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(54) Bullet and splinter protection material/burglary protection material

(57) The invention concerns a bullet and splinter protection material / burglary protection material manufactured by the SHS technique and based on titanium carbide TiC, titanium boride TiB, titanium diboride TiB_2 or titanium carbide aluminium oxide TiC-Al_2O_3 and a metallic binder. The invention also concerns a protective material manufactured by the SHS technique which forms a gradient and lamellar structure and is attached to other protective materials.

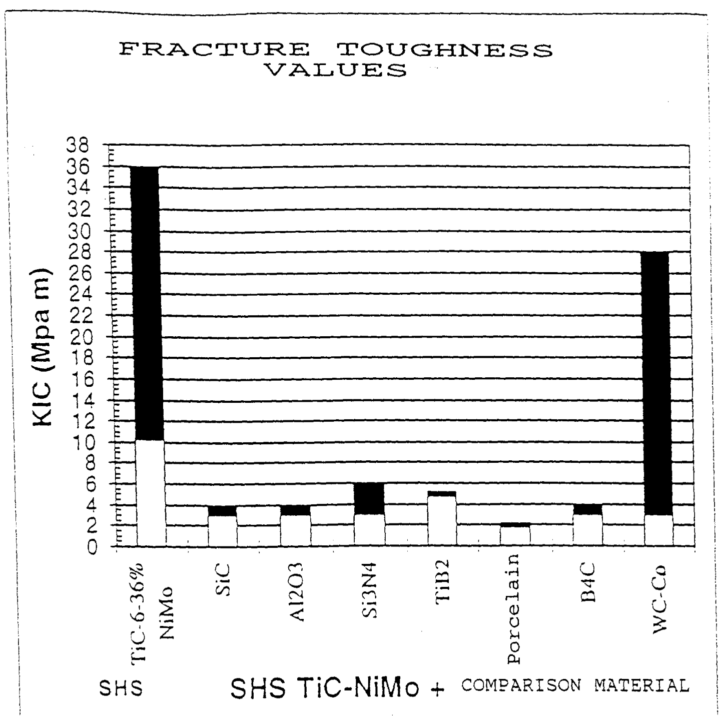

Fig. 2

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Description

[0001] The present invention relates to a bullet and splinter protection material/burglary protection material as defined in the preamble of claim 1.

[0002] The materials used in protective structures must be capable of stopping various types of splinters and bullets. In addition, the protective structure itself must not form dangerous splinters or at least they have to be stopped by other structures. The material properties required of burglary protection materials are largely the same as those of bullet and splinter protection materials. The materials must necessarily have a high degree of hardness so that they cannot be machined e.g. using hard-metal drills or a grinder disk. The material must have a high melting point to make it difficult to cut e.g. with a torch. Further, the material must be sufficiently tough so that it cannot be broken down e.g. by hammering or chiselling. In the design of a protective structure, it is necessary to optimise the material hardness and toughness characteristics as well as the integral structure for each use and against each hazard, such as bullet type, calibre, etc.

[0003] In this application, the term `protective material' refers to bullet and splinter protection material/burglary protection material.

[0004] In prior art, the use of steel based materials and materials based on so-called soft materials, such as aramid fabrics or hard sheets laminated from such fabrics, as protective materials is known.

[0005] These protective structures and materials currently used are almost invariably designed for use against conventional lead bullets or at most steel-cored armour piercing bullets (AP bullets). The above-mentioned protective structures and materials are not capable of stopping modern hard-metal cored AP-bullets, which have a penetrating power about twice as high as that of conventional armour piercing bullets and three times as high as that of conventional lead bullets, except when used in very thick layers. A problem with thick material layers is their large weight.

[0006] The object of the present invention is to eliminate the drawbacks mentioned above.

[0007] A specific object of the present invention is to disclose a hard and tough protective material. A further object of the invention is to disclose a light protective material which is easy to produce in pieces of different shapes and sizes.

[0008] The bullet and splinter protection material/burglary protection material of the invention is characterised by what is presented in claim 1.

