and a spherically shaped segment (FIG. 4B) of an exemplary honeycomb configuration that enables spherical, three-dimensional shaping, in accordance with various embodiments;

[0009] FIGS. 5A, 5B, and 5C depict a schematic drawing of a honeycomb layer segment with alternate fixation points,

shown in unloaded (FIG. 5A) and loaded, deformed conditions (FIG. 5B), and a perspective view of the honeycomb layer in a loaded, deformed condition (FIG. 5C), in accordance with various embodiments;

[0010] FIG. 6 illustrates a cross-sectional mid-sagittal view of an exemplary helmet shown in conjunction with additional layer segments adjacent to the intermediate layer to facilitate sliding of the intermediate layer relative to the inner and outer layers, in accordance with various embodiments;

[0011] FIG. 7 illustrates a cross-sectional mid-sagittal view of one embodiment of a helmet, shown during impact in a loaded, partially deformed configuration, in accordance with various embodiments; and

[0012] FIG. 8 illustrates a cross-sectional view of a section of another embodiment, wherein the outer layer and inner layer are perforated with a multitude of holes, which may allow for ventilation through the honeycomb cells, in accordance with various embodiments.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[0013] In the following detailed description, reference is made to the accompanying drawings which form a part hereof, and in which are shown by way of illustration embodiments that may be practiced. It is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope. Therefore, the following detailed description is not to be taken in a limiting sense, and the scope of embodiments is defined by the appended claims and their equivalents.

[0014] Various operations may be described as multiple discrete operations in turn, in a manner that may be helpful in understanding embodiments; however, the order of description should not be construed to imply that these operations are order dependent.

[0015] The description may use perspective-based descriptions such as up/down, back/front, and top/bottom. Such descriptions are merely used to facilitate the discussion and are not intended to restrict the application of disclosed embodiments.

[0016] The terms “coupled” and “connected,” along with their derivatives, may be used. It should be understood that these terms are not intended as synonyms for each other. Rather, in particular embodiments, “connected” may be used to indicate that two or more elements are in direct physical with each other. “Coupled” may mean that two or more elements are in direct physical or electrical contact. However, “coupled” may also mean that two or more elements are not in direct contact with each other, but yet still cooperate or interact with each other.

[0017] For the purposes of the description, a phrase in the form “A/B” or in the form “A and/or B” means (A), (B), or (A and B). For the purposes of the description, a phrase in the form “at least one of A, B, and C” means (A), (B), (C), (A and B), (A and C), (B and C), or (A, B and C). For the purposes of the description, a phrase in the form “(A)B” means (B) or (AB) that is, A is an optional element.

[0018] The description may use the terms “embodiment” or “embodiments,” which may each refer to one or more of the same or different embodiments. Furthermore, the terms “comprising,” “including,” “having,” and the like, as used with respect to embodiments, are synonymous.

[0019] Embodiments herein provide protective helmets designed to lessen the amount of harmful acceleration (both

straight linear and rotational) that reaches the brain of a wearer during an impact to the head. In various embodiments, the helmets may include a multilayer construction for both cushioning and absorbing impact and rotational energy, thus reducing peak acceleration or deceleration of a wearer's head in an impact. In various embodiments, this reduction in head acceleration and deceleration may result in a corresponding reduction in the magnitude of acceleration or deceleration experienced by the brain, reducing the risk and/or severity of traumatic brain injury (TBI).

[0020] In various embodiments, the helmets disclosed herein may include a suspension of a compressible intermediate layer suspended between generally non-compressible inner and outer layers. In various embodiments, the suspension of the compressible intermediate layer may mitigate transfer of rotational acceleration from the outer layer to the inner layer. In various embodiments, the suspension may be created by coupling the compressible intermediate layer, such as a honeycomb layer, through discrete, alternate (e.g., non-opposing) fixation sites, to the outer and inner helmet layers in a manner that allows substantially tangential translation of the outer layer relative to the inner layer. Thus, in various embodiments, translation of the outer layer relative to the inner layer may induce in-plane compression and tension in the intermediate layer, rather than shearing.

[0021] In various embodiments, in addition to providing a suspension between the inner and outer layers, the intermediate layer also may crumple and/or compress in an essentially non-elastic manner to mitigate linear acceleration by depleting impact energy and minimizing elastic rebound, which can otherwise contribute to linear and rotational head acceleration. As such, in various embodiments, the disclosed helmets may allow tangential impact components to be absorbed by in-plane compressive or tensile deformation of the intermediate layer, and perpendicular impact components to be absorbed by non-elastic crumpling/compression of the intermediate layer.

