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(54) **ARMOR PANEL**

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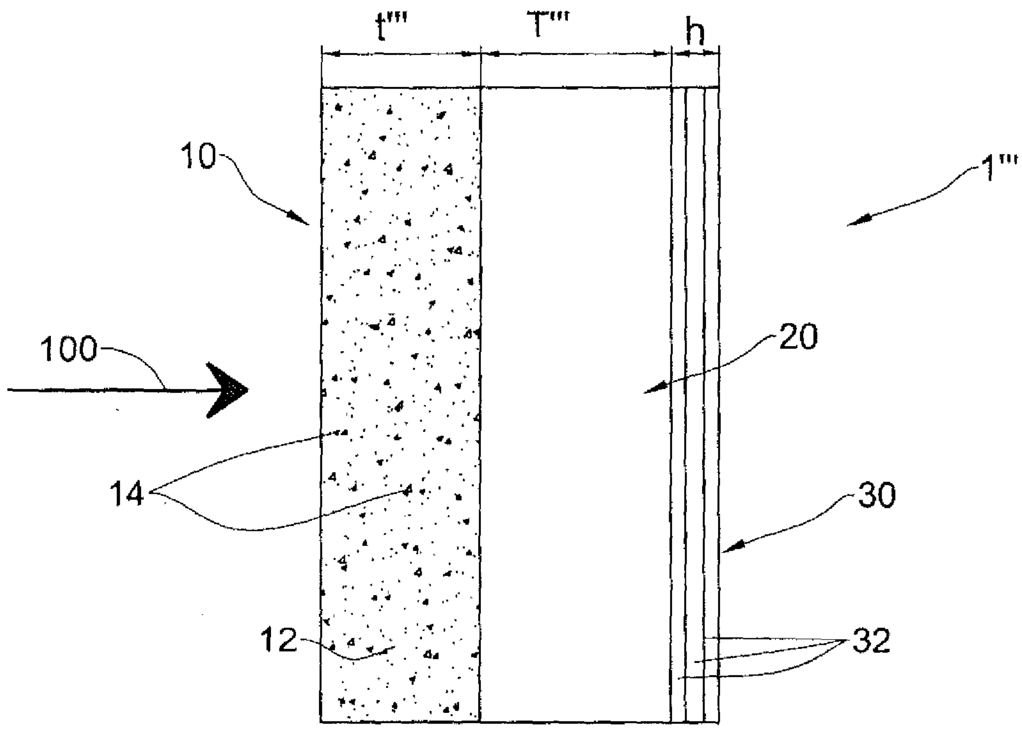
(57) **ABSTRACT**

An armor panel for ballistic protection, comprising at least an armor layer which is at least partially made of cemented carbide in the form of metal-carbide aggregate embedded within a metal binder matrix.



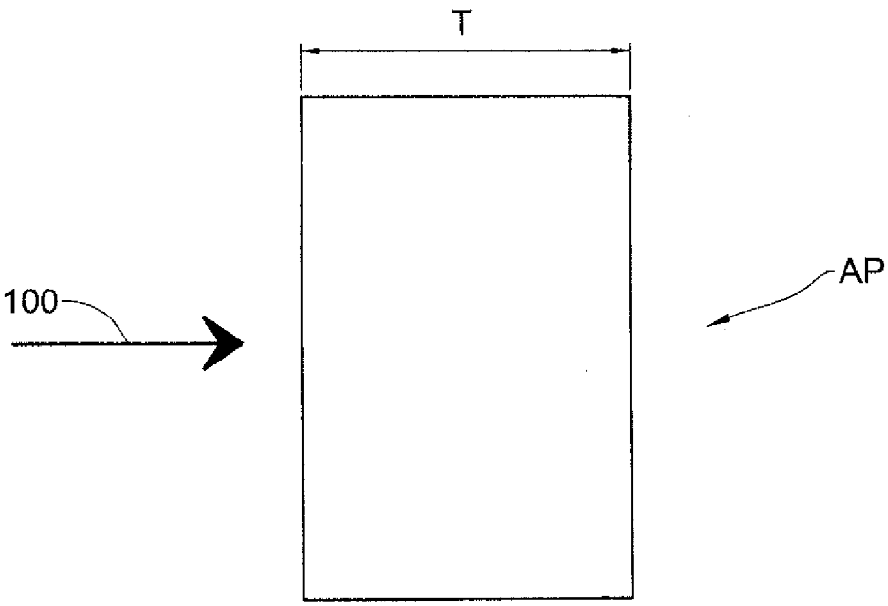


Fig. 1 (Prior Art)

