Protective headgear is described having an energy-absorbing shell attached to a compressible internal liner. The shell includes an outer shell layer, a non-compressible inner shell layer, and a compressible middle layer disposed between the outer shell layer and the non-compressible inner shell layer. The compressible middle layer is made of a thermoplastic elastomer material that can compress upon impact and return substantially to an original shape of the headgear after the impact has ended. Embodiments of the thermoplastic elastomer material have low rebound resilience, a low glass transition temperature, a honeycombed structure, or combinations thereof. The compressible internal liner can also be made of thermoplastic elastomer material.
LAYERED CONSTRUCTION OF PROTECTIVE HEADGEAR WITH ONE OR MORE COMPRESSIBLE LAYERS OF THERMOPLASTIC ELASTOMER MATERIAL.

FIELD OF THE INVENTION

[0001] The invention relates generally to protective headgear. More specifically, the invention relates to a layered construction of protective headgear using compressible materials.

BACKGROUND

[0002] Concussions, also called mild traumatic brain injury, are a common, serious problem in sports known to have detrimental effects on people in the short and long term. With respect to athletes, a concussion is a temporary and reversible neurological impairment, with or without loss of consciousness. Another definition for a concussion is a traumatically induced alteration of brain function manifested by 1) an alteration of awareness or consciousness, and 2) signs and symptoms commonly associated with post-concussion syndrome, such as persistent headaches, loss of balance, and memory disturbances, to list but a few. Some athletes have had their careers abbreviated because of concussions, in particular because those who have sustained multiple concussions show a greater proclivity to further concussions and increasingly severe symptoms. Although concussions are prevalent among athletes, the study of concussions is difficult, treatment options are virtually nonexistent, and "return-to-play" guidelines are speculative. Accordingly, the best current solution to concussions is prevention and minimization.

[0003] Concussion results from a force being applied to the brain, often the result of a direct blow to the head, which results in shearing force to the brain tissue. The magnitude of the force (F) is a function of mass (m) and acceleration (A), as expressed by the well-known equation F=ma. Decreasing the magnitude of acceleration (or deceleration) thus decreases the force applied to the brain, and consequently reduces the risk or severity of a concussion. Acceleration or deceleration of an object is a measure of the change in velocity (v), also known as speed (s), experienced by that object over a given time. The relationship is given by the equation A=(V^2_f-V^2_i)/2t, where A is the acceleration (or deceleration), V_f is the final velocity of the object, V_i is the initial velocity of the object, t is the time over which the change in velocity occurs, and g is a constant value (9.812 m/s^2). In a sports collision, this equation can reduce to A=-V^2_f/2t when an impacted player is brought to a halt (i.e., V_f=0). Alternatively, the equation can reduce to A=V^2_f/2t when the head of a stationary player, i.e., V_i=0, is driven into acceleration by a blow to the head.

[0004] Protective headgear is well known to help protect wearers from head injury by decreasing the magnitude of acceleration or deceleration experienced by their wearers. Helmets fall generally into two categories: single-impact helmets and multiple-impact helmets. Single-impact helmets undergo permanent deformation under impact, whereas multiple-impact helmets are capable of sustaining multiple blows. Applications of single-impact helmets include, for example, bicycling and motorcycling. Participants of contact sports, such as hockey and football, use multiple-impact helmets. Both categories of helmets have similar construction. A semi-rigid outer shell distributes the force of impact over a wide area and a crushable inner layer reduces the force upon the wearer's head.

[0005] The inner layer of single-impact helmets are typically constructed of fused expanded polystyrene (EPS), a polymer impregnated with a foaming agent. EPS reduces the amount of energy that reaches the head by permanently deforming under the force of impact. To be effective against the impact, the inner layer must be sufficiently thick not to crush entirely throughout its thickness. A thick inner layer, however, requires a corresponding increase in the size of the outer shell, which increases the size and bulkiness of the helmet.

