BALLISTIC-RESISTANT HELMET SHELL

The present invention relates to a ballistic-resistant helmet. Specifically it relates to a light-weight shell for a ballistic-resistant helmet.

Ballistic-resistant helmets having a shell comprising a consolidated stack of layers of uni-directionally aligned ballistic resistant fibers and a binder are known in the prior art. For example from WO2007/107359. A drawback with such helmets is that they can be heavy; a significant proportion of the weight comes from the helmet shell itself. A lightweight helmet shell design is described in Taiwan laid open patent application 201825857. A preferred embodiment of this includes a polyurea coating on the helmets shell.

An object of the present invention is to provide a light weight ballistic-resistant helmet shell which provides a high standard of ballistic protection, including projectile stopping capability, V_{50}, and back face deformation. A further object is to provide a helmet shell having improved flame retardancy. Accordingly, the present invention provides a ballistic-resistant helmet shell which comprises:

a. a core layer, which core layer comprises a consolidated stack of layers of uni-directionally aligned ballistic-resistant fibers and a binder;
b. a coating layer on the external surface of the core layer;

characterized in that said coating layer comprises a polyurea and is from 0.3 to 4 mm thick.

The present invention also provides a ballistic-resistant helmet comprising a ballistic-resistant helmet shell.

A helmet shell is the basic structure of a helmet, and provides the ballistic resistance. The shell excludes linings, straps, fittings, decoration and accessories.

As used herein, a consolidated stack refers to multiple layers which are pressed together at elevated temperature to produce a single article.

The term layer of unidirectionally aligned ballistic resistant fibers and a binder refers to a layer of a fibrous network of unidirectionally oriented ballistic resistant fibers and a binder that basically holds the fibers together. The fibers are essentially oriented in parallel to each other within the layer.

Typically, in the stack, the fiber direction in a layer is at an angle α to the fiber direction in an adjacent layer. Typically, α is between 5 and 90°, more preferably between 45 and 90° and most preferably between 75 and 90°.

As used herein, average thickness is measured by taking three measurements, each measurement spaced apart from the other measurements by at least 5 cm, and calculating the mean value. A thickness is preferably calculated as the average thickness.

The term ballistic-resistant fiber comprises not only a monofilament but, amongst others, also a multifilament yarn or a flat tape. The width of a flat tape is preferably between 2 mm and 100 mm, more preferably between 5 mm and 60 mm, most preferably between 10 mm and 40 mm. Thickness of a flat tape preferably is between 10 µm and 200 µm, more preferably between 25 µm and 100 µm.

The ballistic resistant fibers in the invention may be inorganic or organic fibers.

Suitable inorganic fibers are, for example, glass fibers, carbon fibers and ceramic fibers. Preferably the inorganic fibers are carbon fibers produced from polyacrilonitrile.

Suitable organic fibers with such a high tensile strength are, for example, aromatic polyamide fibers (so-called aramid fibers), especially poly(p-phenylene teraphthalamide), liquid crystalline polymer and ladder-like polymer fibers such as polybenzimidazoles or polybenzoxazoles, esp. poly(1,4-phenylene-2,6-benzobisoxazole) (PBO), or poly(2,6-diimidazo[4,5-b-4',5'-e]pyridinylene-1,4-(2,5-dihydroxy)phenylene) (PIPD; also referred to as M5) and fibers of, for example, polyolefins, polyvinyl alcohol, and polyacrylonitrile which are highly oriented, such as obtained, for example, by a gel spinning process.

Suitable polyolefins are in particular homopolymers and copolymers of ethylene and propylene, which may also contain small quantities of one or more other polymers, in particular other alkene-1-polymers.