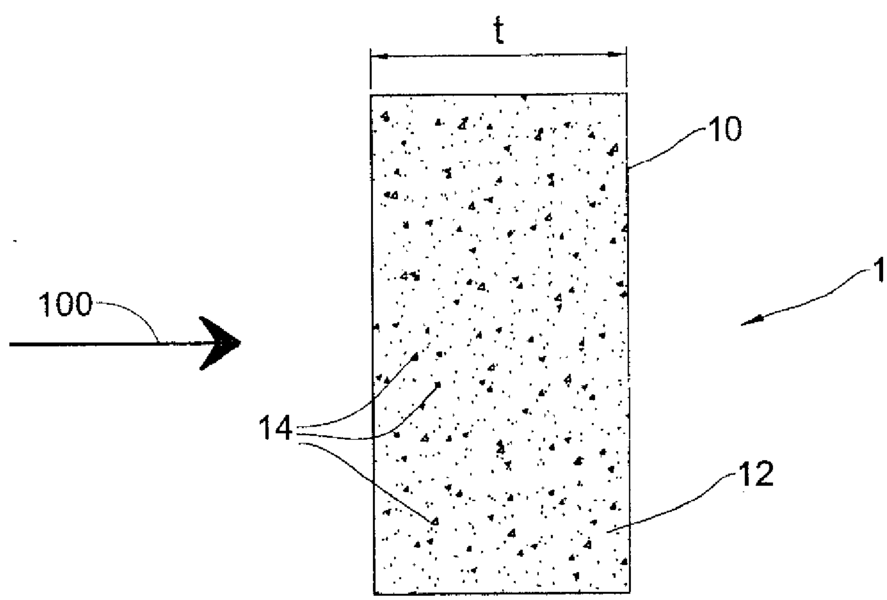


Fig. 2A

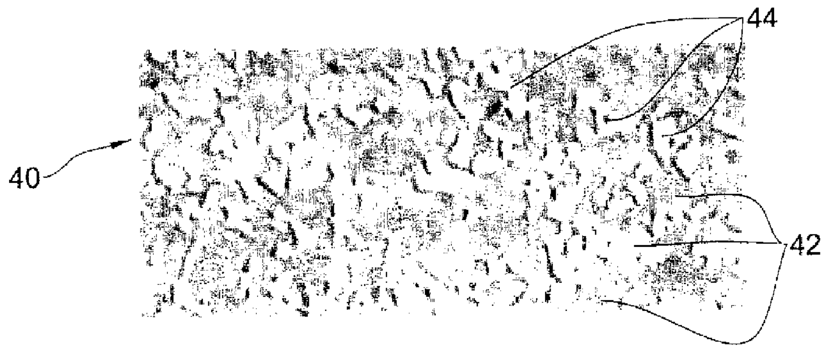


Fig. 2B

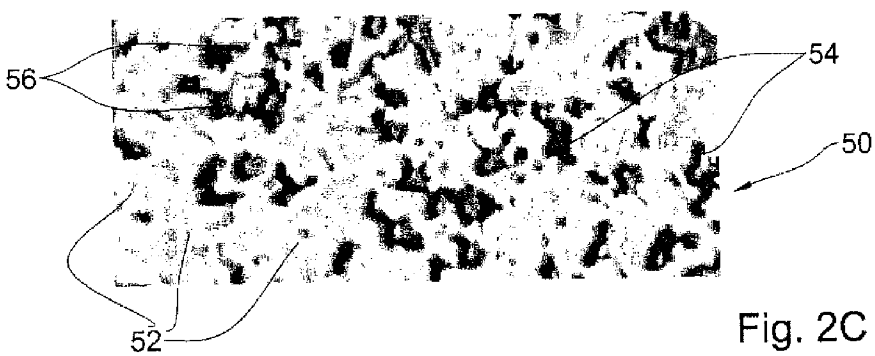


Fig. 2C

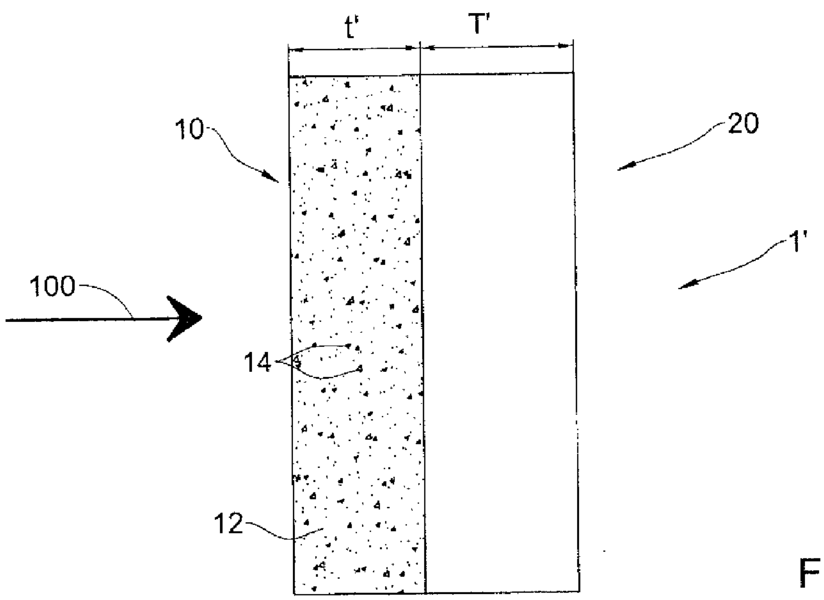


Fig. 3

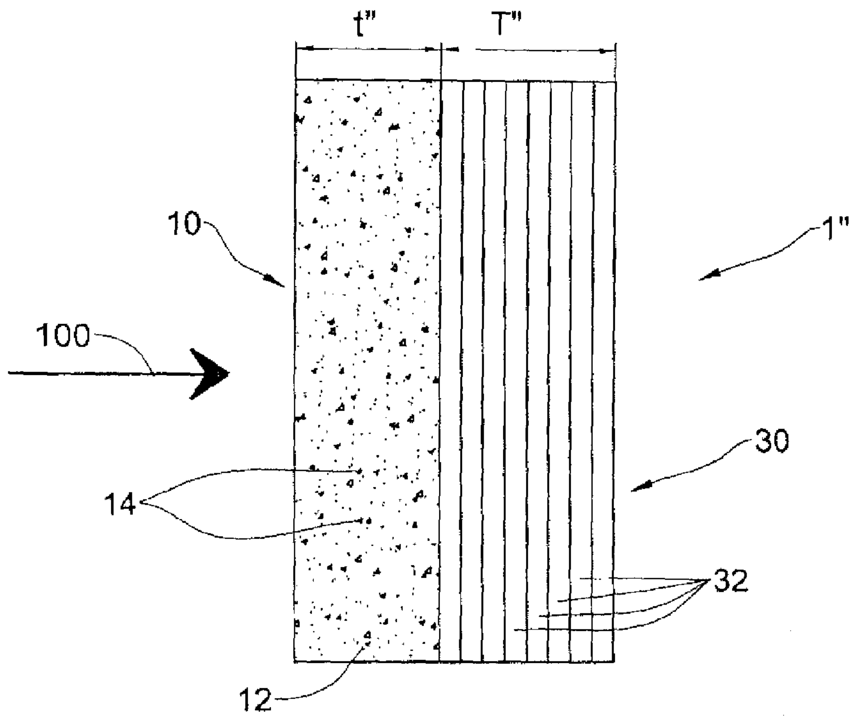


Fig. 4

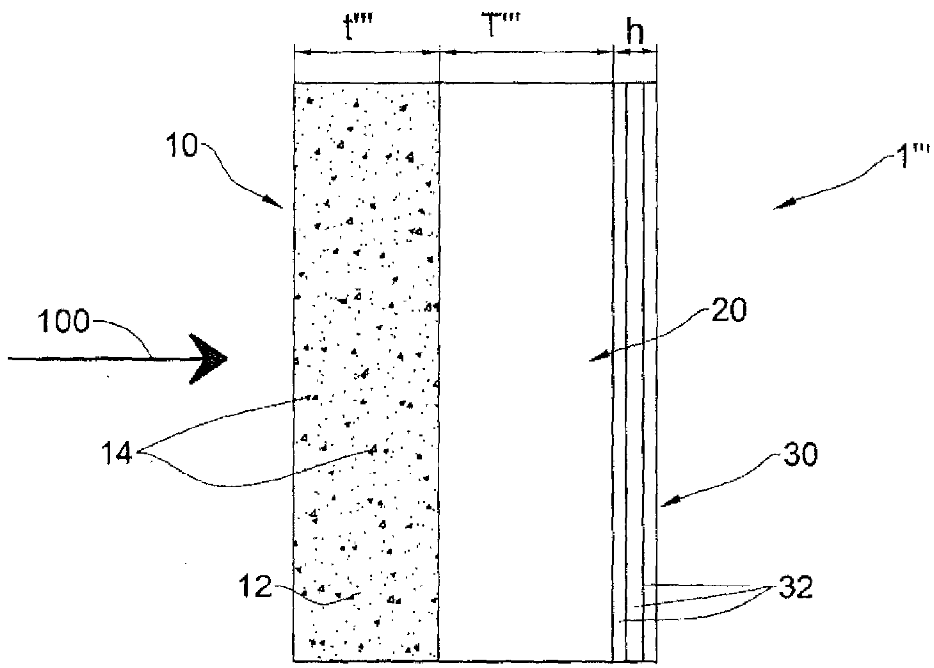


Fig. 5

ARMOR PANEL

[0001] This is a Continuation of U.S. application Ser. No. 12/504,040 filed Jul. 16, 2009, which claims the benefit of Israel Application No. 192894 filed Jul. 17, 2008. The disclosures of the prior applications are hereby incorporated by reference herein in their entirety.