[0006] Inner layers designed for multiple-impact helmets absorb energy through elastic and viscoelastic deformation. To absorb multiple successive hits, these helmets need to rebound quickly to return to their original shape. Materials that rebound too quickly, however, permit some of the kinetic energy of the impact to transfer to the wearer's head. Examples of materials with positive rebound properties, also called elastic memory, include foamed polyurethane, expanded polypropylene, expanded polyethylene, and foamed vinylidene. Although these materials have desirable rebound qualities, an inner layer constructed therefrom must be sufficiently thick to prevent forceful impacts from penetrating its entire thickness. The drawback of a thick layer, as noted above, is the resulting bulkiness of the helmet. Moreover, the energy-absorbing properties of such materials tend to diminish with increasing temperatures, whereas the positive rebound properties diminish with decreasing temperatures. Therefore, there exists a need, therefore, for an improved helmet construction that can reduce the risk and severity of concussions without the aforementioned disadvantages of current helmet designs.

SUMMARY

[0007] In one aspect, the invention features protective headgear comprising an impact-absorbing shell including a hard inner shell layer formed into a shape of a helmet and a compressible layer attached to and covering an outer surface of the hard inner shell layer. The compressible layer is made of a thermoplastic elastomer material that compresses when impacted by a force and returns substantially to the original shape of the helmet after the force ceases.

[0008] In another aspect, the invention features protective headgear comprising an energy-absorbing shell. The shell has an outer shell layer, a non-compressible inner shell layer, and a compressible middle layer disposed between the outer shell layer and the non-compressible inner shell layer. The compressible middle layer is comprised of a thermoplastic elastomer material that can compress upon impact and return substantially to an original shape of the headgear after the impact has ended. The headgear also has a compressible internal liner, which can be made of thermoplastic elastomer material, attached to an inner surface of the energy-absorbing shell. In other embodiments, this internal liner can also be made of materials such as expanded polystyrene or foam.

[0009] In still another aspect, the invention features a method for making a helmet, comprising providing a hard inner shell layer having a shape of a helmet, covering an outer surface of the hard inner shell layer with a compress-
able middle layer of thermoplastic elastomer material, and
covering an outer surface of the compressible middle layer
with an outer shell layer.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The above and further advantages of this invention
may be better understood by referring to the following
description in conjunction with the accompanying drawings,
in which like numerals indicate like structural elements and
features in various figures. The drawings are not necessarily
to scale, emphasis instead being placed upon illustrating
the principles of the invention.

[0011] FIG. 1 is a side view of an embodiment of a helmet
constructed in accordance with the present invention.

[0012] FIG. 2 is a cross-sectional view of the helmet of
FIG. 1 showing an embodiment of a layered construction
having a hard inner layer disposed between compressible
inner and middle layers.

[0013] FIG. 3 is a side view of another embodiment of
a helmet constructed in accordance with the present invention.

DETAILED DESCRIPTION

[0014] The present invention relates to protective head-
gear designed to lessen the amount of force that reaches
the brain of the wearer from an impact to the head. The headgear
has a multilayer construction for cushioning the impact, thus
slowing the change in velocity of the wearer’s head, produ-
cing a corresponding decrease in the magnitude of accel-
eration or deceleration experienced by the wearer, and
potentially reducing the risk or severity of concussion. As
described further below, one or more of the layers of the
headgear include an energy-absorbing compressible mate-
rial. In a preferred embodiment, this compressible material
is a thermoplastic elastomer (TPE). In certain embodiments,
an individual may be able to compress the exterior of the
protective headgear with a moderate touch of a hand or
finger, because a primary layer, as shown below, is made of
a compressible TPE.

[0015] The layered construction of the invention can be
used to construct a variety of types of protective headgear
including, but not limited to, safety helmets, motorcycle
helmets, bicycle helmets, ski helmets, lacrosse helmets,
hockey helmets, and football helmets, batting helmets for
baseball and softball, headgear for rock and mountain clim-
ers, and headgear for boxers. Other applications can include
helmets used on construction sites, in defense and military
applications, and for underground activities. Although the
following description focuses primarily on protective head-
gear, it is to be understood that the layered construction of
the invention applies to other types of equipment used for
sports activities or for other applications, e.g., face masks,
elbow pads, shoulder pads, and shin pads.

