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(54) **BALLISTIC RESISTANT PANEL**

SCHUSSSICHERE TAFEL

PANNEAU RÉSISTANT AUX BALLES

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Description

[0001] The present invention pertains to a ballistic resistant panel, and to a method for manufacturing thereof.

[0002] Ballistic resistant articles are known in the art. WO2009/109632 describes a ballistic resistant moulded article comprising a compressed stack of sheets comprising reinforcing tapes and an organic matrix material, the direction of the tapes within the compressed stack being not unidirectionally, wherein the tapes have a width of at least 2 mm and a width to thickness ratio of at least 10:1 with the stack comprising 0.2-8 wt. % of an organic matrix material. The reinforcing tapes preferably are tapes of ultra-high molecular weight polyethylene.

[0003] For heavy duty ballistic performance, the moulded article may be combined with an inorganic strike face, e.g., a plate of metal or ceramic material.

[0004] It has been found that for heavy-duty ballistic panels which comprise an inorganic strike face in combination with a ballistic resistant moulded article comprising polyethylene tapes, there is sometimes need for improvement of the properties of the panel, in particular as regards the improvement of back face deformation. The present invention provides a solution to this problem.

[0005] The present invention pertains to a ballistic-resistant pane according to claim 1, comprising

- an inorganic strike face with a thickness of at least 1 mm, the strike face comprising one or more of a metal sheet and a sheet of a ceramic material
- a ballistic resistant moulded article below the strike face, the moulded article comprising a HDPE-based layer comprising a compressed stack of sheets comprising reinforcing tapes having a tensile strength of at least 1.0 GPa, a tensile modulus of at least 40 GPa, and a tensile energy-to-break of at least 15 J/g, the direction of the tapes within the compressed stack being not unidirectional, and a high-density polyethylene (HDPE) as matrix material.

[0006] It has been found that the combination of an inorganic strike face and ballistic resistant moulded article comprising a layer based on HDPE as matrix material results in a ballistic resistant panel with improved back face deformation. It has further appeared that the ballistic performance of the panel according to the invention is maintained at higher temperatures. Further advantageous properties of the panel will be discussed below.

[0007] It is noted that WO2009/109632 describes a ballistic resistant moulded article comprising a compressed stack of sheets comprising reinforcing elongate bodies and an organic matrix material. The elongate bodies are, for example, polyethylene tapes. Many possible matrix materials are mentioned. In the examples Prinlin B7137AL is used, which is an aqueous styrene-isoprene-styrene resin.

Further, WO 2009/141276 describes a laminate for antiballistic purposes which comprises unidirectional the placed polymeric tapes with an E-modulus of an individual polymeric tape of at least 50 GPa and a square metre weight of the laminate above 150 g. Again, many possible matrix materials are mentioned. In the example no matrix material is specified.

WO 2009/056287 describes a material sheet comprising a woven fabric of unidirectional tapes of drawn polymer, wherein the width of a tape varies less than 2% on average in the longitudinal direction of the tape. The possibility of using a binder is mentioned, but no information on specific binders is provided. In the example, no binders seem to have been used.

[0008] None of these references discloses the specific combination of an inorganic strike face and ballistic resistant moulded article comprising a layer based on HDPE as matrix material. Further, none of these references, alone or in combination, suggest that the specific ballistic resistant panel of the invention, would show improved back face deformation and improved performance at higher temperatures.

[0009] The ballistic-resistant panel according to the invention will be discussed in more detail below.

[0010] The ballistic resistant panel according to the invention comprises an inorganic strike face with a thickness of at least 1 mm, the strike face comprising one or more of a metal sheet and a sheet of a ceramic material.

The inorganic strike face generally has a thickness between 1 mm and 25 mm, depending on the threat level. In one embodiment the inorganic strike face has a thickness in the range of 1-15 mm, in some embodiments 4-10 mm. In another embodiment, the inorganic strike face has a thickness of 10-25 mm.

Suitable metal sheets for use in the strike face used in the invention include sheets comprising steel and/or titanium.

Suitable ceramic materials for use in the strike face used in the invention include aluminium oxide, boron carbide, silicon carbide, beryllium oxide, and combinations thereof, such as boron carbide mixed with silicon carbide.

For ceramic sheets, the strike face generally has a hardness of at least 1000 kg/mm², in particular at least 1400 kg/mm².

For metal sheets, the strike face generally has a Brinell Hardness of 250, preferably 350.

[0011] The ballistic resistant panel according to the invention further comprises a ballistic resistant moulded article below the strike face. As will be evident to the skilled person, the term "below" is intended to refer to the opposite side of the strike face than the side from which ballistic impact is expected.

[0012] The ballistic resistant moulded article below the strike face comprises a HDPE-based layer comprising a compressed stack of sheets comprising reinforcing tapes having a tensile strength of at least 1.0 GPa, a tensile modulus of at least 40 GPa, and a tensile energy-to-break of at least 15 J/g, the direction of the tapes within the compressed stack

being not unidirectional, and a high-density polyethylene (HDPE) as matrix material.

[0013] Within the context of the present specification, the term HDPE-based layer refers to a layer comprising sheets comprising reinforcing tapes and a high-density polyethylene (HDPE) as matrix. The matrix content of this layer can vary, e.g., between 0.2 and 20 wt.%. The optimum matrix content is determined on the one hand by the amount of HDPE required to provide good delamination properties. On the other hand the amount of matrix should not be more than is required to obtain this effect, as excess matrix does not contribute substantially to the ballistic properties of the panel. It may be preferred for the amount of HDPE matrix material in this layer to be in the range of 0.2 to 15 wt.%, more in particular in the range of 0.2-10 wt.%, still more in particular in the range of 0.2 to 4 wt.%.

The HDPE used in the HDPE-based layer generally has a density in the range of 0.925 to 0.970 g/cm³, determined in accordance with ASTM D792. Materials with a density at the lower end of this range are sometimes sold under the indication MDPE. Within the context of the present specification they are regarded as HDPE.

The HDPE generally has a molecular weight M_w in the range of $1 \cdot 10^4$ to $1 \cdot 10^8$ g/mol, in particular $1 \cdot 10^5$ to $1 \cdot 10^7$ g/mol. The HDPE matrix used in the present invention is an isotropic material and can therewith be distinguished from reinforcing ultra-high molecular weight polyethylene tapes, which are anisotropic in that in the tapes the polymer is predominantly in one direction of the tape.

This can be seen, e.g., from the ratio between the strength of the material in a first direction and the strength of the material in a direction perpendicular thereto. For the HDPE matrix, which is an isotropic material, the ratio between the strength of the material determined in the direction where it strength is highest (machine direction) and the strength in the direction perpendicular thereto is generally at most 5:1. In contrast, for the tapes, the ratio between the strength of the material determined in the direction where it strength is highest (machine direction) and the strength in the direction perpendicular thereto is generally at least 50:1. This parameter can e.g. be determined from the breaking tenacity as determined in accordance with ASTM-D 7744-11.

[0014] It is noted that it is possible for the HDPE-based layer to also encompass other types of matrix material. Within the context of the present specification a layer will be indicated as a HDPE-based layer if of the matrix present in this layer at least 60 wt.% is HDPE. For reasons of efficiency of manufacture and effect to be obtained, it is preferred for the matrix present in the HDPE-based layer to comprise at least 70 wt.% HDPE, preferably at least 80 wt.%, more preferably at least 90 wt.%.