FIELD OF THE INVENTION

[0002] This invention relates to armor panels, in particularly composite armor panels comprising one or more protective layers.

BACKGROUND OF THE INVENTION

[0003] A standard armor panel of the kind to which the present invention particularly refers, comprises a multitude of layers, designed to gradually absorb the kinetic energy of the impact, delivered to the panel by an incoming projectile and finally to completely avoid penetration of the projectile or its fragments to the body to be protected.

[0004] The layers used in such armor panels may be divided into two groups: hard layers, e.g. steel or ceramic, and soft layers, e.g. Aramid or UHMW HDPE (Ultra High Molecular Weight High Density PolyEthylene). The harder layers are usually positioned facing the expected threat and absorb most of its kinetic energy thereof, thereby slowing it down and shattering and/or deforming it substantially. The softer layers absorb the remains of the kinetic energy of the projectile, stopping it and its fragments, thereby preventing them from deforming/coming in contact with the body to be protected or at least from penetrating it.

[0005] It is known in the art to use armor panels having several hard layers of different materials in order to better absorb the kinetic energy of the incoming projectile.

[0006] The choice between various materials that may constitute the hard and/or soft layers of the armor panel is affected by the required end properties of the panel, such as ballistic properties, weight, etc. Thus, for example, a hard ceramic layer may be light-weight, yet brittle, while a hard steel layer having similar ballistic properties, may be very heavy, though easy to work with.

SUMMARY OF THE INVENTION

[0007] According to the present invention, there is provided an armor panel for protecting a body from an incoming projectile having an expected impact direction, said armor panel comprising at least an armor layer made of cemented carbide in the form of metal-carbide aggregate embedded within a metal binder matrix.

[0008] The armor panel may be adapted to protect the human body, i.e. be in the form of personal armor such as a vest, or alternatively, be designed to protect a structure, mobile or immobile, adapted to house individuals to be protected, e.g. a vehicle.

[0009] The 'metal-carbide aggregate' should be understood as being in the form of granular/powder material, and 'embedded within a metal binder matrix' should be understood as being homogenously spread throughout the metal binder matrix.

[0010] It should be noted that cemented carbide may be divided into two major groups, a first group in which the cemented carbide comprises a carbide aggregate embedded within a binder matrix, and a second group in which the cemented carbide comprises an aggregate without a binder.

[0011] For the purpose of simplicity, the metal of said metal-carbide will be referred herein as 'carbide metal' and the metal used for said metal binder matrix will be referred herein as 'binder metal'.

[0012] Said carbide metal and said binder metal may differ in their inherent characteristics. More particularly, the properties of said carbide and said binder metal may differ from one another. The metal of said carbide metal may be chosen from a group of refractory metals, in order to provide said cemented carbide with high hardness, high fracture toughness and a high melting point. The metal of the binder metal may be a metal having a lower hardness than that of the metal of the metal-carbide, in order to reduce the brittleness of the cemented carbide and provide it with high fracture toughness.

[0013] Cemented carbide may be manufactured by a variety of processes in solid, liquid and vapor phases as known per se, for example hot isostatic pressing (HIP) or sintering. During manufacture, binder metal and carbide are heated up until the binder metal is melted down while the aggregate remains in solid phase, thereby providing the cemented carbide with its desired morphology. This is due to the carbide having a higher melting point than that of the binder metal.

[0014] The carbide metals are so chosen as to provide the metal-carbide with relatively high density, high toughness and hardness. Thus, the metal-carbides described above may have a density ranging from 4.93-15.8 gr/cc, a toughness ranging from 240-550 MPa, hardness ranging from 1400-3000 HV50 and a melting point ranging from 1800-3990° C. Fracture toughness of the above metal-carbides is relatively not high, e.g. up to about 12 Mpa*($m^{1/2}$), Some examples of such metal-carbides may be WC, TiC, TaC, NbC, ZrC, HfC, VC, Cr3C2, Mo2C etc. The cemented carbide may comprise several carbide metals forming several kinds of aggregates while using the same metal binder. Some examples of such cemented carbides may be WC—Co, WC—TiC—TaC—NbC—Co, WC—Cr3C2-Co, WC—TiC—TaC—NbC—Cr3C2-Co, TiCN—WC—TiC—TaC—NbC—Ni—Co—Mo2C—VC.