[0016] FIG. 1 shows a side view of an embodiment of a
helmet 2 constructed in accordance with the invention. Here,
the helmet 2 has an aerodynamic shape designed for use by
bicyclists. This shape is merely exemplary; it is to be
understood that the helmet shape can vary, depending upon
the particular sporting event or activity for which the helmet
is designed. Further, helmets of the invention can be con-
structed with various additional features, such as a cage for
a hockey helmet, a face mask for a football helmet, a visor
for a motorcycle helmet, retention straps, chin straps, and the
like.

[0017] The helmet 2 has ventilation openings 6 near the
top to permit air to flow for cooling the wearer’s head. Here,
the ventilation openings 6 are teardrop shaped, each pointing
toward the rear 10 of the helmet 2 to give a visual sensation
of speed. For clarity sake, the various layers of the materials
used in the construction of the helmet 2 appear in the
openings 6 as a single layer 14. Ventilation openings can also
be on the other side of the helmet 2 (not shown) if the helmet
has a symmetric design. Such openings 6 are exemplary, and
can have various other shapes or be omitted altogether,
depending upon the type of helmet. Also, helmets con-
structed in accordance with the invention can have other
types of openings, such as ear holes.

[0018] FIG. 2 shows a cross section of the helmet 2 along
the line A-A’ in FIG. 1. In the embodiment shown, the
helmet 2 includes an outer shell layer 20, a compressible
middle layer 24, a hard inner shell layer 28, and a com-
pressible internal liner 32. The outer shell layer 20, middle
layer 24, and inner shell layer 28 together provide an
impact-absorbing shell 30 of the present invention. As used
herein, a layer is compressible based on the relative ease
with which that layer decreases in thickness in response to
an applied force. In general, compressible layers are more
apt to decrease in thickness in response to an applied force
than hard layers. The compressible layers 24, 32 can com-
press discernibly in response to an applied force. In contrast,
no readily discernible compression, as defined by a readily
discernible decrease in thickness, occurs if a comparable
force is applied directly to the inner shell layer 28, although
that layer may temporarily deform by bending. Numerical
hardness values, determined according to any one of a
variety of hardness tests, such as a Shore (Durometer) Test,
can be used to measure the relative hardness of each layer.
In general, compressible layers measure softer than hard
layers.

[0019] As described in detail below, each of the layers can
be constructed of a lightweight material, thus contributing
towards the construction of a lightweight helmet. Although
not drawn to scale, FIG. 2 shows one example of the relative
thicknesses of the various layers and coating. These relative
thicknesses can also depart from those shown in FIG. 2
without departing from the principles of the invention. For
example, a bike helmet could be made with a thick inner
shell layer 28 (e.g., of expanded polystyrene) and with a
middle layer 24 of TPE that is thinner than the inner shell
layer 28. Also, additional layers can be disposed between the
middle layer 24 and the inner shell layer 28, or between the
internal liner 32 and the inner shell layer 28, without
departing from the principles of the invention.

[0020] The outer shell layer 20 covers the middle layer 24
and serves various functions. For example, the outer shell
layer 20 can provide durability by protecting the helmet 2
from punctures and scratches. Other functions include pre-
senting a smooth surface for deflecting tangential impacts,
waterproofing, and displaying cosmetic features such as
coloring and identifying the product brand name. In a
preferred embodiment, this outer shell layer 20 is made of
DuPont SURLYNE®, an impact-resistant resin with high-
gloss coloring similar to paint. This material is lightweight.
with customizable stiffness and excellent strength-to-weight performance, including in low temperature environments. In other embodiments, this outer shell layer 20 is a thin coating of elastomeric polyurethane or made of an impact-resistant vinyl.

