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Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

[Continued on next page]

(54) Title: OMNI-DIRECTIONAL ANGULAR ACCERATION REDUCTION FOR PROTECTIVE HEADGEAR



Fig. 1

(57) Abstract: Protective headgear includes an outer shell rotatable relative to an inner shell via a thin layer of elastically and/or plastically yielding material disposed between and secured to the inner and outer shells. The yielding material deforms continuously but non-linearly at least in the tangential or shear direction to mitigate angular acceleration of the head during an impact. The yielding material prevents the inner and outer shells from separating or stopping suddenly to avoid imparting a large angular acceleration to the head. In one embodiment, a protective helmet includes an outer shell secured to an inner shell by a yielding material that elastically deforms continuously but non-linearly when subjected to an angular acceleration below a first threshold and plastically deforms when subjected to an angular acceleration above the first threshold.



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OMNI-DIRECTIONAL ANGULAR ACCERATION REDUCTION FOR PROTECTIVE HEADGEAR

BACKGROUND

1. Technical Field

[0001] The present disclosure is related to apparatus and methods for reducing brain injuries associated with head impacts by mitigating angular acceleration of the head during impacts.

2. Background Art

[0002] Various types of protective headgear have been developed to reduce injuries to the brain, skull, and neck resulting from head impacts. Existing helmet designs often employ a hard outer shell in combination with internal padding made of an energy-absorbing material. The internal padding may be secured to the outer shell by chemical fasteners, such as adhesives, or by mechanical fasteners, such as hook and loop closures, or similar structures, for example.

[0003] While conventional helmet designs generally reduce injuries associated with linear acceleration due to impacts, they may not adequately protect users from brain injuries such as subdural hematoma and diffuse axonal injuries, for example, that may be associated with angular or rotational acceleration. These types of injuries have been recognized in the prior art with one proposed solution providing a protective helmet having an outer shell separated from an inner shell by a sliding layer to allow relative displacement between the inner and outer shells. Relative movement is constrained by a deformable connecting member secured to both the inner and outer shells. Another prior art strategy allows an outer layer to yield relative to an inner

layer when subjected to a tangential force that exceeds a selected threshold by using rupturing means for attaching the outer layer to the remainder of the headgear. A similar approach relies on a frictional coupling between the outer and inner shells to allow relative movement during an impact. However, movement between frictionally coupled surfaces is generally difficult to control and requires a larger starting force to overcome the static friction and lower sustaining force to overcome the dynamic friction during an impact event.

SUMMARY

[0004] The apparatus and methods of the present disclosure solve one or more problems of the prior art by providing protective headgear having an outer shell designed to rotate with respect to a user's head by insertion of a thin layer of elastically and/or plastically yielding material between the outer shell and an inner shell. The yielding material deforms continuously but non-linearly at least in the tangential or shear direction to control angular acceleration of the head. The yielding material prevents the inner and outer shells from separating or stopping suddenly to avoid imparting a large angular acceleration to the head. In one embodiment, a protective helmet includes an outer shell secured to an inner shell by a yielding material that elastically deforms continuously but non-linearly when subjected to an angular acceleration below a first threshold and plastically deforms when subjected to an angular acceleration above the first threshold. In one embodiment, the first threshold is about 6000 rad/s/s (rad/s^2). In another embodiment, the yielding material of the inner layer has a rate-dependent shear stiffness that increases non-linearly as the deformation approaches the limit of separating the two layers by relative rotation.

[0005] Embodiments of the present disclosure have various advantages. For example, protective headgear according to the present disclosure reduces angular acceleration of the head to reduce the risk of brain injury to the wearer. Use of a yielding material with rate-dependent shear characteristics provides continuous displacement between inner and outer shells with a low or near-zero threshold for initial movement upon impact. Use of an elastically deformable

yielding material with nonlinear shear characteristics facilitates applications where repeated impacts may occur, such as in football helmets, for example. In addition, in one embodiment, the yielding material is generally isotropic to allow relative rotation between the inner and outer shell regardless of the direction of impact or the location of the impact. Protective headgear embodiments according to the present disclosure can also control for the tightness of fit between the head and the headgear using appropriate selection of the yielding material for a particular application.

[0006] The above advantages and other advantages and features will be readily apparent from the following detailed description of the preferred embodiments when taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Exemplary embodiments of the present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0008] FIGURE 1 is a partial cross-section cut-away of a protective helmet according to one embodiment of the present disclosure; and

[0009] FIGURE 2 is a curve illustrating representative shear characteristics of a yielding material for use in an apparatus or method for reducing angular acceleration of the head during impacts according to one embodiment of the present disclosure.