[0015] In one embodiment, in the ballistic resistant panel according to the invention the moulded article further comprises an elastomer-based layer comprising a compressed stack of sheets comprising reinforcing tapes having a tensile strength of at least 1.0 GPa, a tensile modulus of at least 40 GPa, and a tensile energy-to-break of at least 15 J/g, the direction of the tapes within the compressed stack being not unidirectional, and a thermoplastic elastomer as matrix material, the thermoplastic elastomer matrix material being present in an amount of 0.2-8 wt.%. This elastomer-based layer thus comprises reinforcing tapes and a thermoplastic elastomer as matrix. In this embodiment, the ballistic resistant moulded article of the panel according to the invention thus comprises two layers with different types of matrix materials. It has been found that the combination of a layer comprising HDPE as matrix with a layer comprising a thermoplastic elastomer as matrix results in an article which combines high impact resistance with improved constructional integrity of the article and reduced dynamic and static back face deformation upon impact. In particular the use of this layer combination ensures that the moulded article also shows good performance at extreme temperatures, e.g., -50°C or +70°C or +90°C. The moulded article also shows good peel resistance and good processing properties, in particular being easier to drill or cut.

[0016] For the elastomer-based layer, the matrix content is between 0.2 and 8 wt.%, calculated on the total of tapes and organic matrix material. The use of more than 8 wt.% of matrix material leads to a decrease of the ballistic performance of the article at the same areal weight. On the other hand, it was found that if no matrix material is used at all in this layer, the delamination properties of the article will be unacceptable. It may be preferred for the thermoplastic elastomer matrix material to be present in an amount of at least 1 wt.%, more in particular in an amount of at least 2 wt.%, in some instances at least 2.5 wt.%. In some embodiments it may be preferred for the matrix material to be present in an amount of at most 7 wt.%, sometimes at most 6.5 wt.%.

Thermoplastic elastomers (TPE), sometimes referred to as thermoplastic rubbers, which are used as matrix in the elastomer-based layer of the moulded article of the panel according to the invention are a class of copolymers or a physical mix of polymers (usually a plastic and a rubber) which consist of materials with both thermoplastic and elastomeric properties, i.e., they show plastic flow above their T_g (glass transition temperature), T_m (melting point), or T_s (softening point) (thermoplastic behavior) and resilient properties below the softening point. In one embodiment, the material has an elongation at break of at least 100%, in particular at least 200%. The upper limit is not critical to the present invention. A value of 600% may be mentioned in general. Preferably the elongation at break of the elastomer is higher than the elongation at break of the fiber or tape that may be manufactured from the composition of the present invention, as will be discussed in more detail below. In one embodiment, the thermoplastic elastomer has a tensile modulus (at 25°C) of at most 40 MPa (ASTM D7744-11).

Suitable thermoplastic elastomers include polyurethanes, poly-vinyls, polyacrylates, block copolymers and mixtures

thereof. In one embodiment, the thermoplastic elastomer is a block copolymer of styrene and an alpha-olefin comonomer. Suitable comonomers include C2-C12 alpha-olefins such as ethylene, propylene, butadiene, and isoprene. The use of polystyrene - polybutadiene - polystyrene polymer or polystyrene - isoprene - polystyrene is considered preferred at this point in time. These kind of polymers are commercially available, e.g., under the trade name Kraton or Styroflex.

It is understood that thermoplastic elastomer and the HDPE as described herein are not the same polymer. In particular, the HDPE does not have the characteristic properties of the thermoplastic elastomer, and the other way around. HDPE does not generally behave as thermoplastic elastomers, even if it contains small amounts of other monomers or polymers.

[0017] It is noted that it is possible for the elastomer-based layer to also encompass other types of matrix material. Within the context of the present specification a layer will be indicated as an elastomer-based layer if of the matrix present in this layer at least 60 wt.% is elastomer. For reasons of efficiency of manufacture and effect to be obtained, it is preferred for the matrix present in the elastomer-based layer to comprise at least 70 wt.% thermoplastic elastomer, preferably at least 80 wt.%, more preferably at least 90 wt.%. Of course, a single type of elastomer or combinations of different elastomers may be used. Both the HDPE-based layer and, if present, the elastomer-based layer comprises sheets comprising reinforcing tapes and a matrix.

Within the present specification, the term sheet refers to an individual sheet comprising tapes, which sheet can individually be combined with other corresponding sheets. The sheet may or may not comprise a matrix material, as will be elucidated below.

[0018] In one example, matrix material is provided within the sheets themselves, where it serves to adhere the tapes to each other. In another example, matrix material is provided on the sheet, where it acts as a glue or binder to adhere the sheet to further sheets within the stacks. Obviously, the combination of these two examples is also envisaged.

[0019] In one example, the sheets themselves contain reinforcing tapes and a matrix material. Sheets of this type may, for example, be manufactured as follows. In a first step, the tapes are provided in a layer, and then a matrix material is provided onto the layer under such conditions that the matrix material causes the tapes to adhere together. This example is particularly attractive where the matrix material is in the form of a film. In one example, the tapes are provided in a parallel arrangement. Sheets of this type may, for a further example, also be manufactured by a process in which a layer of tapes is provided, a layer of a matrix material is applied onto the tapes, and a further layer of tapes is applied on top of the matrix. In one example, the first layer of tapes encompasses tapes arranged in parallel and the second layer of tapes are arranged parallel to the tapes in the first layer but offset thereto. In another example, the first layer of tapes is arranged in parallel, and the second layer of tapes is arranged crosswise on the first layer of tapes.

[0020] In one example, the provision of the matrix material is effected by applying one or more films of matrix material to the surface, bottom or both sides of the plane of tapes and then causing the films to adhere to the tapes, e.g., by passing the films together with the tapes, through one or more heated pressure rolls.

[0021] In one example, the tape layer is provided with an amount of a liquid substance containing the matrix material. The advantage of this is that more rapid and better surface coating or wetting of the tapes is achieved. The liquid substance may be for example a solution, a dispersion or a melt of the matrix material. If a solution or a dispersion of the matrix material is used in the manufacture of the sheet, the process also comprises evaporating the solvent or dispersant. This can for instance be accomplished by using an organic matrix material of very low viscosity in wetting the tape surfaces in the manufacture of the sheet. If so desired, the matrix material may be applied at a reduced pressure (vacuum).

[0022] In one example, the matrix material is applied in the form of a powder, which is adhered to the sheets by heat or pressure, or a combination of both.

[0023] In the case that the sheet itself does not contain a matrix material, the sheet may be manufactured by the steps of providing a layer of tapes and where necessary adhering the tapes together by the application of heat and pressure. In one example of this example, the tapes overlap each other at least partially, and are then compressed to adhere to each other. Another example wherein the sheets may be free of matrix are when the sheets are manufactured by weaving tapes, either with other tapes, or with bonding thread.

[0024] The matrix material will then be applied onto the sheets to adhere the sheets to each other during the manufacture of the ballistic material. The matrix material can be applied in the form of a film or in the form of a liquid material, as discussed above for the application onto the tapes themselves. It is also possible to apply the matrix in the form of a powder.

[0025] In one example the matrix material is applied in the form of a web, wherein a web is a discontinuous polymer film, that is, a polymer film with holes. This allows the provision of low weights of matrix materials. Webs can be applied during the manufacture of the sheets, but also between the sheets.

[0026] In another example, the matrix material is applied in the form of strips, yarns, powder, pellets, or fibres of polymer material, the latter for example in the form of a woven or non-woven yarn of fibre web or other polymeric fibrous weft. Again, this allows the provision of low weights of matrix materials. Strips, yarns, powder, pellets or fibres can be applied during the manufacture of the sheets, but also between the sheets.

[0027] In a further example, the matrix material is applied in the form of a liquid material, as described above, where the liquid material may be applied homogeneously over the entire surface of the elongate body plane, or of the sheet,

as the case may be. However, it is also possible to apply the matrix material in the form of a liquid material inhomogeneously over the surface of the elongate body plane, or of the sheet, as the case may be. For example, the liquid material may be applied in the form of dots or stripes, or in any other suitable pattern.