[0009] The invention is based on research work carried out to study hard-metal type composite materials manufactured by the SHS (Self-Propagating High-Temperature Synthesis) technique. During the research work it was discovered that, in respect of their properties, these materials are remarkably well suited for use as protective materials.

[0010] The protective material of the invention, manufactured by the SHS technique, is based on a ceramic material and a metallic binding agent. The protective material manufactured by the SHS technique is a hard-metal type composite material which contains hard ceramic particles and a metallic binder that binds them together. The ceramic material may be titanium carbide TiC, titanium boride TiB, titanium diboride TiB_2 and/or titanium carbide aluminium oxide $TiC\text{-}Al_2O_3$. Normally the ceramic material is titanium carbide TiC or titanium carbide aluminium oxide $TiC\text{-}Al_2O_3$.

[0011] The metallic binder may be any tough metal. Usually the metallic binder is a metal of pendant group 4, 5, 6, 8, 9, 10, 11 and/or 12, a metal of main group 1, 2 and/or 13 and/or a mixture and/or compound of these, such as titanium Ti, zirconium Zr, niobium Nb, chromium Cr, molybdenum Mo, iron Fe, cobalt Co, nickel Ni, copper Cu, zinc Zn, lithium Li, beryllium Be, magnesium Mg and/or aluminium Al and/or a mixture and/or compound of these. The material used as a metallic binder is preferably chromium, cobalt, molybdenum, iron, nickel, aluminium and/or a mixture and/or compound of these.

[0012] In the invention, the term `SHS hard metal' refers to a protective material manufactured by the SHS technique and based on titanium carbide TiC, titanium boride TiB, titanium diboride TiB_2 and/or titanium carbide aluminium oxide $TiC\text{-}Al_2O_3$ and a metallic binder.

[0013] The composition of the protective material manufactured by the SHS technique is selected according to both practical properties and price. The practical properties depend on the protection capability required, i.e. hardness and toughness, weight, finish-ability etc., and the price depends on the costs of the protective material and structure. A hard, tough and light protective material is e.g. an SHS hard metal based on TiC-Ni. Light materials are also SHS hard metals in which the ceramic material is titanium carbide aluminium oxide, e. g. hard metals based on $TiC\text{-}Al_2O_3\text{-}Al$ or $TiC\text{-}Al_2O_3\text{-}Fe$. These are also advantageous in respect of price because they can be manufactured using cheap raw materials, such as coat pigment TiO_2, carbon dust, aluminium and/or iron dust.

[0014] In an embodiment, the protective material of the invention is a TiC-Ni-based SHS hard metal, e.g. an SHS hard metal based on TiC-NiMo and/or TiC-CoNi.

[0015] In another embodiment, the protective material of the invention is a $TiC\text{-}Al_2O_3$-based SHS hard metal, e.g. a SHS hard metal based on $TiC\text{-}Al_2O_3\text{-}Al$ or $TiC\text{-}Al_2O_3\text{-}Fe$.

[0016] The protective material has a binder content in the range of 1 - 60 w-%, depending on the intended use. Protective materials having a low binder content are harder and their fracture toughness is lower than the corresponding properties of materials having a high binder content. The binder percentage is normally 15 - 50 w-%, preferably 20 - 40 w-%.

[0017] The SHS method is based on an extremely exothermic reaction in which powdery raw materials react with each other after a reaction has been ignited from a suitable point using e.g. an electric resistor or a welding flame. After ignition, no external energy is required for the propagation of the reaction. The reaction temporarily produces a very high temperature, at which most of the metals and some of the ceramic materials are in a molten state. From the mixture obtained after the reaction, a compact body is obtained by pressing the mixture in a mould while it is still hot and in a plastic state. In the SHS method, no separate make-up and sintering operations are needed. By this method, it is possible to produce objects of desired shape and size, e.g. curved or complex shapes. In addition, the method allows the use of cheap and readily available commercial powders as raw materials. The SHS method is described e.g. in the publication Lintula P. and Ruuskanen P., Wear and Corrosion Resistant Metal Matrix Composites Produced by Self-Propagating High-Temperature Synthesis (SHS), Proceedings of the 5^{th} European conference on Advanced Materials and Processes and Applications, vol. 1, s. 347-350, 1997.