Beneath the outer shell layer 20, the compressible middle layer 24 covers an outer surface of the inner shell layer 28. The middle layer 24 attaches to the inner shell layer 28 at each point where the layers contact each other. A primary function of the middle layer 24 is impact energy absorption. Preferably, the middle layer 24 is constructed of a thermoplastic elastomer material.

Thermoplastic elastomers or TPEs are polymer blends or compounds, which exhibit thermoplastic characteristics that enable shaping into a fabricated article when heated above their melting temperature, and which possess elastomeric properties when cooled to their designed temperature range. Accordingly, TPEs combine the beneficial properties of plastic and rubber, that is, TPEs are moldable and shapeable into a desired shape when heated and are compressible and stretchable when cooled. In contrast, neither thermoplastics nor conventional rubber alone exhibit this combination of properties.

To achieve satisfactory purposes, conventional rubbers must be chemically crosslinked, a process often referred to as vulcanization. This process is slow, irreversible, and results in the individual polymer chain being linked together by covalent bonds that remain effective at normal processing temperatures. As a result, vulcanized rubbers do not become fluid when heated to these normal processing temperatures (i.e., the rubber cannot be melted). When heated well above normal processing temperatures, vulcanized rubbers eventually decompose, resulting in the loss of substantially all useful properties. Thus, conventional vulcanized rubbers cannot be formed into useful objects by processes that involve the shaping of a molten material. Such processes include injection molding, blow molding, and extrusion, and are extensively used to produce useful articles from thermoplastics.

Thermoplastics are generally not elastic when cooled and conventional rubbers are not moldable using manufacturing processes and equipment currently used for working with thermoplastics, such as injection molding and extrusion. These processes, however, are applicable for working with TPEs.

Most TPEs have a common feature: they are phase-separated systems. At least one phase is hard and solid at room temperature and another phase is elastomeric and fluid. Often the phases are chemically bonded by block or graft polymerization. In other cases, a fine dispersion of the phases is apparently sufficient. The hard phase gives the TPEs their strength. Without the hard phase, the elastomer phase would be free to flow under stress, and the polymers would be unusable. When the hard phase is melted, or dissolved in a solvent, flow can occur and therefore the TPE can be processed. On cooling, or upon evaporation of the solvent, the hard phase solidifies and the TPEs regain their strength. Thus, in one sense, the hard phase of a TPE behaves similarly to the chemical crosslinks in conventional vulcanized rubbers, and the process by which the hard phase does so is often called physical crosslinking. At the same time, the elastomer phase gives elasticity and flexibility to the TPE.

Examples of TPEs include block copolymers containing elastomeric blocks chemically linked to hard thermoplastic blocks, and blends of these block copolymers with other materials. Suitable hard thermoplastic blocks include polystyrene blocks, polyurethane blocks, and polyester blocks. Other examples of TPEs include blends of a hard thermoplastic with a vulcanized elastomer, in which the vulcanized elastomer is present as a dispersion of small particles. These latter blends are known as thermoplastic vulcanizates or dynamic vulcanizates.

TPEs can also be manufactured with a variety of hardness values, e.g., a soft gel or a hard 90 Shore A or greater. One characteristic of the TPE material is its ability to return to its original shape after the force against the helmet 2 is removed (i.e., TPE material is said to have memory). Other characteristics of TPE include its resistance to tear, its receptiveness to coloring, and its rebound resilience. Rebound resilience is the ratio of regained energy in relation to the applied energy, and is expressed as a percentage ranging from 0% to 100%. A perfect energy absorber has a percentage of 0%; a perfectly elastic material has a percentage of 100%. In general, a material with low rebound resilience absorbs most of the applied energy from an impacting object and retransmit little or none of that energy. To illustrate, a steel ball that falls upon material with low rebound resilience experiences little or no bounce; the material absorbs the energy of the falling ball. In contrast, the ball bounces substantially if it falls upon material with high rebound resilience.