[0028] In various examples, the matrix material is distributed inhomogeneously over the sheets. In one example the matrix material is distributed inhomogeneously within the compressed stack. In this example more matrix material may be provided there where the compressed stack encounters the most influences from outside which may detrimentally affect stack properties.

[0029] As indicated above, in one embodiment the ballistic-resistant moulded article used in the panel according to the invention comprises a HDPE-based layer and an elastomer-based layer. If so desired, the article may comprise more than one HDPE-based layer and/or more than one elastomer-based layer.

[0030] In one embodiment, the moulded article comprises a HDPE-based layer at or near the back face of the article, wherein the back face is the face opposite the strike face side, which is the side from which impact is expected, and where the inorganic strike face is located. It is expected that the presence of the HDPE-based layer at or near the back face of the article helps to prevent delamination and fragmentation of the article. Further the retention of internal structure is maintained.

[0031] In the context of the present specification the wording "at the back face" means that the lowest point of the layer at issue is within 5%, determined over the cross-section of the article, from the bottom of the article in question, preferably within 3%, in particular at 0% (thus at the outer side of the article, not counting layers not comprising reinforcing tapes and matrix, e.g., cover layers). In the context of the present specification the wording "near the back face" means that the lowest point of the layer at issue is between 5 and 20%, determined over the cross-section of the article, from the bottom of the article in question.

[0032] In another embodiment, the moulded article comprises a HDPE-based layer at or near the strike face side of the article.

[0033] In the context of the present specification the wording "at the strike face side" means that the highest point of the layer at issue is within 5% from the front of the moulded article in question, determined over the cross-section of the article, preferably within 3%, in particular at 0% (thus at the outer side of the article, not counting layers not comprising reinforcing tapes and matrix, e.g., cover layers).

[0034] In the context of the present specification the wording "near the strike face side" means that the highest point of the layer at issue is between 5 and 20% from the front of the article in question, determined over the cross-section of the article.

[0035] In a further embodiment the article comprises a HDPE-based layer at or near the strike face side of the article, and a HDPE-based layer at or near the back face of the article. In this embodiment, an elastomer-based layer will be present between the HDPE-based layers.

[0036] In a further example the article comprises an elastomer-based layer at or near the strike face of the article, and an elastomer-based layer at or near the back face of the article. In one example, the article with this structure is a helmet. In this example, a HDPE-based layer will be present between the elastomer-based layers. This example may be attractive where a system with a very high stiffness is desired.

[0037] As will be evident to the skilled person, systems with more than three layers, e.g., 4, 5, 6, or even more can also be manufactured if so desired.

[0038] The ballistic resistant moulded article according to the invention may be flat, single-curved, double curved, or multicurved. Examples include panels, e.g., for use in vehicles and helicopters, shields, and helmets.

[0039] In one example, the panel according to the invention meets the requirements of one or more of NIJ standard threat level III, NIJ III+, NIJ IV, Stanag 4569, and AEP 55.

[0040] In one example the ballistic resistant moulded article according to the invention is a helmet which meets the requirements of class NIJ III and higher of the NIJ Standard - 0106.01, ammunition type AK 47MSC and SS109). In this example an inorganic strike face thickness of 1 to 5 mm is preferred. This ballistic performance is preferably accompanied by a low areal weight, in particular a mass per area of at most 20 kg/m², more in particular at most 15 kg/m², even more in particular at most 11 kg/m². In another example, the requirements of class NIJ IV threat level of the said Standard are met. In this example an inorganic strike face thickness of 4 to 10 mm is preferred. This ballistic performance is preferably accompanied by a low areal weight, in particular a mass per area of at most 40 kg/m², more in particular at most 35 kg/m², even more in particular at most 30 kg/m².

[0041] Within the context of the present specification layers are parallel to the main (i.e. largest) outer surface of the article. It is preferred for the various layers of the article to extend along substantially the entire article, as this is believed to provide the best possible properties. It is of course possible that, e.g., at the edges of the article one or more of the layers are not present but it is preferred that both a HDPE based-layer and an elastomer-based layer are present over at least 75%, preferably at least 85%, more preferably at least 90% of the panel, determined from a top or bottom perspective.

[0042] The composition of the moulded article used in the panel according to the invention can vary within wide ranges,

depending on the required properties of the resulting article.

[0043] In one example, the article comprises only HDPE-based layers. Where the article also comprises elastomer-based layers, they are generally present in an amount of 5-95 wt.%, the HDPE-based layers also being present in an amount of 5-95 wt.%. In one example, the article comprises at least 50 wt.% of HDPE-based layers.

[0044] Layers comprising reinforcing tapes and other matrix materials may be present, but their optional presence does not detract from the preference for the ranges given above. In one example, the HDPE-based layer(s) and elastomer-based layer(s) build up at least 70 wt% of the article, preferably at least 80 wt%, more preferably at least 90 wt% (percentages calculated on layers comprising reinforcing tapes).

[0045] Depending on the final use, the expected threat level, and the thickness of the individual sheets, the number of sheets in the stack in the ballistic resistant article according to the invention is generally at least 10, in particular at least 20. The number of sheets generally is at most 500, in particular at most 400.

[0046] Various sheet configurations are possible. In one example, a sheet comprises a single layer of parallel tapes, wherein the tapes do not overlap or overlap to a very limited extent. In another example, a sheet comprises a first layer of parallel tapes and a second layer of parallel tapes on top of the first layer of parallel tapes, wherein the tapes of the second layer are parallel to the tapes of the first layer but offset thereto. If so desired, a third, and even a fourth, layer of parallel tapes may be provided, in each case parallel to the tapes in the previous layer, but offset thereto. In this example it is generally preferred for the sheet to comprise two or three layers of parallel tapes, in particular two layers of parallel tapes. In a further example, the sheet comprises woven tapes.

[0047] While it is possible to combine different sheet configurations within the same panel, it may be preferred for reasons of process efficiency for the different sheets within the panel to have the same configuration. For example, the moulded article may comprise a compressed stack of sheets wherein the sheets comprise a single layer of parallel tapes which do not overlap, and wherein the direction of the tapes in a second sheet is rotated with respect to the direction of the tapes in the adjacent sheet. For a further example, the moulded article may comprise a compressed stack of sheets wherein the sheets comprise a first layer of parallel tapes and a second layer of parallel tapes on top of the first layer of parallel tapes, wherein the tapes of the second layer are parallel to the tapes of the first layer but offset thereto, and wherein the direction of the tapes in a second sheet is rotated with respect to the direction of the tapes in the adjacent sheet.

[0048] In the present invention the direction of tapes within the compressed stack is not unidirectional. This means that in the stack as a whole, tapes are oriented in different directions.

[0049] In one example of the present invention the tapes in a sheet are unidirectionally oriented, and the direction of the tapes in a sheet is rotated with respect to the direction of the tapes of other sheets in the stack, more in particular with respect to the direction of the tapes in adjacent sheets. Good results are achieved when the total rotation within the stack amounts to at least 45 degrees. Preferably, the total rotation within the stack amounts to approximately 90 degrees. In one example, the stack comprises adjacent sheets wherein the direction of the tapes in one sheet is perpendicular to the direction of tapes in adjacent sheets. The ballistic-resistant panel according to the invention, which comprises an inorganic strike face and a ballistic resistant moulded article may be manufactured by various methods.

[0050] In one embodiment, a ballistic-resistant moulded article is manufactured, and then combined with the inorganic strike face.

[0051] In another embodiment, the ballistic-resistant panel is manufactured in a single step.