Good results are obtained if linear polyethylene (PE) is selected as the polyolefin. Linear polyethylene is herein understood to mean polyethylene with less than 1 side chain per 100 C atoms, and preferably with less than 1 side chain per 300 C atoms; a side chain or branch generally containing at least 10 C atoms. The linear polyethylene may further contain up to 5 mol% of one or more other alkenes that are copolymerisable therewith, such as propene, butene, pentene, 4-methylpentene, octene. Preferably, the linear polyethylene is of high molar mass with an intrinsic viscosity (IV, as determined on solutions in decalin at 135°C) of at least 4 dl/g; more preferably of at least 8 dl/g. Such polyethylene is also referred to as ultra-high molecular weight polyethylene. Intrinsic viscosity is a measure for molecular weight that

can more easily be determined than actual molar mass parameters like M_n and M_w. There are several empirical relations between IV and M_w, but such relation is highly dependent on molecular weight distribution. Based on the equation $M_w = 5.37 \times 10^4 [IV]^{1.37}$ (see EP 0504954 A1) an IV of 4 or 8 dl/g would be equivalent to M_w of about 360 or 930 kg/mol, respectively. Preferably, the ballistic resistant fibers are ultra-high molecular weight polyethylene.

Preferably the ballistic resistant fibers have a tensile strength of at least about 1.2 GPa and a tensile modulus of at least 40 GPa. More preferably, the fibers have a tensile strength of at least 2 GPa, more preferably at least 2.5 GPa or most preferably at least 3 GPa. The advantage of these fibers is that they have very high tensile strength, so that they are in particular very suitable for use in lightweight ballistic-resistant articles.

The term binder refers to a material that binds or holds the fibers together in the sheet comprising mono-layers of unidirectional oriented fibers and a binder, the binder may enclose the fibers in their entirety or in part, such that the structure of the mono-layer is retained during handling and making of preformed sheets.

In a preferred embodiment, the binder is a polymeric matrix material, and may be a thermosetting material or a thermoplastic material, or mixtures of the two. In the case the matrix material is a thermosetting polymer vinyl esters, unsaturated polyesters, epoxies or phenol resins are preferably selected as matrix material. In the case the matrix material is a thermoplastic polymer polyurethanes, polyvinyls, polyacrylics, polyolefins or thermoplastic elastomeric block copolymers such as polyisopropene-polyethylene-butylene-polystyrene or polystyrene-polyisoprene-polystyrene block copolymers are preferably selected as matrix material. Preferably the binder consists of a thermoplastic polymer, which binder preferably completely coats the individual filaments of said fibers in a mono-layer, and which binder has a tensile modulus (determined in accordance with ASTM D638, at 25° C) of at least 75 MPa, more preferably at least 150 MPa and even more preferably at least 250 MPa, most preferably of at least 400 MPa. Preferably the binder has a tensile modulus of at most 1000 MPa. Such a binder results in high flexibility of a sheet comprising a mono-layer, and of a high enough stiffness in a consolidated stack. Preferably, the binder is polyurethane.

Typically, the amount of binder in a layer comprising unidirectionally oriented ballistic resistant fibers and a binder is at most 30 mass%, more preferably at

most 25, or 20% of the mass of the helmet shell. Preferably, the binder is present in an amount of from 12 to 20 % by weight of the layer comprising unidirectionally oriented ballistic resistant fibers and a binder. More preferably, it is present in an amount of from 13 to 18 wt.%; most preferably around 15 to 16 wt.%. This results in the best ballistic performance. In the case that the ballistic resistant fibers are tapes, the amount of binder may be lower still, for example at most 7, 5 or even at most 3 % of the mass of the layer comprising unidirectionally oriented ballistic resistant fibers and a binder.

The coating layer comprises a polyurea. The coating layer may be a polyurea coating or a polyurethane/polyurea hybrid coating. A polyurea coating is the result of a one-step reaction between an isocyanate component and a resin blend component. The resin blend should only contain amine-terminated resins and/or chain extenders and not any hydroxyl reactive polymer components. The isocyanate can be monomer based, a prepolymer, a polymer or a blend. For the prepolymer, amine- and/or hydroxyl-terminated resins may be used.