[0022] In various embodiments, the intermediate layer may include a honeycomb, such as a honeycomb formed from any material having little or no elastic rebound. For example, in various embodiments, the honeycomb may be formed from compressible aluminum elements. Although the examples illustrated herein use aluminum honeycombs, one of skill in the art will appreciate that other lightweight, compressible materials may be employed that have little or no elastic rebound, such as cardboard or paper pulp, various natural or synthetic foams (such as aluminum foam), plastic, non-elastic polymers, and the like.

[0023] In various embodiments, the layered construction of the helmets disclosed herein may be used to construct any type of protective headgear, such as safety helmets, motorcycle helmets, bicycle helmets, ski helmets, lacrosse helmets, hockey helmets, football helmets, batting helmets for baseball and softball, headgear for rock and mountain climbers, headgear for boxers, construction helmets, helmets for defense and military applications, and headgear for underground activities. In other embodiments, the layered technologies disclosed herein may be adapted for use in other types of protective gear, such as elbow pads, knee pads, shoulder pads, shin guards, and the like.

[0024] FIG. 1 illustrates a cross-sectional mid-sagittal view of an example of a helmet, shown in an unloaded, non-deformed configuration, in accordance with various embodiments. In the illustrated embodiment, the helmet 101 has an

aerodynamic shape designed for use by bicyclists. As illustrated, helmet 101 may include an outer layer 104, an inner layer 105, and an intermediate layer 102. In various embodiments, intermediate layer 102 may be made from a honeycomb material, such as an aluminum honeycomb material, and may be coupled to the outer and inner layers 104, 105 at alternate fixation sites 103a, 103b, 103c. As defined herein, the term "alternate fixation sites" refers to attachment points between the outer and intermediate layers, or the intermediate and inner layers, that are spaced apart such that the outer and intermediate layers are not coupled together at a point directly above (e.g., across a thickness dimension of the helmet) a fixation site between the intermediate and inner layers. The term "alternate fixation sites" does not require that each fixation site alternates with respect to adjacent sites along a length of a layer. In embodiments, there may be, for example, two fixation sites adjacent to each other between the intermediate layer 102 and the outer layer 104 and one or more fixation sites between the intermediate layer 102 and the inner layer 105 further in one direction along the layers. In various embodiments, these alternate fixation sites 103a, 103b, 103c may be positioned such that intermediate layer 102 is not coupled to both the outer and inner layers 104, 105 at opposing locations of intermediate layer 102, so that, for example, a fixation site 103b between intermediate layer 102 and outer layer 104 is not directly opposed to a fixation site 103a, 103c between intermediate layer 102 and inner layer 105, and vice versa. In various embodiments, this alternate fixation may leave portions of intermediate layer 102 that are coupled to neither outer layer 104 nor inner layer 105, enabling stretching and/or compression of intermediate layer 102 between alternate fixation sites 103a, 103b, 103c, thus enabling translation of outer layer 104 relative to inner layer 105, as described in greater detail below.

[0025] In various embodiments, outer helmet layer 104 may be sufficiently stable, rigid, and/or non-compressible to distribute impact forces over an extended area. One of skill in the art will appreciate that the shape depicted in FIG. 1 is merely exemplary, and that the helmet shape can vary depending on the particular sporting event or activity for which the helmet is designed. Furthermore, helmets in accordance with the present disclosure may include additional features, such as a cage for a hockey helmet, a face mask for a football helmet, a visor for a motorcycle helmet, and/or retention straps, chin straps, and the like. Although not shown in the illustrated embodiment, inner, intermediate, and/or outer layers 105, 102, 104 may include one or more ventilation openings to permit air flow for cooling the wearer's head.

[0026] In the illustrated embodiment, intermediate layer 102 may include an aluminum honeycomb, arranged with its cells oriented generally perpendicular to the outer layer 104 of the helmet. In various embodiments, inner layer 105 may be applied to at least a portion of the intermediate layer 102 interior surface. In embodiments, the inner layer covers most if not all of the intermediate layer. The inner layer may be comprised of a singular component, of multiple, partially overlapping components, or of multiple components that are joined together in a flexible manner (e.g., like the sewn patches of a soccer ball). As described above, in various embodiments, intermediate layer 102 may be coupled to outer layer 104 and inner layer 105 at discrete and alternate fixation sites 103a, 103b, 103c so as to provide a suspension between outer layer 104 and inner layer 105. For example, in some embodiments, outer layer 104 may be coupled to intermediate

layer **102** at the helmet crown **103b**, and inner layer **105** may be coupled to intermediate layer **102** at the helmet periphery **103a**, **103c**. Without being bound by theory, this configuration may reduce the rotational head acceleration caused by the impact component acting tangential to the helmet surface, and it also may reduce linear head acceleration caused by the impact component acting perpendicular to the helmet surface, as described in greater detail below. Other configurations/arrangements may be used in other embodiments.