[0018] Protective materials manufactured by the SHS technique can be used in so-called gradient structures and lamellar structures. In gradient structures and lamellar structures, the composition and hardness of the protective material vary as a function of the thickness of the structure.

[0019] In a gradient structure, the hardness varies as a function of the thickness of the protective material without a sharp boundary surface. A change in the hardness of the material is achieved by varying the metallic binder content.

[0020] In an embodiment, the protective material is so selected that the material hardness at the surface is very high and the material becomes tougher towards the backing, in other words, the binder content of the protective material is low at the surface and increases as the depth increases. Gradient structures are preferably manufactured from TiC-Ni-based SHS hard metal combinations.

[0021] A lamellar structure consists of different protective material layers. Different layers are formed from protective materials in which the composition of the metallic binder and/or ceramic material varies.

[0022] In an embodiment, the material has a very hard surface layer, e.g. of a TiC-Ni based SHS hard metal, while the backing material consists of a lighter TiC-Al_2O_3 based SHS hard metal, e.g. an SHS hard metal in which the metallic binder is iron or aluminium.

[0023] With applications in which a very hard surface layer is achieved using gradient and lamellar structures, it is possible to crush, deform or deflect even a hard-metal bullet core, thus destroying its penetrating power. The tougher backing structure will stop any splinters detached from the surface layer, as well as remnants of the hard-metal core.

[0024] The protective material of the invention manufactured by the SHS technique can be attached to various protective materials and/or protective structures, such as other SHS hard metals, ceramic materials, metal sheets, splinter panels, fibre composite structures, such as aramid fabrics and polymer fibre fabrics, e.g. polyethylene and/or other corresponding materials and/or structures. By combining SHS hard metals with other SHS hard metals and other protective materials, it is possible to produce integrated structures whose materials are well in keeping with the requirements regarding materials used in protective structures.

[0025] The advantages of the protective material of the invention manufactured by the SHS technique include its hardness and toughness. In addition, these properties as well as the integral structure formed from the material can be easily varied and optimised for different uses and against different hazards. Furthermore, the invention allows a considerable reduction in the weight of protective structures because a hard and tough protective material need not be used in layers as thick as in the case of prior-art materials. Especially when used to protect against hard-metal core bullets, the materials of the invention allow a considerable reduction in weight. A further advantage of the invention is that it allows easy manufacture of objects of desired shape and size for each use. An additional advantage of the invention is economical efficiency because no separate make-up and sintering operations are needed in the manufacture of the protective material by the SHS technique. Moreover, the raw materials are cheap commercial powders that are readily available.

[0026] In the following, the invention will be described in greater detail by the aid of a few examples with reference to the attached drawing, wherein

Fig. 1 presents hardness and toughness values of TiC based hard metals manufactured by the SHS technique, and

Fig. 2 presents toughness values of a TiC based hard metal manufactured by the SHS technique and commercial ceramic materials.

Example 1

[0027] This experiment was carried out to study the effect of the composition and proportion of the metallic binder on the hardness and toughness of TiC based hard metals manufactured by the SHS technique. The hardness was measured as Vickers hardness using a 1 kg weight (HVI) and the toughness was measured by the IF (Indentation Fracture) method. The metallic binders used in the test were a mixture of nickel and molybdenum with different binder percentages and a mixture of cobalt, chromium and nickel. The results are presented in Fig. 1.

[0028] As can be seen from Fig. 1, a TiC-NiMo SHS hard metal with a lower binder content is harder and has a lower fracture toughness than a corresponding TiC-NiMo based SHS hard metal with a lower binder content.

[0029] Fig. 2 presents toughness values of a TiC-Ni-Mo based SHS hard metal manufactured by the SHS technique and commercial ceramic materials. The dark part of the column represents the variation between different composition percentages or different manufacturers. The toughness values for the ceramic materials have been collected from commercial brochures.

[0030] Fig. 2 shows that the TiC-NiMo based SHS hard metal has a higher fracture toughness than the commercial ceramic materials.