Preferred embodiments of the middle layer 24 are constructed of a TPE material with low rebound resilience (here, a low rebound resilience corresponds to a rebound percentage of approximately 50% or less, and preferably 25% or less). Examples of TPEs with low rebound resilience include Trefsin™, manufactured by Advanced Elastomer Systems of Akron, Ohio, and the product TP6DAA manufactured by Kraburg TPE Corp of Duluth, Ga. An advantage of these TPEs is that their low rebound characteristic exists over a wide range of temperatures. Preferably, the TPE material of the middle layer 24 has a glass-transition temperature of less than ~20 degrees Fahrenheit. The glass-transition temperature is the temperature below which the material loses its soft and rubbery qualities. A TPE material with an appropriate glass-transition temperature can be selected for the middle layer 24 depending on the particular application of the helmet 2 (e.g., a glass-transition temperature of 0 degrees Fahrenheit may be sufficient for baseball helmets, whereas a glass-transition temperature of ~40 degrees Fahrenheit may be needed for football and hockey helmets).

TPEs can also be formed into a variety of structures. In one embodiment, the middle layer 24 has a honeycomb structure (i.e., waffle-type). The interconnected hexagonal cells of a honeycomb structure provide impact absorption and a high strength-to-weight ratio, which permits construction of a lightweight helmet. The interconnected cells absorb and distribute the energy of an impact evenly throughout the structure. The honeycomb structure also reduces material costs because much of the material volume is made of open cells. This structure can be any one in which the material is formed into interconnected walls and open cells. The cells can have a shape other than
hexagonal, for example, square, rectangular, triangular, and circular, without departing from the principles of the invention.

[0030] The formation of the middle layer 24 on the inner shell layer 28 can be accomplished using an extrusion, casting, or injection molding process. The compressible middle layer 24 and inner shell layer 28 can be manufactured separately and adhered together after production, or they may be manufactured as one component, with the two layers being adhered to each other during manufacturing. TPEs bond readily to various types of substrates, such as plastic, and, thus, TPEs and substrates are commonly manufactured together. The softness (or conversely, the hardness) of the middle layer 24 can also be determined over a range of durometers. Preferably, the range is between 5 and 90 on the Shore A scale, inclusive. The thickness of the middle layer 24 can be varied without departing from the principles of the invention. In one embodiment, the middle layer 24 is approximately 1/2 inch thick.

[0031] The inner shell layer 28 is constructed of a hardened material, such as a rigid thermoplastic, a thermoplastic alloy, expanded polystyrene, or a fiber-reinforced material such as fiberglass, TWINTEX®, KEVLAR®, or BI Curv™. The inner shell layer 28 operates to provide structure to the helmet 2, penetration resistance, and impact energy distribution to the internal liner 32. In one embodiment, the thickness of the inner shell layer 28 is 1/16 of an inch. The thickness of the inner shell layer 28 can be varied without departing from the principles of the invention.

[0032] Providing another impact-absorbing layer, the internal liner 32 contacts the wearer's head. Other functions of the internal liner 32 may include sizing, resilience, airflow, and comfort. In general, the internal liner 32 is constructed of a foam material of, for example, approximately 1/2 to 1 inch thickness, or it may be constructed of expanded polystyrene. The compressible internal liner 32 is attached to an inner surface of the inner shell layer 28. The method of attachment depends upon the type of materials used (of the inner shell layer 28 and of the internal liner 32).

[0033] Embodiments of the internal liner 32 include one or more of the following, either alone or in combination: thermoplastic elastomer (TPE), expanded polystyrene, silicone gel, silicone foam, viscoelastic or memory foam, and polyurethane foam. Brock Foam™, manufactured by Brock of Boulder, Colo., is an example of a foam material that may be suitable for the internal liner 32 of the invention. Brock Foam™ is made of partially fused polymer beads and elastic adhesive that together provide energy absorption, multiple impact capability, free flow of air and moisture, and improved fit and comfort. Another example is Bayfill EA, an energy absorbing semi-rigid polyurethane foam made by Bayer Material Science of Pittsburgh, Pa. The thickness and type of foam material can be varied without departing from the principles of the invention.