[0027] FIG. 2 illustrates a cross-sectional mid-sagittal view of a helmet **201** shown during impact in a loaded, partially deformed configuration, and depicting relative translation between the outer and inner layers **204**, **205**, accommodated by in-plane compression and tension of the intermediate layer **202**, in accordance with various embodiments. In the illustrated embodiment, as described above, intermediate layer **202** may be suspended between inner layer **205** and outer layer **204** via coupling to both layers **204**, **205** at alternate fixation sites **203a**, **203b**, **203c**. In use, when helmet **201** is exposed to a primarily tangential impact, this impact induces relative translation between outer layer **204** and inner layer **205**, accommodated by in-plane compression **206** and tension **207** (e.g., expansion) of intermediate layer **202**.

[0028] In various embodiments, the suspension of intermediate layer **202** between inner layer **205** and outer layer **204** also may allow for small amounts of translation of inner layer **205** perpendicular to and away from outer layer **204**. In various embodiments, this increase in separation between outer layer **204** and inner layer **205** may accommodate tangential translation between outer and inner layers **204**, **205** in an ovoid, non-spherical shape of helmet **201**. Without being bound by theory, in various embodiments, a primary benefit of translation between the outer and inner layers **204**, **205** during impact may be mitigation of rotational head acceleration. In some embodiments, an additional benefit may be that translation distributes the impact over a larger segment of intermediate layer **202**, which may increase absorption of the impact force component perpendicular to the outer layer **204** by controlled crumpling of the honeycomb of the intermediate layer **202** in a direction perpendicular to the honeycomb elements. In some embodiments, a surface of inner layer **205**, outer layer **204**, or intermediate layer **202** may include one or more indicators that show the amount of translation **208** between the outer and inner layers **204**, **205** in response to an impact to estimate impact severity. For example, such indicators may be comprised of graded color bands **209**, **210** that circumscribe the periphery of the inside of outer layer **204**, whereby increased exposure of color bands **209**, **210** indicates an increased impact force.

[0029] In some embodiments, the intermediate layer may include two or more layers of honeycomb materials having different stiffness, such that the less stiff layers protect the brain during mild impacts, and the stiffer layers protect the brain during severe impacts. In other embodiments, the honeycomb cells may be entirely or partially filled with an additional energy absorbing material, such as an expanded foam. In particular embodiments, the additional energy absorbing material may be of non-uniform thickness, and may be configured, for example, such that the intermediate layer becomes progressively stiffer as it is crushed in the direction tangential to the outer layer, and/or in the direction perpendicular to the outer layer. In still other embodiments, the additional energy absorbing material also may form a solid layer on the inner and/or outer surface of the honeycomb.

[0030] FIGS. 3A and 3B illustrate non-elastic, plastic deformation of an example of a honeycomb layer, shown in non-deformed (FIG. 3A) and deformed, partially cut-away (FIG. 3B) states, in accordance with various embodiments. In various embodiments, an impact force acting perpendicular to the outer helmet surface in excess of the compressive strength of the honeycomb layer may induce plastic, permanent compression of the honeycomb layer by means of crumpling of honeycomb cells. In various embodiments, the plastic, non-recoverable crumpling of honeycomb cells may absorb an impact by depleting a portion of the impact force. Thus, this crumpling may reduce or eliminate rebound after impact, which may otherwise induce rotational head acceleration subsequent to a primary impact. In some embodiments, in order to minimize an initial peak force required to initiate crumpling, the honeycomb layer may be pre-crushed to a certain degree, such as about 1-20% of its thickness, or about 5-15% in various embodiments.

[0031] FIGS. 4A and 4B illustrate schematic drawings of a planar portion (FIG. 4A) and a spherically shaped portion (FIG. 4B) of an example honeycomb configuration that enables spherical, three-dimensional shaping, in accordance with various embodiments. In the illustrated example, this honeycomb configuration **404** enables conforming of an aluminum honeycomb into the spherical, three-dimensional shape of a helmet, while retaining a substantially symmetric shape of honeycomb elements without buckling of honeycomb elements.