A polyurethane / polyurea hybrid coating has a composition which further comprises the result of a reaction between an isocyanate component and a resin blend comprising hydroxyl containing resins. The isocyanate component may be the same as for the “pure” polyurea systems. The resin blend is a blend of amine-terminated and hydroxyl-terminated polymer resins and/or chain extenders. The resin blend may also contain additives, or non-primary components. To bring the reactivity of the hydroxyl-containing resins to the same level of reactivity as the amine-terminated resins, the addition of one or more catalysts may be applied.

The coating layer comprising a polyurea is preferably applied by spraying using techniques known in the art. Typically a mixture of isocyanate and resin blend in a diluent is used during spraying. In addition, additives may be included in the spray.

A preferred polyurea coating is Paxcon® available from Line-X®, Huntsville, Alabama, USA.

Preferably, the helmet shell further comprises:

c. a coating layer on the internal surface of the core layer;

characterized in that said coating layer comprises a polyurea and is from 0.3 to 4 mm thick. The thickness of coating layer comprising polyurea is from 0.3 to 4 mm. Typically, the coating layer is from 0.4 to 3 mm thick. Preferably, the coating layer is from 0.5 to 2 mm thick. A thinner coating reduces weight. However, a thicker coating provides increased advantages in, for example, V_{50}, back face deformation and flame

retardancy. Typically, each of the coating layers b and c are from 0.4 to 3 mm thick. Preferably, each of the coating layers b and c are from 0.5 to 2 mm thick.

A tie layer is a layer which is bonded at each face to different layers and facilitates bonding between those two layers. A ballistic-resistant helmet shell of the present invention typically comprises a tie layer between the core layer and one or both of the coating layers, b and c.

A typical tie layer comprises a fabric impregnated with a matrix. The fabric may comprise a fiber selected from the earlier listed range of ballistic-resistant fibers. A preferred ballistic-resistant fiber is ultra-high molecular weight polyethylene. Alternatively, the fiber may be a carbon fiber. The matrix of the tie layer may be any suitable matrix. It may be selected from those listed in relation to the core layer. Typically, it is selected from thermoplastic or thermoset resins. Preferably, the matrix is an epoxy resin, a polyurethane resin, a vinylester resin, a phenolic resin, a polyester resin, an acrylic-based resin or a mixture thereof.

Preferably, the tie layer comprises fibers of ultra-high molecular weight polyethylene and a matrix. Preferably, the fibers of the tie layer are woven.

The core layer of a ballistic-resistant helmet shell is typically from 5 to 7 mm thick. Preferably, it is approximately 6 mm thick.

The ballistic-resistant helmet shell typically has an average thickness of from 6 to 10 mm. Typically the average thickness is from 7 to 9 mm. Preferably, the average thickness is about 7.5 mm.

Typically, the helmet shell of the present invention further comprises at least one layer of carbon fiber composite. Preferably, the at least one layer of carbon fiber composite is located close to or at the outer surface of the helmet shell, or the at least one layer of carbon fiber composite is located close to or at the inner surface of the helmet shell, or when there are at least two layers of carbon fiber composite, both. A layer of carbon fiber composite comprises woven or non-woven, including unidirectionally oriented, carbon fibers and a binder. Said binder is typically a liquid (co)polymer resin impregnated in between the fibers and optionally subsequently hardened. Hardening or curing may be done by any means known in the art, e.g. a chemical reaction, or by solidifying from molten to solid state. Suitable examples include thermoplastic or thermoset resins. Preferably, the polymeric resin is an epoxy resin, a polyurethane resin, a vinylester resin, a phenolic resin, a polyester resin or a mixture thereof. An advantage of including a carbon fiber composite is that it gives a higher structural rigidity to the ballistic-resistant helmet shell, for example ear to ear

stiffness. This means that a person wearing such helmet has a further improved side protection of e.g. his ears upon impact.