[0034] Important to the use of the helmet of the invention is for the helmet to fit properly and to remain in place during the impact. In an embodiment not shown, the helmet extends downwards from the regions near the ears and covers the angle of the wearer's jaw. This extension may be flexible, and when used in conjunction with a chinstrap, may be drawn in tightly to provide a snug fit around the jaw. FIG. 3 shows another embodiment of a helmet 2 constructed in accordance with the invention. Here, the helmet 2' is a football helmet (facemask and chinstrap not shown). This helmet 2' illustrates a design that covers the ears and a portion of the wearer's jaw. The helmet 2' has ventilation openings 6 near the top and on the sides of the helmet 2' and an ear hole 8. Again, for clarity sake, the various layers of materials used in the construction of the helmet 2' appear in each opening 6 as a single layer 14.

[0035] While the invention has been shown and described with reference to specific preferred embodiments, it should be understood that described in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the following claims.

What is claimed is:
1. Protective headgear, comprising an impact-absorbing shell including a hard inner shell layer formed into a shape of a helmet and a compressible layer attached to and covering an outer surface of the hard inner shell layer, the compressible layer being made of a thermoplastic elastomer that compresses when impacted by a force and returns substantially to the original shape of the helmet after the force ceases.
2. The protective headgear of claim 1, wherein the thermoplastic elastomer material has a honeycomb structure.
3. The protective headgear of claim 1, wherein the thermoplastic elastomer has a glass-transition temperature below or equal to 0 degrees Fahrenheit.
4. The protective headgear of claim 1, wherein the thermoplastic elastomer material has low rebound resilience.
5. The protective headgear of claim 1, further comprising a compressible internal liner attached to an inner surface of the impact-absorbing shell, the internal liner making contact with the head of a wearer.
6. The protective headgear of claim 5, wherein the internal liner is made of a thermoplastic elastomer material.
7. The protective headgear of claim 5, wherein the internal liner is made of an expanded polystyrene foam.
8. The protective headgear of claim 1, wherein the impact-absorbing shell further comprises an outer shell layer disposed on an outer surface of the compressible layer.
9. Protective headgear, comprising:
   an energy-absorbing shell including:
   - an outer shell layer;
   - a non-compressible inner shell layer; and
   - a compressible middle layer disposed between the outer shell layer and the non-compressible inner shell layer, the compressible middle layer being comprised of a thermoplastic elastomer material that can compress upon impact and return substantially to an original shape of the headgear after the impact has ended; and
   a compressible internal liner attached to an inner surface of the energy-absorbing shell.
10. The protective headgear of claim 9, wherein the thermoplastic elastomer material has a honeycomb structure.
11. The protective headgear of claim 9, wherein the thermoplastic elastomer material of the middle layer has a glass-transition temperature below or equal to 0 degrees Fahrenheit.
12. The protective headgear of claim 9, wherein the thermoplastic elastomer material of the middle layer and of the internal liner has low rebound resilience.

13. The protective headgear of claim 9, wherein the internal liner is made of thermoplastic elastomer material.

14. The protective headgear of claim 9, wherein the internal liner is made of expanded polystyrene foam.

15. A method for making a helmet, comprising
   providing a hard inner shell layer formed in a shape of a helmet; and
   covering an outer surface of the hard inner shell layer with a compressible middle layer of thermoplastic elastomer material; and
   covering an outer surface of the compressible middle layer with an outer shell layer.

16. The method of claim 15, wherein the thermoplastic elastomer material has a honeycomb structure.

17. The method of claim 15, wherein the thermoplastic elastomer material of the compressible middle layer has a glass-transition temperature below or equal to 0 degrees Fahrenheit.

18. The method of claim 15, wherein the thermoplastic elastomer material of the compressible middle layer and of the internal liner has low rebound resilience.

19. The method of claim 15, further comprising attaching a compressible internal liner made of thermoplastic elastomer material to an inner surface of the hard inner shell layer.

20. The method of claim 15, further comprising attaching a compressible internal liner made of expanded polystyrene foam to an inner surface of the hard inner shell layer.