[0052] Thus, in one embodiment of the present invention a ballistic-resistant panel according to the invention is manufactured by a method according to claim 12, comprising the steps of

- manufacturing a ballistic resistant moulded article by stacking sheets comprising reinforcing tapes in such a manner that the direction of the tapes within the compressed stack is not unidirectional to form a stack of sheets, wherein the stack of sheets comprises a high-density polyethylene (HDPE) as matrix material, and compressing the stack of sheets to form a ballistic resistant moulded article, and
- combining the ballistic resistant moulded article with an inorganic strike face to form a ballistic resistant panel.

[0053] The ballistic-resistant moulded article may be manufactured by methods used in the art, e.g., as described in WO2009/109632. Suitable methods include the manufacture of sheets, stacking the sheets in such a manner that the direction of the tapes within the compressed stack is not unidirectional, and compressing the stack, wherein it is ensured during manufacture that the layer structure and matrix content of the article are obtained. For this, reference is made to what has been stated above. Compressing can be done under pressure, e.g., of at least 0.5 MPa. Compression can also be performed under vacuum.

[0054] Where necessary, the temperature during compression is selected such that the matrix material is brought above its softening or melting point, if this is necessary to cause the matrix to help adhere the tapes and/or sheets to each other. Compression at an elevated temperature is intended to mean that the moulded article is subjected to the given pressure for a particular compression time at a compression temperature above the softening or melting point of the organic matrix material and below the softening or melting point of the tapes.

[0055] The required compression time and compression temperature depend on the nature of the tape and matrix material and on the thickness of the moulded article and can be readily determined by the person skilled in the art.

[0056] Where the compression is carried out at elevated temperature, it may be preferred for the cooling of the compressed material to also take place under pressure. Cooling under pressure is intended to mean that the given minimum pressure is maintained during cooling at least until so low a temperature is reached that the structure of the moulded article can no longer relax under atmospheric pressure. It is within the scope of the skilled person to determine this temperature on a case by case basis. Where applicable it is preferred for cooling at the given minimum pressure to be down to a temperature at which the organic matrix material has largely or completely hardened or crystallized and below the relaxation temperature of the reinforcing tapes. The pressure during the cooling does not need to be equal to the pressure at the high temperature. During cooling, the pressure should be monitored so that appropriate pressure values are maintained, to compensate for decrease in pressure caused by shrinking of the moulded article and the press.

[0057] In the process the stack may be made starting from loose sheets. Loose sheets are difficult to handle, however, in that they easily tear in the direction of the tapes. It is therefore preferred to make the stack from consolidated sheet packages containing from 2 to 8, as a rule 2, 4 or 8. For the orientation of the sheets within the sheet packages, reference is made to what has been stated above for the orientation of the sheets within the compressed stack.

[0058] Consolidated is intended to mean that the sheets are firmly attached to one another. Very good results are achieved if the sheet packages, too, are compressed. The sheets may be consolidated by the application of heat and/or pressure, as is known in the art.

[0059] The thus-obtained ballistic resistant moulded article can be combined with the inorganic strike face via methods known in the art. This can be done, e.g., using an adhesive. If so desired, bonding layers may be present between the ballistic-resistant moulded article and the inorganic strike face, to improve the connection between the two. The bonding layer may, e.g., be an adhesive film layer connected to the ballistic-resistant moulded article, which serves as a carrier for the adhesive layer.

[0060] If so desired, the structural integrity of the ballistic-resistant moulded article may be improved by applying stitching through the article.

[0061] In one embodiment of the present invention, the ballistic-resistant panel is manufactured by a process according to claim 13, comprising the steps of

- providing an inorganic strike face, stacking sheets comprising reinforcing tapes onto the back side of the strike face in such a manner that the direction of the tapes within the compressed stack is not unidirectional to form a stack of sheets, wherein the stack of sheets comprises a high-density polyethylene (HDPE) as matrix material, and
- compressing the stack of sheets and the inorganic strike face together to form a ballistic resistant panel.

[0062] This embodiment has the advantage that the shape of the ballistic-resistant moulded article is matched exactly to the shape of the inorganic strike face.

[0063] Compression can take place by methods described above. Compression under vacuum may be preferred in this embodiment, because it ensures that a homogeneous pressure is applied irrespective of the shape of the inorganic strike face.

[0064] A bonding layer may be applied between the inorganic strike face and the stack of sheets comprising reinforcing tapes. The bonding layer may, e.g., be a thin fabric layer connected to the ballistic-resistant moulded article, which serves as a carrier for the adhesive layer.

[0065] If so desired, additional measures can be effected to connect the strike face and moulded article, such as winding the panel with a fabric or webbing.

[0066] Tape as used in the present invention is an object of which the length is larger than the width and the thickness, while the width is in turn larger than the thickness. In the tapes which may be used in the present invention, the ratio between the width and the thickness is more than 10:1, in particular more than 20:1, more in particular more than 50:1, still more in particular more than 100:1. The maximum ratio between the width and the thickness is not critical to the present invention. It generally is at most 1000:1, depending on the tape width.

[0067] The width of the tape which may be used in the present invention is at least 2 mm, in particular at least 10 mm, more in particular at least 20 mm. The width of the tape is not critical and may generally be at most 500 mm. The thickness of the tape is generally at least 8 microns, in particular at least 10 microns. The thickness of the tape is generally at most 150 microns, more in particular at most 100 microns.

[0068] In one example the tapes which may be used in the present invention have a linear density of at least 500 dtex, in particular at least 1000 dtex, more in particular at least 3000 dtex, still more in particular at least 5000 dtex, even more in particular at least 10000 dtex, or even at least 15000 dtex. Higher dtex tapes have the advantages that fewer tapes have to be used to obtain an article of a certain areal weight. This is not only process efficient, but may also reduce the risk of edge effects.

[0069] The ratio between the length and the width of the tapes used in the present invention is not critical. It depends

on the width of the tape and the size of the ballistic resistant moulded article. The ratio between length and width is at least 1. As a general value, a maximum length to width ratio of 1 000 000 may be mentioned.

[0070] Any natural or synthetic tapes may in principle be used in the present specification. Use may be made of for instance tapes made of metal, semimetal, inorganic materials, organic materials or combinations thereof. For application of the tapes in ballistic-resistant moulded articles it is essential that the tapes bodies be ballistically effective, which, more specifically, requires that they have a high tensile strength, a high tensile modulus and a high energy absorption, reflected in a high energy-to-break. The tapes used in the present invention have a tensile strength of at least 1.0 GPa, a tensile modulus of at least 40 GPa, and a tensile energy-to-break of at least 15 J/g. Suitable inorganic tapes having a high tensile strength are for example carbon fibre tapes, glass fibre tapes, and ceramic fibre tapes. Suitable organic tapes having a high tensile strength are for example tapes made of aramid, of liquid crystalline polymer, and of highly oriented polymers such as polyolefins, polyvinylalcohol, and polyacrylonitrile.

[0071] In the present invention the use of homopolymers and copolymers of polyethylene and polypropylene is preferred. These polyolefins may contain small amounts of one or more other polymers, in particular other alkene-1-polymers.

[0072] It is preferred for the tapes used in the present invention sheet to be high-drawn tapes of high-molecular weight linear polyethylene. High molecular weight here means a weight average molecular weight of at least 400 000 g/mol. Linear polyethylene here means polyethylene having fewer than 1 side chain per 100 C atoms, preferably fewer than 1 side chain per 300 C atoms. The polyethylene may also contain up to 5 mol % of one or more other alkenes which are copolymerisable therewith, such as propylene, butene, pentene, 4-methylpentene, octene.