[0015] Said binder metal may have a density ranging from 7.8-8.9 gr/cc, fracture toughness ranging up to 400 Mpa*($m^{1/2}$) which is considerably higher than that of the metal-carbides, and a melting point ranging from 1450-1536° C. Some examples of such binder metals may be Co, Ni, Fe etc.

[0016] The binder metals listed above have an atomic weight essentially lower than that of the carbide metals, providing the cemented carbide used for the armor panel with an essentially lower overall density than a similar cemented carbide in which the metal (such as W, Ti, Nb etc.) is of an atomic weight close to that of the carbide metals.

[0017] In the cemented carbide layer, the metal-carbide aggregate may be in the form of grains homogenously spread throughout the binder. The grain size of the metal-carbide aggregate may be such that it does not exceed 20 μm per grain. For example, for grains of tungsten carbide (WC), the grain size may range between about 0.5 μm-2.3 μm, more particularly between 0.7 μm-2.1 μm, and still more particularly between 0.9 μm-1.9 μm, and having an average grain size of about 1.3 μm. For grains of titanium carbide (TiC), the grain size may range between about 2.5 μm-6.2 μm, more particularly between 2.7 μm-6 μm, and still more particularly between 2.9 μm-5.8 μm, and having an average grain size of about 2.7 μm.

[0018] The composition of the cemented carbide may be such that, by weight percentage, the metal carbide aggregate does not exceed 80%. The metal carbide aggregate may constitute between about 80-96%, more particularly between about 85-94%, and still more particularly between about 90-92%. The metal binder matrix may be such that, by weight, does not exceed 80%. The metal binder matrix may constitute between about 4%-20%, more particularly between about 6%-15%, and still more particularly between about 8%-10%.

[0019] The composition of the cemented carbide may also be such that, by volume percentage, the metal carbide aggregate does not exceed 70%. The metal carbide aggregate may constitute between about 82-96%, more particularly between about 86-92%, and still more particularly between about 88-90%. The metal binder matrix may be such that, by volume, does not exceed 30%. The metal binder matrix may constitute between about 4%-18%, more particularly between about 8%-14%, and still more particularly between about 10%-12%.

[0020] It should be appreciated that the cemented carbide may comprise metal carbide aggregates of various metal, for example both titanium carbide (TiC) aggregates and tungsten carbide (WC) aggregates. In this case, the composition of the cemented carbide may be such that, by weight, WC ranges between 70%-85%, more particularly between 74%-80%, and still more particularly between 76%-79%. The weight percentage of the titanium carbide (TiC) may range between 10%-20%, more particularly between 12%-18%, and still more particularly between 14%-16%. The weight percentage of the binder may range between 4%-20%, more particularly between 6%-15%, and still more particularly between 8%-10%.

[0021] In the above case, the composition of the cemented carbide may be such that, by volume, WC may range between 50%-65%, more particularly between 53%-62%, and still more particularly between 56%-60%. The volume percentage of the titanium carbide (TiC) may range between 24%-40%, more particularly between 27%-36%, and still more particularly between 30%-33%. The volume percentage of the binder may range between 4%-16%, more particularly between 6%-14%, and still more particularly between 9%-12%.

[0022] The said cemented carbide may have an overall density ranging from 5.5-15.5 gr/cc, a toughness ranging from 1.7-4.1 GPa, hardness ranging from 87-93 HRa, and fracture toughness up to 20 Mpa*($m^{1/2}$), i.e. lower than that of the binder metal yet higher that of the metal-carbide.

[0023] It should also be understood that the above compositions are chosen specifically in order to provide the cemented carbide, on the one hand, with high hardness due to the metal-carbide aggregate, and on the other hand, high fracture toughness due to the metal-binder matrix. In particular, since the cemented carbide is used in an armor panel, the composition is chosen such that it may be adapted to withstand a high impact during a short time interval.

[0024] It should be noted that the armor panel may also comprise a layer which is partially made of cemented carbide, for example, containing cemented carbide pellets and/or tiles. The term 'pellets' should be understood to refer to armor elements adapted to be incorporated within the armor panel, and usually having a polygonal/cylindrical shape extending along a central axis. The design of the armor panel may be such that the pellets/tiles are incorporated within a matrix which is of different characteristics than that of the metal-binder matrix, for example, made of a light weight metal (e.g. aluminum) or a thermoplastic/thermosetic polymer (e.g. resin).