DETAILED DESCRIPTION

[0010] As those of ordinary skill in the art will understand, various features of the embodiments illustrated and described with reference to any one of the Figures may be combined with features illustrated in one or more other Figures to produce embodiments that are not explicitly illustrated or described. The combinations of features illustrated provide representative embodiments for typical applications. However, various combinations and modifications of the features consistent with the teachings of the present disclosure may be desired for particular applications or implementations. The representative embodiments used in the illustrations relate generally to protective headgear for various types of competitive and recreational applications where single or multiple impacts may occur such as football, as well as motorcycle, scooter, bicycle, and horseback riding, for example. However, the teachings of the present disclosure may also be used in other applications. Those of ordinary skill in the art may recognize similar applications or implementations with other engine/vehicle technologies.

[0011] Reference will now be made to embodiments of the present disclosure, which include the best mode of practicing the invention presently contemplated by the inventors. The Figures are not necessarily to scale. However, it is to be understood that the disclosed embodiments are merely exemplary and that various other embodiments are within the scope of the disclosure. Therefore, specific details disclosed herein are not to be interpreted as limiting, but merely as a representative basis for any aspect of the disclosure and/or as a representative basis for teaching one skilled in the art to variously employ the teachings herein. Furthermore, the terminology used herein is used only for the purpose of describing particular embodiments of the present invention and is not intended to be limiting in any way.

[0012] With reference to Figure 1, a cross-section of a representative helmet 10 includes an inner shell 12 and an outer shell 14 generally surrounding inner shell 12. Outer shell 14 and inner shell 12 are separated by a thin layer 16 of a yielding material to allow relative displacement or movement between inner shell 12 and outer shell 14 during an impact. As

shown in Fig. 1, layer 16 is disposed between, and secured to, both inner shell 12 and outer shell 14. Inner shell 12 is generally made of an elastically or plastically deformable energy absorbing material that may vary depending on the type of protective headgear or helmet 10. For example, headgear intended for a single impact, such as a bicycle or motorcycle helmet, may include a plastically deformable inner shell 12, while headgear intended for repeated impacts of generally lesser force, such as a football helmet, may include an elastically deformable inner shell 12.

[0013] In one embodiment, layer 16 is a yielding material having a non-linear rate-dependent shear characteristic such that layer 16 deforms during an impact so outer shell 14 is displaced relative to inner shell 12 to reduce angular acceleration imparted to a head of a user (not shown). As generally illustrated in Figure 2 and described herein, layer 16 may be made of a yielding material that is elastically deformable and/or plastically deformable depending upon the particular application.

[0014] Figure 2 is a graph 30 illustrating shear characteristics of a representative yielding material for use in forming intermediate layer 16 in protective headgear 10 according to one embodiment of the present disclosure. As illustrated by graph 30, the representative yielding material has a non-linear increasing shear stiffness/stress as the strain/deformation increases. The yielding material may have an elastically deformable characteristic 32 up to a first threshold, generally represented by peak 34, where plastic deformation occurs and the shear stiffness may decrease with increasing deformation beyond peak 34. However, according to the teachings of the present disclosure, the yielding material characteristics should generally be selected so that shear stiffness continually and non-linearly increases from a near-zero starting point with peak 34 representing failure of the material to avoid separation of the inner shell 12 from the outer shell 14, and a large angular acceleration being imparted to the head due to a sudden stop in relative movement between inner shell 12 and outer shell 14. As also illustrated by portion 32 of graph 30, thin layer 16 deforms continuously but non-linearly with increasing shear stiffness as deformation/strain increases.

[0015] According to one embodiment of the present disclosure, layer 16 includes a material that is generally isotropic in the shear direction such that outer shell 14 rotates with respect to inner shell 12 regardless of the direction of impact, or the location of impact. As also shown in Fig. 2, the representative yielding material may be selected with shear properties such that relative rotation between the inner and outer layers begins at a desired torque corresponding to a tightness of fit for a particular type of helmet. In the illustrated example, the shear stiffness is near zero for an application such as a bicycle helmet, but may be increased for tighter fitting helmets, such as a football helmet, for example. In general, the yielding material should have a shear stiffness wherein resistance to relative rotation between inner shell 12 and outer shell 14 increases as a function of extent of rotation or displacement to avoid a sudden stop and associated large angular acceleration to the head as previously described.

[0016] As those of ordinary skill in the art will appreciate, the protective headgear as generally illustrated in the cross-section of Fig. 1 using an intermediate layer 16 between inner shell 12 and outer shell 14 having the characteristics generally illustrated and described with respect to Fig. 2 illustrates one embodiment of a method according to the present disclosure. The method for mitigating angular acceleration imparted through protective headgear to a user includes securing inner shell 12 of the headgear 10 to an intermediate layer 16 and securing outer shell 14 of headgear 10 to an opposite side of intermediate layer 16, wherein intermediate layer 16 is a yielding material having a shear stiffness that increases nonlinearly with increasing relative displacement of inner shell 12 and outer shell 14 due to increasing deformation of the yielding material.