[0073] It may be particularly preferred to use tapes of ultra-high molecular weight polyethylene (UHMWPE), that is, polyethylene with a weight average molecular weight of at least 500 000 g/mol. The use of tapes with a molecular weight of at least $1 \cdot 10^6$ g/mol may be particularly preferred. The maximum molecular weight of the UHMWPE tapes suitable for use in the present invention is not critical. As a general value a maximum value of $1 \cdot 10^8$ g/mol may be mentioned. The molecular weight distribution and molecular weight averages (M_w , M_n , M_z) can be determined as described in WO2009/109632.

[0074] In one example, the tensile strength of the tapes is at least 1.2 GPa, more in particular at least 1.5 GPa, still more in particular at least 1.8 GPa, even more in particular at least 2.0 GPa. In one embodiment, the tensile strength of these tapes is at least 2.0 GPa, in particular at least 2.5 GPa, more in particular at least 3.0 GPa, still more in particular at least 4 GPa. Tensile strength is determined in accordance with ASTM D7744-11.

[0075] In one example, the tapes have a tensile modulus of at least 50 GPa. More in particular, the tapes may have a tensile modulus of at least 80 GPa, more in particular at least 100 GPa, still more in particular at least 120 GPa, even more in particular at least 140 GPa, or at least 150 GPa. The modulus is determined in accordance with ASTM D7744-11.

[0076] In one example, the tapes have a tensile energy to break of at least 20 J/g, in particular at least 25 J/g. In another example, the tapes have a tensile energy to break of at least 30 J/g, in particular at least 35 J/g, more in particular at least 40 J/g, still more in particular at least 50 J/g. The tensile energy to break is determined in accordance with ASTM D7744-11. It is calculated by integrating the energy per unit mass under the stress-strain curve.

[0077] In one example, the polyethylene tapes which may be used in the present invention have a high molecular orientation as is evidenced by their XRD diffraction pattern.

[0078] In one example, the tapes have a 200/110 uniplanar orientation parameter Φ of at least 3. The 200/110 uniplanar orientation parameter Φ is defined as the ratio between the 200 and the 110 peak areas in the X-ray diffraction (XRD) pattern of the tape sample as determined in reflection geometry. The 200/110 uniplanar orientation parameter gives information about the extent of orientation of the 200 and 110 crystal planes with respect to the tape surface. For a tape sample with a high 200/110 uniplanar orientation the 200 crystal planes are highly oriented parallel to the tape surface. It has been found that a high uniplanar orientation is generally accompanied by a high modulus, high tensile strength and high tensile energy to break. The ratio between the 200 and 110 peak areas for a specimen with randomly oriented crystallites is around 0.4. However, in the tapes that are preferentially used in one embodiment of the present invention the crystallites with indices 200 are preferentially oriented parallel to the film surface, resulting in a higher value of the 200/110 peak area ratio and therefore in a higher value of the uniplanar orientation parameter. This parameter can be determined as described in WO2009/109632.

[0079] The UHMWPE tapes used in one example of the ballistic material have a 200/110 uniplanar orientation parameter of at least 3. It may be preferred for this value to be at least 4, more in particular at least 5, or at least 7. Higher values, such as values of at least 10 or even at least 15 may be particularly preferred. The theoretical maximum value for this parameter is infinite if the peak area 110 equals zero. High values for the 200/110 uniplanar orientation parameter are often accompanied by high values for the strength and the energy to break.

[0080] In one example, the UHMWPE tapes which may be used in the present invention have a narrow molecular weight distribution have an M_w/M_n ratio of at most 6. More in particular the M_w/M_n ratio is at most 5, still more in particular at most 4, even more in particular at most 3. The use of materials with an M_w/M_n ratio of at most 2.5, or even at most 2 is envisaged in particular.

[0081] In one example, the UHMWPE tapes, in particular UHMWPE tapes have a DSC crystallinity of at least 74%,

more in particular at least 80%. The DSC crystallinity can be determined as described in WO2009/109632.

[0082] The polyethylene used in this example can be a homopolymer of ethylene or a copolymer of ethylene with a co-monomer which is another alpha-olefin or a cyclic olefin, both with generally between 3 and 20 carbon atoms. Examples include propene, 1-butene, 1-pentene, 1-hexene, 1-heptene, 1-octene, cyclohexene, etc. The use of dienes with up to 20 carbon atoms is also possible, e.g., butadiene or 1-4 hexadiene. The amount of non-ethylene alpha-olefin in the ethylene homopolymer or copolymer used in the process according to the invention preferably is at most 10 mole%, preferably at most 5 mole%, more preferably at most 1 mole%. If a non-ethylene alpha-olefin is used, it is generally present in an amount of at least 0.001 mol.%, in particular at least 0.01 mole%, still more in particular at least 0.1 mole%. The use of a material which is substantially free from non-ethylene alpha-olefin is preferred. Within the context of the present specification, the wording substantially free from non-ethylene alpha-olefin is intended to mean that the only amount non-ethylene alpha-olefin present in the polymer are those the presence of which cannot reasonably be avoided.

[0083] In general, the UHMWPE tapes have a polymer solvent content of less than 0.05 wt.%, in particular less than 0.025 wt.%, more in particular less than 0.01 wt.%.

[0084] In one example, the tapes which may be used in the present invention, in particular UHMWPE tapes have a high strength in combination with a high linear density. In the present application the linear density is expressed in dtex. This is the weight in grams of 10.000 metres of tape. In one example, the tapes which may be used in the invention have a denier of at least 500 dtex, in particular at least 100 dtex, more in particular at least 3000 dtex, even more in particular at least 5000 dtex, more in particular at least 10000 dtex, even more in particular at least 15000 dtex, or even at least 20000 dtex, in combination with strengths of at least 1.0 GPa, in particular at least 1.5 GPa, more in particular at least 2.0 GPa, still more in particular at least 2.5 GPa, more in particular at least 3.0 GPa, still more in particular at least 3.5 GPa, and even more in particular at least 4 GPa.

[0085] In one example, the polyethylene tapes are tapes manufactured by a process which comprises subjecting a starting polyethylene with a weight average molecular weight of at least 100 000 gram/mole, an elastic shear modulus

G_N^0 , determined directly after melting at 160°C of at most 1.4 MPa to a compacting step and a stretching step under such conditions that at no point during the processing of the polymer its temperature is raised to a value above its melting point.

[0086] The starting material for said manufacturing process is a highly disentangled UHMWPE. This can be seen from the combination of the weight average molecular weight and the elastic modulus. For further elucidation. As indicated above, the starting polymer has an elastic shear modulus G_N^0 determined directly after melting at 160°C of at most 1.4 MPa, more in particular at most 1.0 MPa, still more in particular at most 0.9 MPa, even more in particular at most 0.8 MPa, and even more in particular at most 0.7. The wording "directly after melting" means that the elastic modulus is determined as soon as the polymer has melted, in particular within 15 seconds after the polymer has melted. For this polymer melt, the elastic modulus typically increases from 0.6 to 2.0 MPa in several hours.

[0087] The elastic shear modulus directly after melting at 160°C is a measure for the degree of entangledness of the polymer. G_N^0 is the elastic shear modulus in the rubbery plateau region. It is related to the average molecular weight between entanglements M_e , which in turn is inversely proportional to the entanglement density. In a thermodynamically stable melt having a homogeneous distribution of entanglements, M_e can be calculated from G_N^0 via the formula

$G_N^0 = g_N \rho RT / M_e$, where g_N is a numerical factor set at 1, ρ is the density in g/cm³, R is the gas constant and T is the absolute temperature in K. A low elastic modulus thus stands for long stretches of polymer between entanglements, and thus for a low degree of entanglement. The adopted method for the investigation on changes in with the entanglements formation is the same as described in publications (Rastogi, S., Lippits, D., Peters, G., Graf, R., Yefeng, Y. and Spiess, H., "Heterogeneity in Polymer Melts from Melting of Polymer Crystals", Nature Materials, 4(8), 1st August 2005, 635-641 and PhD thesis Lippits, D.R., "Controlling the melting kinetics of polymers; a route to a new melt state", Eindhoven University of Technology, dated 6th March 2007, ISBN 978-90-386-0895-2).