[0025] One of surprising properties that may be obtained in the cemented carbide armor layer as defined above, is that this layer, on the one hand, exhibits uniform mechanical properties as in known, and widely used in the field of armor, ceramic tiles, and on the other hand, may be essentially less brittle then these tiles (due to the inherent ductile properties of the binder metal), due to which the armor layer may have a high multi-hit capability compatible to that of an armor layer made of metal carbide pellets or armor elements within a matrix, and the ability to be processed, in particular cut, without causing its fracture, e.g. using CNC tools, to have a desired design.

[0026] Tests carried out on an armor panel having an armor layer of cemented carbide as described above, in comparison with a reference armor panel having a steel armor layer of a greater thickness than that of the cemented carbide layer and otherwise being of a design similar to that of the cemented carbide panel, exhibits penetration resistance properties similar to that of the reference panel, though at an essentially lower weight. The armor panel may comprise two or more layers which may be made of the same or different cemented carbides.

[0027] Said armor panel may comprise in addition to the at least one layer of cemented carbide, a complementary armor layer positioned in front or behind said cemented carbide layer, and/or an optional a backing layer. The additional layers may be made of any appropriate ballistic materials, such as steel, metal, ceramic or any other ballistic material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] In order to understand the invention and to see how it may be carried out in practice, embodiments will now be described, by way of non-limiting examples only, with reference to the accompanying drawings, in which:

[0029] FIG. **1** is a schematic cross-sectional view of a conventional, reference armor panel;

[0030] FIG. **2**A is a schematic cross-sectional view of an armor panel according to one embodiment of the present invention;

[0031] FIGS. **2**B and **2**C are respective schematic morphological representations of a cemented carbide according to the present invention and a hard metal according to the prior art;

[0032] FIG. **3** is a schematic cross-sectional view of an armor panel according to another embodiment of the present invention;

[0033] FIG. **4** is a schematic cross-sectional view of an armor panel according to yet another embodiment of the present invention;

[0034] FIG. **5** is a schematic cross-sectional view of an armor panel according to still a further embodiment of the present invention; and

DETAILED DESCRIPTION OF EMBODIMENTS

[0035] In embodiments described below, examples of different designs of an armor panel according to the present invention are presented, including a cemented carbide layer either alone or with additional layers. Examples of materials and processes that may be used for the manufacture of the cemented carbide layer are generally presented in the Summary of Invention, whilst for the purpose of the present detailed description, one specific non-limiting example of the cemented carbide will be referred to, which is a cemented carbide produced from tungsten carbide as a metal-carbide aggregate with cobalt as a binder metal, by a process including heating up both the binder metal and the carbide to high temperatures of about 1600° C. Since the melting point of the carbide, in this case tungsten-carbide (≅1800° C.), is higher than that of the cobalt binder (≅1550° C.), the cobalt binder is melted to assume a liquid phase while the tungsten-carbide aggregate remains in solid state. This manufacturing process provides even dispersion of the aggregate within the binder and causes the resulting cemented carbide to have extremely low porosity, e.g. about 2%.

[0036] FIG. **2**B shows a morphological representation of a cemented carbide **40** of the kind used in armor panels according to the present invention, in particular such as in the specific example described above. As seen in FIG. **2**B, the carbide metal aggregate **42** is formed in clusters (shown in gray) and is bound by a binder **44** (shown in white). The clusters **42** are immersed in the binder **44**, i.e. the connection of the clusters **42** to the binder **44** is achieved by the clusters **42** being a kind of dissolved in, and homogenously spread throughout, the metal binder **44**.

[0037] FIG. **2**C shows a cemented carbide **50** of a different kind where no metal binder matrix is used. Thus, the cemented carbide shown in FIG. **2**C comprises WC clusters **52** (gray), TiC clusters **54** (dark gray), and TaC clusters **56** (light gray). In the present example, there is no binder between the clusters, and they are attached directly to one another in solid phase.

[0038] In the example shown in FIG. **2**B, the presence of the binder provides the material with fracture toughness of up to 20 Mpa*($m^{1/2}$), as opposed to about 12 Mpa*($m^{1/2}$) of the material shown in FIG. **2**C. Increased fracture toughness may allow for a higher multi-hit capability of the armor panel.

[0039] For the purpose of illustrating the performance of armor panels described below, they will be compared with that of a reference armor panel AP (shown FIG. **1**), made of steel and having a thickness T, and a weight W, as summarized in the table below:

Sample	Properties	
No.	Areal Weight [Kg/m^2]	Thickness [mm]
1	172.5	22

[0040] With reference to FIG. **2**A, a first example of an armor panel according to the present invention, generally designated as 1, is shown, made of a monolith layer **10** of the cemented carbide, constituted by a metal binder matrix **12** and a carbide aggregate **14**.