[0032] FIGS. 5A, 5B, and 5C depict a schematic drawing of a honeycomb layer segment with alternate fixation points, shown in unloaded (FIG. 5A) and loaded, deformed conditions (FIG. 5B), and a perspective view of the honeycomb layer in loaded, deformed condition (FIG. 5C), in accordance with various embodiments. FIG. 5A illustrates an example of a non-deformed honeycomb **502**, with some fixation sites **510** attached to an inner helmet layer, and other fixation sites **511** attached to an outer helmet layer. In various embodiments, honeycomb **502** may include void sections **512** for ventilation, which may correspond to similar void sections in the inner and outer helmet layers. FIG. 5B illustrates honeycomb **502** under tangential loading, whereby honeycomb segments between alternate fixation points **510** and **511** are deformed to accommodate suspension and translation between the inner and outer helmet layers. FIG. 5C illustrates again the deformed shape of honeycomb **502** due to tangential force introduction through fixation point **511**.

[0033] In some embodiments, the alternate fixation sites between the respective layers may include non-permanent connections, such as hook-and-loop connections, and may allow for replacement of the inner, outer, or intermediate layer if damaged. In other embodiments, the inner layer may be attached to the outer layer with an elastic material, and wherein the elastic material holds the inner layer in place during normal wearing, but allows relative displacement between the inner layer and outer layer in an impact.

[0034] FIG. 6 illustrates an example of a helmet **601** having an intermediate layer **602** in suspension between outer layer **604** and inner layer **605**, wherein intermediate layer **602** is coupled to the inner and outer layers via alternate fixation sites **603**. In the illustrated embodiment, helmet **601** also includes a padding layer **608** on the inside of inner layer **605** to improve comfort and help attenuate impacts. In various embodiments, padding layer **608** may include a single layer or may be comprised of multiple sections. In some embodi-

ments, one or more glidable interface layers **607** may be added between at least a part of intermediate layer **602** and outer layer **604**. In some embodiments, one or more glidable interface layers **606** may be added between at least a part of intermediate layer **602** and inner layer **605**. In some embodiments, these interface layers **606** and **607** may reduce friction to enhance tangential displacement between the inner and outer layers during an oblique impact. In addition, in some embodiments, inner layer **605** may be configured with perforations or alternative means to reduce its in-plane stiffness in order to enhance tangential displacement between the inner and outer layer during an oblique impact. In further embodiments, intermediate layer **602**, and/or inner **605** layer or outer **607** layer, may be provided with a colorimetric indicator that indicates the severity of impact when the helmet sustains an impact force. In some embodiments, the severity of impact may be shown as the degree of displacement of the outer layer **607** relative to the inner **605** and/or intermediate **602** layers.

[0035] FIG. 7 illustrates a cross-sectional mid-sagittal view of another embodiment of a helmet **701** shown during impact in a loaded, partially deformed configuration. In this embodiment, some or all of the fixation points **703a**, **703b**, **703c** are not rigid connections (**703b**), but rather are unidirectional couplings **703a**, **703c** that locally couple the layers together upon tangential forces in one direction, while allowing free relative displacement upon tangential forces in another direction. For example, in the illustrated embodiment, relative translation between the outer layer **704** and inner layer **705** is accompanied by in-plane compression of the intermediate layer **702** on one side **706**, but the other side **707** remains undeformed in the in-plane direction. In the illustrated embodiment, the inner layer **705** is held in place in the undeformed configuration by elastic connections **708**, and in various embodiments, these elastic connections may allow for relative displacement between the outer layer **704** and inner layer **705** in an impact. In practice, this embodiment may allow for greater control of the in-plane stiffness of the intermediate layer **701**.

[0036] FIG. 8 illustrates a cross-sectional view of a section of another embodiment, wherein the outer layer **801** and inner layer **802** are perforated with a multitude of holes **803**, which may allow for ventilation through the honeycomb cells in intermediate layer **804**. Although a particular hole size is illustrated, one of skill in the art will appreciate that a range of hole sizes is contemplated, for example, from about 1 mm to about 3 cm, such as about 0.5-2 cm, or about 1 cm, depending on the application. The holes may be ordered in an array or random in placement, and different portions of the helmet may have holes of different sizes and/or placement, depending on the ventilation needs of the particular application. It will be appreciated that it may be advantageous to supply the helmet with a multitude of small ventilation holes in order to prevent the gaps in protection that may result from the larger ventilation holes used in most conventional helmets. Additionally, providing a multitude of small holes may enable the helmet to have a more streamlined, smooth shape, which in turn may reduce the chance that a helmet contour may “catch” on an obstacle or obstruction during a fall or other head impact, which could increase rotational impact forces.

[0037] Although certain embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that a wide variety of alternate and/or equivalent embodiments or implementations calculated to achieve the same purposes may be substituted for the embodi-

ments shown and described without departing from the scope. Those with skill in the art will readily appreciate that embodiments may be implemented in a very wide variety of ways. This application is intended to cover any adaptations or variations of the embodiments discussed herein. Therefore, it is manifestly intended that embodiments be limited only by the claims and the equivalents thereof.