[0088] The disentangled polyethylene for use in this example may be manufactured by a polymerisation process wherein ethylene, optionally in the presence of other monomers as discussed above, is polymerised in the presence of a single-site polymerisation catalyst at a temperature below the crystallisation temperature of the polymer, so that the polymer crystallises immediately upon formation. Suitable methods for manufacturing polyethylenes which may be used in the present invention are known in the art. Reference is made, for example, to WO01/21668 and US20060142521.

[0089] The UHMWPE tapes which may be used in the present invention may be manufactured by solid state processing of the UHMWPE, which process comprises compacting UHMWPE powder, and stretching the resulting compacted sheets to form tapes. Suitable methods for solid state processing UHMWPE are known in the art, and described, e.g., in WO2009/109632, WO2009/153318 and WO2010/079172 and require no further elucidation here.

[0090] The present invention is illustrated by the following examples, without being limited thereto or thereby.

Example 1

[0091] A ballistic resistant panel according to the invention was manufactured as follows.

[0092] The starting material consisted of UHMW polyethylene tapes commercially available as Endumax Tape TA23 from Teijin Endumax. The tapes had a width of 133 mm and a thickness of 50 μm . The tapes had a tensile strength of 2.0 GPa, a tensile modulus of 188, and a tensile energy to break of 20 J/g.

[0093] UD-sheets were manufactured by aligning tapes in parallel to form a first layer, aligning a further layer of tapes onto the first layer parallel and offset to the tapes in the first layer, and heat-pressing the tape layers to form a UD-sheet. A HPDE foil is applied between the two tape layers and on top of the upper tape layer.

[0094] UD-sheets were cross-plyed to form a cross-ply sheet. 58 cross-ply sheets were stacked and compressed at a temperature of 136-137°C, at a pressure of 60 bar. The material was cooled down and removed from the press to form a ballistic-resistant moulded article. The article comprised 58 layers of cross-ply sheet, had an areal weight of 12.5 kg/m² and a matrix content of 9 wt.%.

[0095] The ballistic resistant moulded article thus obtained was combined with an inorganic strike face, namely a 7 Alotec 96 SB 7 mm, which is a ceramic aluminium oxide tile with an areal weight of 26.25 kg/m² and a density of 3.75 g/cm³. The panel and the strike face were adhered together using a commercially available adhesive film, viz. Nolax S22.2031. Consolidation of the complete ballistic resistant article including inorganic strike face was performed on a vacuum table at 135 °C for 30 minutes.

[0096] The panel was subjected to ballistic testing in accordance with the VRAM standard APR 2006 and PM 2007 (test level 9) employing AP7.62 mm ammunition (full metal jacket (FMJ) Armour Piercing (AP) hardened steel core, P80). A 63 mm cartridge was used to achieve higher projectile velocities. The distance between barrel and target was 5 m. The tests were carried out at 20°C and 90°C, the latter to investigate the performance of the panel at higher temperature. The results are presented in Table 1.

	20C	90C
V50 (m/s)	998	987
SEA (Jm ² /g)	25.38	24.82

[0097] From the table it can be seen that the panel according to the invention showed good performance, both at 20°C and at 90°C, with only a limited decrease in performance at the higher temperature. The panel showed a good structural performance, with only small trauma, and without delamination occurring.

Example 2

[0098] Panels were manufactured as described above for Example 1, except that 33 or 36 cross-ply sheets comprising 4 UHMWPE tape layers were used and an 8 mm Alotec 96 SB ceramic aluminium oxide tile with an areal weight of 30 kg/m² and a density of 3.75 g/cm³ was used. The panels were tested at 20°C according to the method described above, and the results are presented in Table 2.

Table 2

	V50 (m/s)	SEA (Jm ² /s)
33 layer panel (areal weight 37.6 kg/m ²)	970	25.05
36 layer panel (areal weight 37.6 kg/m ²)	986	25.45

[0099] The panel showed a good structural performance, with only small trauma, and without delamination occurring.

Example 3

[0100] A panel was prepared as described in Example 1, except that rather than cross-ply sheets comprising four tape layers stacked in a 0-0-90-90 degree order, cross-ply sheets comprising four tape layers in a 0-90-0-90 degree order were applied. The panel was combined with the 7 mm strike face described above. The panel, which had an areal weight of 39.3 kg/m² was tested at 20°C according to the method described above, and the results are presented in Table 3.

Table 3

V50 (m/s)	969
SEA (Jm ² /g)	23.92

Example 4

[0101] To investigate the effect of an HDPE matrix in comparison with a standard elastomeric matrix the following experiment was carried out.

[0102] A panel according to the invention was prepared analogous to that in described in example 1 using a 7 mm ceramic plate and 60 layers of cross-ply sheets as in example 1. A comparative panel was prepared in the same manner, except that instead of an HDPE matrix the panel contained 4 weight percent of a styrene-isoprene-styrene matrix (Kraton). To obtain the same panel weight 65 layers of polyethylene tape cross-ply were used. Both panels had an areal weight of 39.1 kg/m².

[0103] The panels were tested at 90°C as described above. The results are presented in table 4.

Table 4

	V50 (m/s)
Panel according to the invention	951
Comparative panel	903

[0104] From the results in table 4 it can be seen that the panel according to the invention has a higher V50 than the comparative panel. This is particularly surprising since the comparative panel contains more polyethylene tapes and would therefore be expected to show better results.

Example 5

[0105] To further investigate the effect of an HDPE matrix in comparison with a standard elastomeric matrix the following experiment was carried out.

[0106] A panel according to the invention was prepared analogous to that in described in example 1 using a 8 mm ceramic plate and 37 layers of cross-ply sheet. A comparative panel was prepared in the same manner, except that instead of an HDPE matrix the panel contained 4 weight percent of a styrene-isoprene-styrene matrix (Kraton). To obtain the same panel weight 40 layers of polyethylene tape cross-ply. Both panels had an areal weight of about 37.8 kg/m².

[0107] Figure 1 shows photographs of the strike face and the back face of the panel according to the invention and the comparative panel. Both panels were shot according to NIJ standard 01.0104 level IV with 30.06 AP ammunition at muzzle velocity. As can be seen from the photographs, the damage to the strike face of both panels is comparable. The back face of the comparative panel split into two and showed severe trauma. The back face of the panel according to the invention remained whole and showed only limited trauma. This shows the advantageous effects of the present invention.

Claims

1. Ballistic-resistant panel comprising

- an inorganic strike face with a thickness of at least 1 mm, the strike face comprising one or more of a metal sheet and a sheet of a ceramic material,
- a ballistic-resistant moulded article below the strike face, the moulded article comprising a HDPE-based layer comprising a compressed stack of sheets comprising reinforcing tapes having a tensile strength of at least 1.0 GPa, a tensile modulus of at least 40 GPa, and a tensile energy-to-break of at least 15 J/g, the direction of the tapes within the compressed stack being not unidirectional, and a high-density polyethylene (HDPE) as matrix material.

2. Ballistic resistant panel according to claim 1 wherein the inorganic strike face has a thickness between 1 mm and

25 mm, and for ceramic sheets, a hardness of at least 1000 kg/mm², in particular at least 1400 kg/mm² and for metal sheets, a Brinell Hardness of 250, preferably 350.