A helmet shell as described may have very good ballistic resistant properties in relation to its weight. Typically, a helmet shell of the present invention can stop 9mm FMJ (full metal jacket) ammunition above 380 m/s; preferably above 400 m/s; more preferably above 420 m/s.

An advantage of such a helmet shell is that it is very light. Typically such a helmet shell has a mass of less than 1300 g. Preferably it has a mass of less than 1200 g. More preferably, it has a mass of less than 1100 g.

The helmet shell may be of any suitable design. For example it may be PASGT, MICH or other design known in the art. In order to achieve particularly low weight, the ballistic-resistant helmet shell is suitable for the modular integrated communications helmet (MICH) design. In particular, it may be suitable for a MICH design modified for Asian head shape. Such modification is known in the art and involves a higher left-right:front-back distance ratio than standard MICH design. A particularly low weight design is the MICH high-cut design. This typically has a mass of from 500 to 650 g; more preferably from 550 to 600 g. Helmet shells typically are produced in small medium and large sizes. References herein are preferably to medium size helmet shells. A large helmet shell may be approximately 3, 5, 7 or even 10% larger. A small helmet shell may be approximately 3, 5, 7 or even 10% smaller.

A helmet shell according to the present invention may be produced by:

i) stacking multiple layers comprising unidirectionally oriented ballistic resistant fibers and a binder to form a stack;

ii) consolidating said stack under elevated temperature and pressure to produce a core layer; and

iii) applying a coating layer comprising polyurea to the core layer.

To consolidate the stack, the stack is typically placed in an open mould, consisting of a female and a male part, and subsequently the stack is clamped to one part of the mould, generally the female part. This clamping is done through a so-called control member and is done in such a way that the stack is fixed in its position towards the said female mould part, but that the stack can still slip and move during the closing of the mould, i.e. when moving of the male part into the female mould part. This clamping through the control member may suitably be done by pressing the stack at its outer regions against the female mould part. The force with which the control member

is clamped to one part of the mould preferably ranges between 50 and 5000 N, more preferably between 100 and 3000 N and can be optimized by a skilled person through some routine experimentation.

After the stack is clamped to one part of the mould, the mould is closed e.g. by moving the male part into the female mould part and the stack is consolidated under temperature and pressure into the shape of a helmet shell. The consolidated stack is preferably cooled in the mould, still under pressure. As soon as the consolidated stack has cooled to a temperature, typically of 80 ˚C or 50 ˚C, the mould can be opened and the consolidated stack is released from the mould. Moreover the consolidated stack may further be processed through known mechanical techniques as sawing, grinding, drilling to the desired final dimensions.

The temperature during consolidation is chosen below the temperature at which the ballistic resistant fiber loses its high mechanical properties due to e.g. melting. In the case of e.g. HMWPE fibers, often having a melting temperature of 155 °C, a mould temperature below 135 °C is generally used. The minimum temperature generally is chosen such that a reasonable speed of consolidation is obtained. In this respect 50 °C is a suitable lower temperature limit, preferably this lower limit is at least 75 °C, more preferably at least 95 °C, most preferably at least 115 °C.

The pressure during consolidating is typically at least 7 MPa, more preferably at least 10 MPa, even more preferably at least 15 MPa and most preferably at least 20 MPa. In this way a better ballistic resistant performance is achieved. Optionally this consolidating may be preceded by a low pressure pre-shaping step. Pressure during this pre-shaping step may vary between 2 and 5 MPa. After pre-shaping and before consolidating the mould may be opened and the occurrence of blisters may be verified, which may subsequently be removed by e.g. piercing with a sharp object. Other options to prevent blisters include degassing during moulding or use of vacuum.

The optimum time for consolidation generally ranges from 5 to 120 minutes, depending on conditions such as temperature, pressure and part thickness and can be verified through routine experimentation. Typically the consolidation time is less than 90 minutes; and preferably less than 60 minutes.

If a tie layer is used, the tie layer may be added to the stack prior to consolidation. Alternatively, the tie layer may be added to the consolidated stack and then further consolidated. The coating is then applied, typically by spraying, as

described above.