What is claimed is:

1. A helmet for protecting a head during an impact, comprising:
 - an outer layer;
 - an inner layer; and
 - at least one deformable intermediate layer, wherein the intermediate layer has substantially no elastic rebound, and wherein the intermediate layer is coupled to both the outer and inner layers at alternate fixation sites.
2. The helmet of claim 1, wherein the intermediate layer is configured to provide a suspension between the outer and inner layers.
3. The helmet of claim 1, wherein the outer layer is configured to translate in a substantially tangential direction relative to the inner layer via in-plane deformation of at least a portion of the intermediate layer.
4. The helmet of claim 3, wherein the intermediate layer is configured to absorb impact energy by deformation in directions both perpendicular and tangential to the outer layer.
5. The helmet of claim 3, wherein the outer layer is further configured to translate in a direction substantially perpendicular to the inner layer.
6. The helmet of claim 1, wherein the helmet further comprises a glidable interface layer disposed between the intermediate layer and the inner and/or outer layer, wherein the glidable interface layer is configured to facilitate sliding between the intermediate layer and the inner and/or outer layer.
7. The helmet of claim 1, wherein the inner, outer, and/or intermediate layer comprises a colorimetric indicator configured to indicate the severity of an impact sustained by the helmet.
8. The helmet of claim 1, wherein an alternate fixation site between the intermediate layer and the inner or outer layer comprises a unidirectional coupling, and wherein the unidirectional coupling permits tangential translation at the unidirectional coupling site between the intermediate layer and the inner or outer layer in only one direction.
9. The helmet of claim 8, wherein the unidirectional coupling is configured such that a tangential impact deforms the intermediate layer only in compression, and not in tension.
10. The helmet of claim 8, wherein the unidirectional coupling comprises an edge or hook on the inner and/or outer layer that overlaps at least a portion of the intermediate layer.
11. The helmet of claim 1, wherein the outer and/or inner layer is perforated with a plurality of holes having an average diameter of from about 1 mm to about 3 cm.
12. The helmet of claim 1, wherein the alternate fixation sites comprise removable couplings.
13. The helmet of claim 1, wherein the alternate fixation sites comprise elastic couplings, and wherein the elastic couplings are configured to allow relative displacement between the inner layer and outer layer in an impact.
14. A helmet for protecting a head during an impact, comprising:
 - an outer layer;
 - an inner layer; and

at least one deformable intermediate layer, wherein the intermediate layer comprises a honeycomb, and wherein the helmet is configured to permit relative tangential displacement of the inner and/or outer layers with respect to one another.

15. The helmet of claim **14**, wherein the honeycomb is an aluminum honeycomb.

16. The helmet of claim **14**, wherein the honeycomb comprises a plurality of honeycomb elements configured to retain a substantially symmetric shape and/or resist buckling when the intermediate layer adopts a curved or substantially spherical shape.

17. The helmet of claim **14**, wherein the honeycomb is configured to crumple and absorb an impact force component actin substantially perpendicular to the outer layer.

18. The helmet of claim **17**, wherein the honeycomb provides a substantially linear crush response.

19. The helmet of claim **17**, wherein the honeycomb is pre-crushed by 1-20% of its thickness.

20. The helmet of claim **14**, wherein the intermediate layer comprises at least two layers of honeycomb, wherein each layer of honeycomb has a different crush resistance.

21. The helmet of claim **14**, wherein the honeycomb cells are at least partially filled with an additional energy-absorbing material.

22. The helmet of claim **21**, wherein the additional energy-absorbing material comprises an expanded foam.

23. The helmet of claim **21**, wherein the additional energy-absorbing material has a non-uniform thickness, and wherein the additional energy-absorbing material is configured such that the intermediate layer becomes progressively more crush-resistant as it is crushed in a direction tangential to the outer layer and/or in a direction perpendicular to the outer layer.

24. The helmet of claim **14**, wherein the outer layer and/or inner layer is permeable to air and configured to allow for ventilation through the honeycomb.

25. A method for making a helmet that mitigates linear and rotational acceleration of a head during impact, the method comprising:

suspending an intermediate layer between an outer layer and an inner layer, wherein suspending the intermediate layer comprises coupling the intermediate layer to the inner layer and the outer layer at alternate fixation sites, wherein the intermediate layer is configured to absorb impact energy by deformation in a direction perpendicular to the outer layer and in a direction tangential to the outer layer.

* * * * *