3. Ballistic-resistant panel according to any one of the preceding claims, wherein the compressed stack of sheets has a matrix content between 0.2 and 20 wt.%.
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4. Ballistic-resistant panel according to any one of the preceding claims wherein the HDPE has a density in the range of 0.925 to 0.970 g/cm³, determined in accordance with ASTM D792.

5. Ballistic-resistant panel according to any one of the preceding claims wherein the HDPE has a molecular weight Mw in the range of 1.10⁴ to 1.10⁸ g/mol, in particular 1.10⁵ to 1.10⁷ g/mol.
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6. Ballistic resistant panel according to any one of the preceding claims wherein the moulded article further comprises an elastomer-based layer comprising a compressed stack of sheets comprising reinforcing tapes having a tensile strength of at least 1.0 GPa, a tensile modulus of at least 40 GPa, and a tensile energy-to-break of at least 15 J/g, the direction of the tapes within the compressed stack being not unidirectional, and a thermoplastic elastomer as matrix material, the thermoplastic elastomer matrix material being present in an amount of 0.2-8 wt.%.
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7. Ballistic-resistant panel according to claim 6, wherein the moulded article comprises a HDPE-based layer at or near the back face of the article, wherein the back face is the face opposite the strike face.
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8. Ballistic-resistant panel according to claim 6 or 7 wherein the moulded article comprises a HDPE-based layer at or near the strike face side of the article.

9. Ballistic-resistant panel according to any one of claims 6-8 wherein the article comprises a HDPE-based layer at or near the strike face of the article, and a HDPE-based layer at or near the back face of the article.
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10. Ballistic-resistant panel according to any one of the preceding claims wherein the reinforcing tapes are ultra-high molecular weight polyethylene (UHMWPE) tapes.
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11. Ballistic-resistant panel according to any one of the preceding claims, which is flat, single-curved, double curved, or multicurved.

12. Method for manufacturing a ballistic-resistant panel according to any one of the preceding claims comprising the steps of
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- manufacturing a ballistic resistant moulded article by stacking sheets comprising reinforcing tapes in such a manner that the direction of the tapes within the compressed stack is not unidirectional to form a stack of sheets, wherein the stack of sheets comprises a high-density polyethylene (HDPE) as matrix material, and compressing the stack of sheets to form a ballistic resistant moulded article, and
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- combining the ballistic resistant moulded article with an inorganic strike face to form a ballistic resistant panel.

13. Method for manufacturing a ballistic-resistant panel according to any one of claims 1-11 comprising the steps of
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- providing an inorganic strike face, stacking sheets comprising reinforcing tapes onto the back side of the strike face in such a manner that the direction of the tapes within the compressed stack is not unidirectional to form a stack of sheets, wherein the stack of sheets comprises a high-density polyethylene (HDPE) as matrix material, and
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- compressing the stack of sheets and the inorganic strike face together to form a ballistic resistant panel.

Patentansprüche

1. Geschosshemmende Platte, umfassend
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- eine anorganische Auftrefffläche mit einer Dicke von mindestens 1 mm, die Auftrefffläche umfassend eines oder mehrere von einem Metallblech und einer Lage aus einem keramischen Material,
- einen geschosshemmenden Formkörper unter der Auftrefffläche, der Formkörper umfassend eine Schicht auf

HDPE-Basis, umfassend einen komprimierten Stapel von Lagen, umfassend Verstärkungsbänder, die eine Zugfestigkeit von mindestens 1,0 GPa, ein Zugmodul von mindestens 40 GPa und eine Zugbruchenergie von mindestens 15 J/g aufweisen, wobei die Richtung der Bänder innerhalb des komprimierten Stapels nicht unidirektional ist, und ein Polyethylen hoher Dichte (HDPE) als Matrixmaterial.

2. Geschosshemmende Platte nach Anspruch 1, wobei die anorganische Auftrefffläche eine Dicke von zwischen 1 mm und 25 mm, und für keramische Lagen, eine Härte von mindestens 1000 kg/mm², insbesondere mindestens 1400 kg/mm², und für Metallbleche, eine Brinell-Härte von 250, vorzugsweise 350, aufweist.
3. Geschosshemmende Platte nach einem der vorstehenden Ansprüche, wobei der komprimiert Stapel von Lagen einen Matrixgehalt zwischen 0,2 und 20 Gew.-% aufweist.
4. Geschosshemmende Platte nach einem der vorstehenden Ansprüche, wobei das HDPE eine gemäß ASTM D792 bestimmte Dichte im Bereich von 0,925 bis 0,970 g/cm³ aufweist.
5. Geschosshemmende Platte nach einem der vorstehenden Ansprüche, wobei das HDPE ein Molekulargewicht, Mw, im Bereich von 1·10⁴ bis 1·10⁸ g/mol, insbesondere 1·10⁵ bis 1·10⁷ g/mol, aufweist.
6. Geschosshemmende Platte nach einem der vorstehenden Ansprüche wobei der Formkörper weiter eine Schicht auf Elastomerbasis, umfassend einen komprimierten Stapel von Lagen, umfassend Verstärkungsbänder, die eine Zugfestigkeit von mindestens 1,0 GPa, ein Zugmodul von mindestens 40 GPa und eine Zugbruchenergie von mindestens 15 J/g aufweisen, wobei die Richtung der Bänder innerhalb des komprimierten Stapels nicht unidirektional ist, und ein Thermoplastelastomer als Matrixmaterial umfasst, wobei das Thermoplastelastomermatrixmaterial in einer Menge von 0,2-8 Gew.-% vorliegt.
7. Geschosshemmende Platte nach Anspruch 6, wobei der Formkörper eine Schicht auf HDPE-Basis an oder nahe der Rückfläche des Körpers umfasst, wobei die Rückfläche die Fläche gegenüberliegend der Auftrefffläche ist.
8. Geschosshemmende Platte nach Anspruch 6 oder 7, wobei der Formkörper eine Schicht auf HDPE-Basis an oder nahe der Auftreffflächenseite des Körpers enthält.
9. Geschosshemmende Platte nach einem der Ansprüche 6-8, wobei der Körper eine Schicht auf HDPE-Basis an oder nahe der Auftrefffläche des Körpers und eine Schicht auf HDPE-Basis an oder nahe der Rückfläche des Körpers umfasst.
10. Geschosshemmende Platte nach einem der vorstehenden Ansprüche, wobei die Verstärkungsbänder Bänder aus ultrahochmolekularem Polyethylen (UHMWPE) sind.
11. Geschosshemmende Platte nach einem der vorstehenden Ansprüche, die flach, einfach gekrümmt, doppelt gekrümmt oder mehrfach gekrümmt ist.
12. Verfahren zum Herstellen einer geschosshemmenden Platte nach einem der vorstehenden Ansprüche, umfassend die Schritte
 - Herstellen eines geschosshemmenden Formkörpers durch Stapeln von Lagen, umfassend Verstärkungsbänder, derart, dass die Richtung der Bänder innerhalb des komprimierten Stapels nicht unidirektional ist, zum Bilden eines Stapels von Lagen, wobei der Stapel von Lagen ein Polyethylen hoher Dichte (HDPE) als Matrixmaterial umfasst, und Komprimieren des Stapels von Lagen zum Bilden eines geschosshemmenden Formkörpers und
 - Kombinieren des geschosshemmenden Formkörpers mit einer anorganischen Auftrefffläche zum Bilden einer geschosshemmenden Platte.
13. Verfahren zum Herstellen einer geschosshemmenden Platte nach einem der Ansprüche 1-11, umfassend die Schritte
 - Bereitstellen einer anorganischen Auftrefffläche, Stapeln von Lagen, umfassend Verstärkungsbänder, auf der Rückfläche der Auftrefffläche derart, dass die Richtung der Bänder innerhalb des komprimierten Stapels nicht unidirektional ist, zum Bilden eines Stapels von Lagen, wobei der Stapel von Lagen ein Polyethylen hoher

Dichte (HDPE) als Matrixmaterial umfasst, und
- gemeinsames Komprimieren des Stapels von Lagen und der anorganischen Auftrefffläche zum Bilden einer geschosshemmenden Platte.