[0017] As such, embodiments of the present disclosure include protective headgear having various advantages. For example, protective headgear 10 according to the present disclosure reduces angular acceleration of the head to reduce the risk of brain injury to the wearer. Use of a yielding material for intermediate layer 16 with rate-dependent shear characteristics provides continuous displacement between inner 12 and outer shells 14 with a low or near-zero threshold for initial movement upon impact. Use of an elastically deformable

yielding material with nonlinear shear characteristics facilitates applications where repeated impacts may occur, such as in football helmets, for example. In addition, use of a yielding material that is generally isotropic allows relative rotation between the inner 12 and outer shell 14 regardless of the direction of impact or the location of the impact. Protective headgear embodiments according to the present disclosure can also control for the tightness of fit between the head and the headgear using appropriate selection of the yielding material for a particular application.

[0018] While embodiments of the invention have been illustrated and described, it is not intended that these embodiments illustrate and describe all possible forms of the invention. Rather, the words used in the specification are words of description rather than limitation, and it is understood that various changes may be made without departing from the spirit and scope of the invention.

What is Claimed Is:

1. A helmet comprising:
an inner shell;
an outer shell generally surrounding the inner shell;
a thin layer disposed between, and secured to, the inner shell and the outer shell, the thin layer having a non-linear rate-dependent shear characteristic such that the thin layer deforms during impact so the outer shell is displaced relative to the inner shell to reduce angular acceleration imparted to a head of a user.
2. The helmet of claim 1 wherein the inner shell comprises an energy absorbing material.
3. The helmet of claim 1 wherein the thin layer comprises an elastically deformable material.
4. The helmet of claim 1 wherein the thin layer comprises an elastically deformable material having a shear stiffness that increases non-linearly as a function of increasing strain/deformation.
5. The helmet of claim 1 wherein the thin layer deforms continuously but non-linearly with increasing stiffness as deformation increases.
6. The helmet of claim 1 wherein the thin layer is generally isotropic in the shear direction such that the outer shell rotates with respect to the inner shell regardless of the direction of impact or location of impact.
7. The helmet of claim 1 wherein the thin layer comprises a material having shear properties such that relative rotation between the inner and outer layers begins at a desired torque corresponding to a tightness of fit for a particular type of helmet.

8. The helmet of claim 7 wherein resistance to rotation increases as a function of extent of rotation.

9. The helmet of claim 1 wherein the thin layer comprises a deformable yielding material that deforms elastically when angular acceleration is below a first threshold, but plastically when angular acceleration exceeds the first threshold.

10. The helmet of claim 9 wherein the first threshold is about 6000 radians per second squared.

11. The helmet of claim 1 wherein the thin layer comprises a yielding material that prevents the inner and outer shells from stopping suddenly to avoid imparting a large angular acceleration to the head.

12. The helmet of claim 1 wherein the thin layer comprises a material having an isotropic rate-dependent shear stiffness that increases non-linearly as deformation approaches a separation limit of the inner and outer shells by relative rotation.

13. A method for mitigating angular acceleration imparted through protective headgear to a user, the method comprising:

securing an inner shell of the headgear to an intermediate layer;

securing an outer shell of the headgear to an opposite side of the intermediate layer;

wherein the intermediate layer is a yielding material having a shear stiffness that increases nonlinearly with increasing relative displacement of the inner and outer shells due to increasing deformation of the yielding material.

14. The method of claim 13 wherein the intermediate layer comprises a material having a rate-dependent shear stiffness.

15. The method of claim 13 wherein the intermediate layer comprises a yielding material that elastically deforms continuously but nonlinearly.

16. The method of claim 13 wherein the intermediate layer is a yielding material that elastically deforms continuously but nonlinearly when subjected to an angular acceleration above below a first threshold and plastically deforms when subjected to an angular acceleration above the first threshold.

17. The method of claim 16 wherein the first threshold is about 6000 radians per second squared.

18. The method of claim 13 wherein the intermediate layer is isotropic with respect to the shear stiffness.

19. A helmet comprising:

an inner shell;

an outer shell surrounding the inner shell;

an intermediate layer disposed between and connected to the inner shell and the outer shell, the intermediate layer comprised of a substantially isotropic yielding material that deforms continuously, nonlinearly, and with a rate dependent shear characteristic such that the intermediate layer deforms during impact to allow rotation of the inner shell relative to the outer shell to reduce angular acceleration imparted to a head of a user.

20. The helmet of claim 19 wherein the intermediate layer elastically deforms in response to an acceleration up to about 6000 radians per second squared and plastically deforms in response to an acceleration exceeding about 6000 radians per second squared.