FIG. 1 illustrates a MICH type helmet design; which is the preferred helmet design for the present invention.

FIG. 2 illustrates a cross section of a preferred embodiment of the present invention. The helmet shell design comprises a core layer (4) comprising a consolidated stack of layers of uni-directionally aligned ballistic-resistant fibers and a binder; coating layers comprising polyurea on the external surface (2) and on the internal surface (6); tie layers (3) and (5) located respectively between coating layer (2) and core layer (4) between coating layer (6) and core layer (4).

Test methods as referred to in the present application, are as follows:

IV: the Intrinsic Viscosity is determined according to method ASTM D1601 at 135°C in decalin, the dissolution time being 16 hours, with DBPC as anti-oxidant in an amount of 2 g/l solution, by extrapolating the viscosity as measured at different concentrations to zero concentration.

V_{STOP} against 9mm FMJ was carried out in accordance with NIJ 0106.01 level IIA & level II. The helmet shell was fitted with accessories, including straps, padding and external equipment fittings and subjected to ballistic testing. Shooting was performed using 9 mm 124 grain FMJ with an intended speed being about equal to the expected V_{STOP} (436 m/s). The actual projectile speed was measured before impact. Each helmet was subjected to four shots V_{STOP} was determined as the average of the three highest speeds with a stop. The same numbers are used for calculating the standard deviation.

Back face deformation was measured according to NIJ0106.01 with a 9 mm 124 grain FMJ threat shot at 427-445 m/s against a clay head form. The helmet shells were equipped with pads and a strap system. The back face signature was defined as the remaining indentation of the clay.

V_{50} against 1.1g (17 grain) FSP was determined on a 53 x 53 cm panel at different speeds to a maximum of 6 shots per panel. The final V_{50} was determined as the average of the three highest speeds with a stop, and the three lowest speeds yielding a perforation.

The present invention is illustrated by the following examples which are not intended to be limiting.

EXAMPLES

Example 1

A square shaped stack with dimensions of 53 cm x 53 cm was formed of 70 layers of unidirectionally aligned ultra-high molecular weight polyethylene fiber in a 17 wt% polyurethane matrix, whereby the fiber direction in each mono-layer is at an angle of 90 ° with respect to an adjacent monolayer. The material was 35 layers of HB210 from DSM Dyneema, Geleen, the Netherlands. The areal density of the stack was 4.8 kg/m^2. The stack was clamped in position over the female part of a helmet mould. Areal density is measured with respect to the outside surface of the helmet shell.

A clamping pressure of about 2000N was applied to the control member such that the stack was flat and fixed in its position towards the said female mould part, but that the stack could still slip and move during the closing of the mould. The mould was closed by inserting the male part into the female part of the mould whereby the flat stack slowly was positioned against the female mould surface. This closing was done in a time span of 5 minutes in order to have a temperature transfer from the male and female mould part to the stack. The temperature of the mould was about 130 °C. The applied pressure was 2 MPa and the stack was retained in the mould until the temperature at the centre of the stack was 130 °C. The system was degassed 3 times while at 2 MPa and left for 5 minutes. Subsequently, the pressure was increased to a compressive pressure of about 25 MPa, and the stack was kept under this pressure for 15 minutes at 130 °C. Next, the stack was cooled to a temperature of 50°C over a period of 30 minutes at the same compressive pressure. Subsequently the mould was opened and debris was cut from the helmet to obtain a smooth helmet edge.

The resulting helmet shell was coated by hand with Paxcon® polyurea coating from Line-X®, Huntsville, Alabama, USA and allowed to dry.

The resulting helmet shell was weighed, and average thickness was measured as described above, using a non-destructive modified vernier caliper system. The helmet accessories were added and V_{STOP} and BFD were measured against 9mm FMJ according to NIJ 0106.01 as described above. Results are shown in Table 1.