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Revendications

1. Panneau pare-balles comprenant

10 - une face de frappe inorganique avec une épaisseur d'au moins 1 mm, la face de frappe comprenant une ou plusieurs d'une feuille de métal et une feuille de matériau de céramique,
- un article moulé pare-balles en dessous de la face de frappe, l'article moulé comprenant une couche à base de HDPE comprenant une pile de feuilles compressée comprenant des bandes de renfort présentant une résistance à la traction d'au moins 1,0 GPa, un module en traction d'au moins 40 GPa, et une énergie de rupture à la traction d'au moins 15 J/g, la direction des bandes dans la pile compressée étant non unidirectionnelle, et un polyéthylène haute densité (HDPE) en tant que matériau de matrice.

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2. Panneau pare-balles selon la revendication 1 dans lequel la face de frappe inorganique présente une épaisseur entre 1 mm et 25 mm, et pour des feuilles de céramique, une dureté d'au moins 1 000 kg/mm², en particulier au moins 1 400 kg/mm² et pour des feuilles de métal, une dureté Brinell de 250, de préférence 350.

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3. Panneau pare-balles selon l'une quelconque des revendications précédentes, dans lequel la pile de feuilles compressée présente un contenu de matrice entre 0,2 et 20 % en poids.

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4. Panneau pare-balles selon l'une quelconque des revendications précédentes dans lequel le HDPE présente une densité dans la plage de 0,925 à 0,970 g/cm³, déterminée conformément à l'ASTM D792.

5. Panneau pare-balles selon l'une quelconque des revendications précédentes dans lequel le HDPE présente un poids moléculaire Mw dans la plage de 1·10⁴ à 1·10⁸ g/mol, en particulier 1·10⁵ à 1·10⁷ g/mol.

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6. Panneau pare-balles selon l'une quelconque des revendications précédentes dans lequel l'article moulé comprend en outre une couche à base d'élastomère comprenant une pile de feuilles compressée comprenant des bandes de renfort présentant une résistance à la traction d'au moins 1,0 GPa, un module en traction d'au moins 40 GPa, et une énergie de rupture à la traction d'au moins 15 J/g, la direction des bandes dans la pile compressée étant non unidirectionnelle, et un élastomère thermoplastique en tant que matériau de matrice, le matériau de matrice d'élastomère thermoplastique étant présent en une quantité de 0,2 à 8 % en poids.

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7. Panneau pare-balles selon la revendication 6, dans lequel l'article moulé comprend une couche à base de HDPE au niveau ou près de la face arrière de l'article, dans lequel la face arrière est la face opposée à la face de frappe.

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8. Panneau pare-balles selon la revendication 6 ou 7 dans lequel l'article moulé comprend une couche à base de HDPE au niveau ou près du côté face de frappe de l'article.

9. Panneau pare-balles selon l'une quelconque des revendications 6-8 dans lequel l'article comprend une couche à base de HDPE au niveau ou près de la face de frappe de l'article, et une couche à base de HDPE au niveau ou près de la face arrière de l'article.

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10. Panneau pare-balles selon l'une quelconque des revendications précédentes dans lequel les bandes de renfort sont des bandes de polyéthylène à ultra-haut poids moléculaire (UHMWPE).

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11. Panneau pare-balles selon l'une quelconque des revendications précédentes, qui est plat, à une seule incurvation, à double incurvation ou à incurvations multiples.

12. Procédé de fabrication d'un panneau pare-balles selon l'une quelconque des revendications précédentes comprenant les étapes consistant à

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- fabriquer un article moulé pare-balles en empilant des feuilles comprenant des bandes de renfort de manière à ce que la direction des bandes dans la pile compressée soit non unidirectionnelle pour former une pile de

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feuilles, dans lequel la pile de feuilles comprend du polyéthylène haute densité (HDPE) en tant que matériau de matrice, et en compressant la pile de feuilles pour former un article moulé pare-balles, et
- combiner l'article moulé pare-balles avec une face de frappe inorganique pour former un panneau pare-balles.

5 **13.** Procédé de fabrication d'un panneau pare-balles selon l'une quelconque des revendications 1-11 comprenant les étapes consistant à

10 - fournir une face de frappe inorganique, empiler des feuilles comprenant des bandes de renfort sur le côté arrière de la face de frappe de manière à ce que la direction des bandes dans la pile compressée soit non unidirectionnelle pour former une pile de feuilles, dans lequel la pile de feuilles comprend du polyéthylène haute densité (HDPE) en tant que matériau de matrice, et
- compresser la pile de feuilles et la face de frappe inorganique ensemble pour former un panneau pare-balles.

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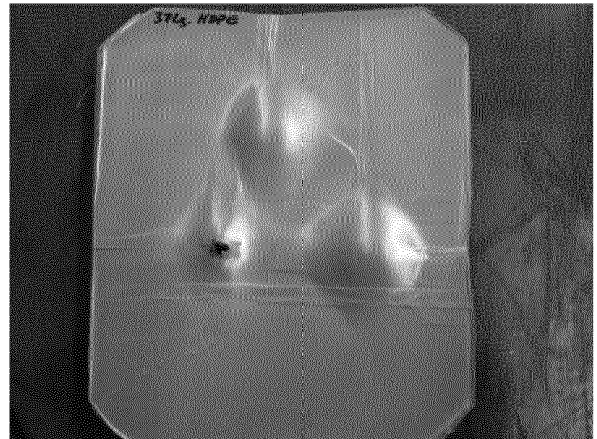
Figure 1

Panel according to the invention

Strike face (ceramic)



Back face

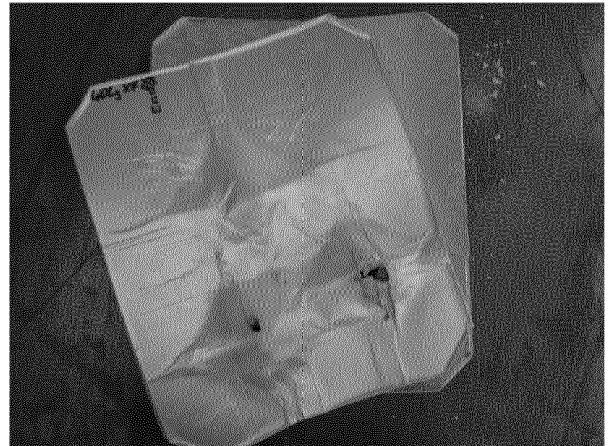


Comparative panel

Strike face (ceramic)



Back face



REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 2009109632 A [0002] [0007] [0053] [0073] [0078] [0081] [0089]
- WO 2009141276 A [0007]
- WO 2009056287 A [0007]
- WO 0121668 A [0088]
- US 20060142521 A [0088]
- WO 2009153318 A [0089]
- WO 2010079172 A [0089]

Non-patent literature cited in the description

- RASTOGI, S. ; LIPPITS, D. ; PETERS, G. ; GRAF, R. ; YEFENG, Y. ; SPIESS, H. Heterogeneity in Polymer Melts from Melting of Polymer Crystals. *Nature Materials*, 01 August 2005, vol. 4 (8), 635-641 [0087]
- PHD THESIS LIPPITS, D.R. Controlling the melting kinetics of polymers; a route to a new melt state. *Eindhoven University of Technology*, 06 March 2007, ISBN ISBN 978-90-386-0895-2 [0087]