[0041] To compare the ballistic performance of the armor panel 1 with that of the above reference panel AP, the armor panel 1 has been produced with a thickness t of 10 mm and an areal weight w approx. 69 Kg/m^2. Namely, the armor panel 1 is essentially lighter and thinner than the reference armor panel AP, the respective weight and thickness ratios m and d between the armor panels 2 and 1 being

$$m = \frac{w}{W} = \frac{69}{172} = 0.401,$$

and

$$d = \frac{t}{T} = \frac{10}{22} = 0.454.$$

[0042] Surprisingly, despite the above essential thickness and weight ratios d and m, respectively, the armor panel 1 has appeared to provide the same level of protection (level 3 threats according to STANAG 4569), as that of the armor panel 1 and withstand AP rounds and FSP. It should also be appreciated that the armor panel 1 may provide protection against hollow charges as well.

[0043] Turning now to FIG. **3**, another example of an armor panel is shown, generally designated as 1'. The armor panel 1' comprises a first layer **10** of the cemented carbide and a second layer **20** of steel, and such combination appears to improve anti-penetration ability of the entire armor panel.

[0044] It should be noted that the terms 'first' and 'second' are used with reference to an expected impact direction of incoming projectiles, i.e. among the two layer the 'first' layer meets an incoming projectile before the 'second' layer. Hereinafter, arrow **100** denotes the expected impact direction.

[0045] The panel 1' may for example, be produced with a thickness t' of the first, cemented carbide layer **10** being 4 mm and a thickness T' of the second, steel layer **20** being 5 mm. Such an armor panel 1' has appeared to withstand the same threats as those withstood by the reference armor panel 1, whilst being essentially thinner and lighter.

[0046] With reference to FIG. **4**, a further example of an armor panel is shown generally designated as 1". The armor panel 1" comprises a first layer **10** of the cemented carbide and a backing layer **30** made of a plurality of HDPE sheets. The panel 1" may, for example, be produced with a thickness t" of the first, cemented carbide layer **10** being 4 mm, and a thickness T' of the second, HDPE layer **30** being 23 mm. Such an armor panel 1" has also been shown to withstand the same threats as those withstood by the reference armor panel 1, though being essentially lighter.

[0047] Turning now to FIG. **5**, a still further example of an armor panel is shown, generally designated as 1'''. The armor panel 1" comprises a first layer **10** of cemented carbide, a second layer **20** of steel, and a third, backing layer **30** made of a plurality of Kevlar® sheets **32**, the cemented carbide having a thickness t''', the steel layer having a thickness T''' and the backing layer having a thickness h. Several tests have been performed on panels having this design, though different thicknesses and different weights, and their results are presented below:

Sample	Properties	
No.	Areal Weight [Kg/m^2]	Thickness [mm]
1	86.3	18.5

Exp. No.	Bullet Type	Velocity [m/s]	Penetration
1	7.62*51 AP (WC core)	952	No
2	7.62*51 AP (WC core)	933	No
3	7.62*51 AP (WC core)	949	No
4	7.62*51 AP (WC core)	950	No
5	7.62*51 AP (WC core)	948	No
6	7.62*51 AP (WC core)	942	No
7	7.62*51 AP (WC core)	950	No
8	7.62*51 AP (WC core)	945	No

Sample	Properties	
No.	Areal Weight [Kg/m^2]	Thickness [mm]
2	98.74	22.8

Exp. No.	Bullet Type	Velocity [m/s]	Penetration
1	20 mm FSP	788	No
2	20 mm FSP	774	No
3	20 mm FSP	815	No

Sample	Properties	
No.	Areal Weight [Kg/m^2]	Thickness [mm]
3	90.2	19.1

Exp. No.	Bullet Type	Velocity [m/s]	Penetration
1	20 mm FSP	789	No
2	20 mm FSP	795	No

Sample	Properties	
No.	Areal Weight [Kg/m^2]	Thickness [mm]
4	94.8	18.2

Exp. No.	Bullet Type	Velocity [m/s]	Penetration
1	20 mm FSP	845	No
2	20 mm FSP	794	No

Sample	Properties	
No.	Areal Weight [Kg/m^2]	Thickness [mm]
5	90.2	19.1

Exp. No.	Bullet Type	Velocity [m/s]	Penetration
1	7.62 × 54 AP B32	862	No
2	7.62 × 54 AP B32	850	No
3	7.62 × 54 AP B32	847	No
4	7.62 × 54 AP B32	734	No
5	7.62 × 54 AP B32	738	No
6	7.62 × 54 AP B32	735	No
7	7.62 × 54 AP B32	864	No
8	7.62 × 54 AP B32	860	No

[0048] It should be obvious from the above test tables that the armor panel according to the present invention is capable to provide at least the same ballistic protection as the reference armor panel AP, however, with reduced overall weight and thickness.