Table 1:

Thickness [mm]	Weight [g]	Stop 9mm @ 436 m/s [y/n]	BFD [mm]

7.5	1100	Y	13.1

The results indicate that a helmet shell of the present invention with a weight of 1100 g can stop 9mm FMJ at 436 m/s, and have a low Back Face Deformation of only 13.1 mm.

Example 2

Example 1 was repeated, except that the areal density of the stack was 5.5 Kgm^{-2}; the stack was pressed between flat mold parts to yield a flat panel; and the panel was coated by hand with 0.5 mm Paxcon® polyurea coating on each side. The panel was shot with 1.1g (17 grain) FSP and V_{50} was determined.

Comparative Example 1

Example 2 was repeated except that no coating was applied.

Example 3

Example 2 was repeated, except that a panel was produced as follows:

A square shaped stack with dimensions of 53 cm x 53 cm and having an areal density of 7.0 Kgm^{-2} was formed of unidirectionally aligned ultra-high molecular weight polyethylene fiber sheets. The sheets each comprised 4 layers, each layer comprising unidirectionally aligned fibers of UHMWPE embedded in a matrix of 17% of a polyurethane resin, and layered in the configuration of fiber direction 0°/90°/0°/90°. The material was HB26 from DSM Dyneema, Heerlen, Netherlands.

The stack was pressed, coated and shot in the same way as for Example 2.

Comparative Example 2

Example 3 was repeated except that no coating was applied.

Table 2:

Example	Core	Coated	V_{50} 1.1g (17 grain) FSP (ms^{-1})

C. Ex. 1	5.5 Kgm^{-2} HB210	No	730
Ex. 2	5.5 Kgm^{-2} HB210	Yes	774
C. Ex. 2	7.0 Kgm^{-2} HB26	No	662
Ex. 3	7.0 Kgm^{-2} HB26	Yes	684

The results demonstrate an increase in V_{50} of 3 to 5 % as a result of the presence of the coating.

CLAIMS

1. A ballistic-resistant helmet shell which comprises:
   a. a core layer, which core layer comprises a consolidated stack of layers of uni-directionally aligned ballistic-resistant fibers and a binder;
   b. a coating layer on the external surface of the core layer;
   characterized in that said coating layer comprises a polyurea and is from 0.3 to 4 mm thick.

2. A ballistic-resistant helmet shell according to claim 1, further comprising
   c. a coating layer on the internal surface of the core layer;
   characterized in that said coating layer comprises a polyurea and is from 0.3 to 4 mm thick.

3. A ballistic-resistant helmet shell according to claim 2, wherein each of the coating layers b and c are from 0.5 to 2 mm thick.

4. A ballistic-resistant helmet shell according to claim 2 or claim 3, which further comprises a tie layer between the core layer and one or both of the coating layers, b and c.

5. A ballistic-resistant helmet shell according to any one of claims 1 to 4, wherein the core layer is from 5 to 7 mm thick.

6. A ballistic-resistant helmet shell according to any one of claims 1 to 5, wherein the helmet shell is from 6 to 10 mm thick.

7. A ballistic-resistant helmet shell according to any one of claims 1 to 6, wherein the ballistic resistant fibers are ultra-high molecular weight polyethylene.

8. A ballistic-resistant helmet shell according to any one of claims 1 to 7 wherein the binder is polyurethane.

9. A ballistic-resistant helmet shell according to any one of claims 1 to 8 wherein the tie layer comprises fibers of ultra-high molecular weight polyethylene and a matrix.

10. A ballistic-resistant helmet shell according to claim 9, wherein the fibers of the tie layer are woven.

11. A ballistic-resistant helmet shell according to any one of claims 1 to 10, which further comprises at least one layer of carbon fiber composite.

12. A ballistic-resistant helmet shell according to any one of claims 1 to 11, which has a mass less than 1100 g.

13. A ballistic-resistant helmet comprising a ballistic-resistant helmet shell as defined in any one of claims 1 to 12.