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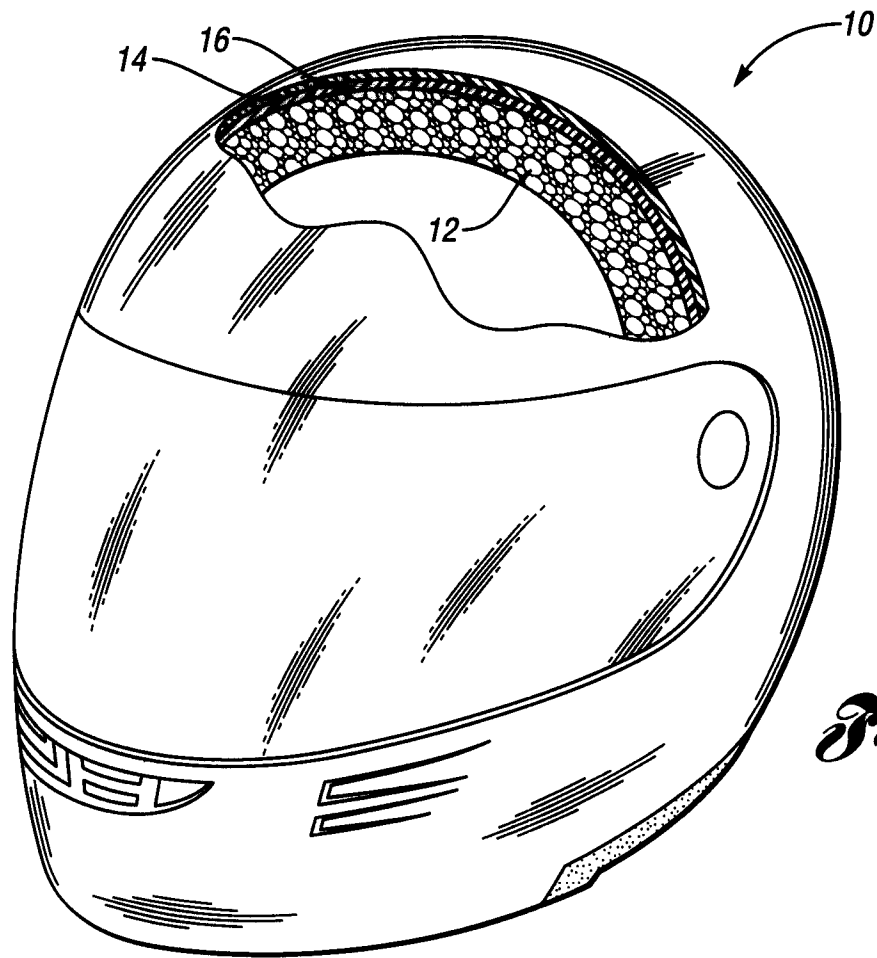


Fig. 1

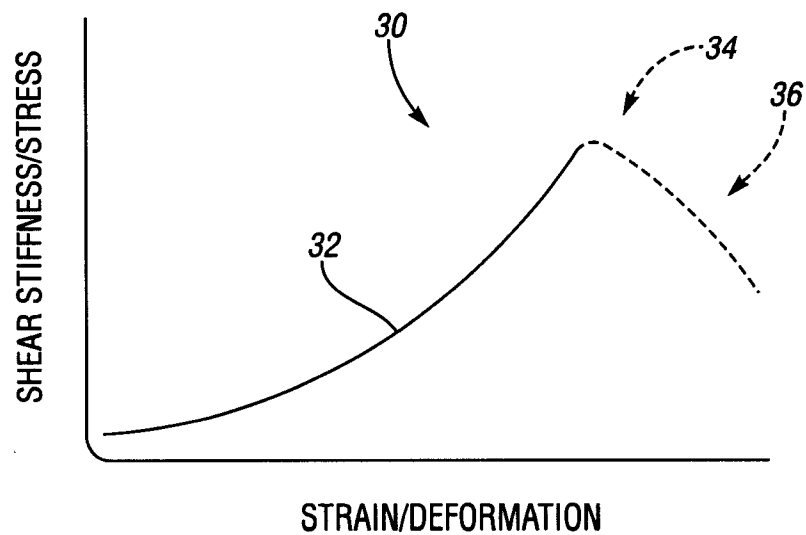


Fig. 2

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2010/039769

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - A42B 3/06 (2010.01)

USPC - 2/412

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)

IPC(8) - A42B 3/06, 3/10, 3/12; A63B 71/10 (2010.01)

USPC - 2/411, 412, 425

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)

PatBase

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6,658,671 B1 (VON HOLST et al) 09 December 2003 (09.12.2003) entire document	1-5
X	US 2008/0066217 A1 (DEPREITERE et al) 20 March 2008 (20.03.2008) entire document	1, 3-20

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Date of the actual completion of the international search

11 August 2010

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