[0049] Those skilled in the art to which this invention pertains will readily appreciate that numerous changes, variations, and modifications can be made without departing from the scope of the invention.

1. An armor panel for ballistic protection, comprising:

a monolithic layer made only of cemented carbide in the form of metal-carbide aggregate embedded within a metal binder matrix, wherein said cemented carbide has a fracture toughness ranging from 7-20 Mpa*(m$^{1/2}$); and

at least one ballistic backing layer fitted to said monolithic layer, said backing layer having a hardness lower than that of said monolithic layer, wherein the monolithic layer is capable of being used on its own as a stand-alone ballistic layer.

2. An armor panel according to claim **1**, wherein the metal-carbide aggregate is in the form of grains having a grain size not exceeding 20 μm.

3. An armor panel according to claim **1**, wherein the composition is such that said metal-carbide aggregate constitutes at least one of the following:

(i) at least 70% by volume; and

(ii) at least 80% by weight.

4. An armor panel according to claim **1**, wherein the composition is such that said metal binder matrix constitutes at least one of the following:

(i) No more than 30% by volume; and

(i) No more than 80% by weight.

5. An armor panel according to claim **1**, wherein said carbide aggregate has a melting point ranging from 1800-3990° C.

6. An armor panel according to claim **1**, wherein the metal of said metal binder has a melting point ranging from 1450-1536° C.

7. An armor panel according to claim **1**, wherein said cemented carbide has a hardness ranging from 87-93 HRa.

8. An armor panel according to claim **1**, wherein said cemented carbide has a density ranging from 5.5-15.5 gr/cc.

9. An armor panel according to claim **1**, wherein said cemented carbide has a porosity ranging from 0-2%.

10. An armor panel according to claim **1**, wherein said metal-carbide aggregate has a higher melting point than that of said metal binder.

11. An armor panel according to claim **1**, wherein said metal-carbide aggregate has a lower fracture toughness than that of said metal binder.

12. A method of manufacture of an armor panel, comprising:

manufacturing a monolithic layer made only of cemented carbide in the form of a metal-carbide aggregate embedded within a metal matrix, said cemented carbide having a fracture toughness ranging from 7-20 Mpa*($m^{1/2}$), and incorporating said monolithic layer within said armor panel; and

fitting at least one ballistic backing layer fitted to said monolithic layer, said backing layer having a hardness lower than that of said monolithic layer,

wherein the monolithic layer is capable of being used on its own as a stand-alone ballistic layer.

13. An armor panel according to claim **1**, wherein, compared to a reference plate made of the same material as the at least one ballistic backing layer and having a thickness T and weight W, T and W being the minimal required to allow the reference plate to withstand a level 3 STANAG 4569 ballistic threat, the monolithic layer of cemented carbide provides the same level of ballistic protection with a thickness t>T and weight w<W.

14. An armor panel according to claim **13**, wherein the ratio w/W is approximately 0.4.

15. An armor panel according to claim **13**, wherein the ratio t/T is approximately 0.5.

16. An armor panel for ballistic protection, comprising:

at least a layer made of a plurality of armor pellets made only of cemented carbide in the form of metal-carbide aggregate embedded within a metal binder matrix, wherein said cemented carbide has a fracture toughness ranging from 7-20 Mpa*($m^{1/2}$).

17. An armor panel according to claim **1**, wherein said backing layer is a metallic layer having no metallic interface with said monolithic layer.

18. An armor panel according to claim **1**, wherein said backing layer is configured for serving as a spall-liner.

19. An armor panel according to claim **1**, wherein the monolithic layer is a separately manufactured layer.

20. An armor panel according to claim **1**, wherein, compared to a reference plate made of the same material as the at least one ballistic backing layer and having a thickness T and weight W, T and W being the minimal required to allow the reference plate to withstand a level 3 STANAG 4569 ballistic threat, the armor panel provides the same level of ballistic protection with a thickness t>T and weight w<W.

21. An armor panel according to claim **1**, wherein the metal-carbide aggregate is in the form of grains homogenously spread throughout the binder.

22. An armor panel according to claim **12**, wherein the metal-carbide aggregate is in the form of grains homogenously spread throughout the binder.

* * * * *