Example 2

[0031] In a firing experiment, TiC-Ni and TiC-A1203-Fe based SHS hard metals (=SHS material) and composite structures formed from them were tested to study their properties as bullet and splinter protection materials as compared with the properties of armour steel. The bullets used in the experiment were

a) 7.62x51 AP bullet Carl-Gustaf with hard-metal core, which has the highest penetrating power among 7.62 assault rifle cartridges,
b) corresponding 7.62x39 calibre bullet (AP 411) with hard-metal core, and
c) P-80 7.62x51 armour piercing bullet with steel core.

[0032] The bullet in case a) was stopped with a structure having a weight per square metre of 84 kg/m^2 (SHS material 38.6 + Fe 46.8 kg/m^2). Using 470 HB armour steel, 195 kg/m^2 would have been needed.

[0033] The bullet in case b) was stopped with a structure having a weight per square metre of 45 kg/m^2 (SHS material 37.2 + Al 8.1 kg/m^2) and a structure consisting of a pack of aramid fabric (2x21 layers, 9.2 kg/m^2) with 54 kg/m^2 SHS material on top of it. Using 470 HB armour steel, 119 kg/m^2 would have been needed.

[0034] The bullet in case c) was stopped with a structure in which a 6.0 mm thick SHS disc was placed on top of armour steel (500HB), the weight per square metre being 31 + 47 = 78 kg/m^2, and a structure consisting of a pack of aramid fabric (2x21 layers, 9.2 kg/m^2) with 31 kg/m^2 SHS material on top of it. With the first structure, a bulge of only 0.5 mm appeared in the backing, which means that the bullet could have been stopped using a considerably lighter structure.

[0035] The light $TiC\text{-}Al_2O_3\text{-}Fe$ based SHS hard metal was also well applicable as bullet and splinter protection material for steel-cored armour piercing bullets and normal lead bullets.

[0036] The invention is not restricted to the examples of its embodiments described above, but many variations are possible within the scope of the inventive idea defined in the claims

Claims

1. Bullet and splinter protection material/burglary protection material manufactured by the SHS technique, **characterised** in that the material consists of a ceramic material and a metallic binder.

2. Protective material as defined in claim 1, **characterised** in that the ceramic material is titanium carbide TiC, titanium boride TiB, titanium diboride TiB_2 and/or titanium carbide aluminium oxide $TiC\text{-}Al_2O_3$.

3. Protective material as defined in claim 1 or 2, **characterised** in that the metallic binder is a metal of pendant group 4, 5, 6, 8, 9, 10, 11 and/or 12, a metal of main group 1, 2 and/or 13 and/or a mixture and/or compound of these, normally Ti, Zr, Nb, Cr, Mo, Fe, Co, Ni, Cu, Zn, Li, Be, Al and/or Mg and/or a mixture and/or compound of these.

4. Protective material as defined in any one of claims 1 - 3, **characterised** in that the metallic binder is Cr, Co, Mo, Fe, Ni, Al and/or a mixture and/or compound of these.

5. Protective material as defined in any one of claims 1 - 4, **characterised** in that the ceramic material is titanium carbide and the metallic binder is nickel or a nickel based mixture.

6. Protective material as defined in any one of claims 1 - 4, **characterised** in that the ceramic material is titanium carbide aluminium oxide and the metallic binder is aluminium and/or iron.

7. Protective material as defined in any one of claims 1 - 6, **characterised** in that the proportion of metallic binder is 1 - 60 w-%, normally 15 - 50 w-%, preferably 20 - 40 w-%.

8. Protective material as defined in any one of claims 1 - 7, **characterised** in that the composition and hardness of the protective material change as a function of protective material thickness.

9. Protective material as defined in claim 8, **characterised** in that the proportion of metallic binder varies as a function of protective material thickness.

10. Protective material as defined in claim 8 or 9, **characterised** in that the composition of the metallic binder and/or ceramic material varies as a function of protective material thickness.

11. Protective material as defined in any one of claims 1 - 10, **characterised** in that it is attached to other SHS hard metals and/or other protective materials and/or structures, such as ceramic materials, metal sheets, splinter panels and/or fibre composite structures, such as aramid fabrics and/or polyethylene fibre fabrics.

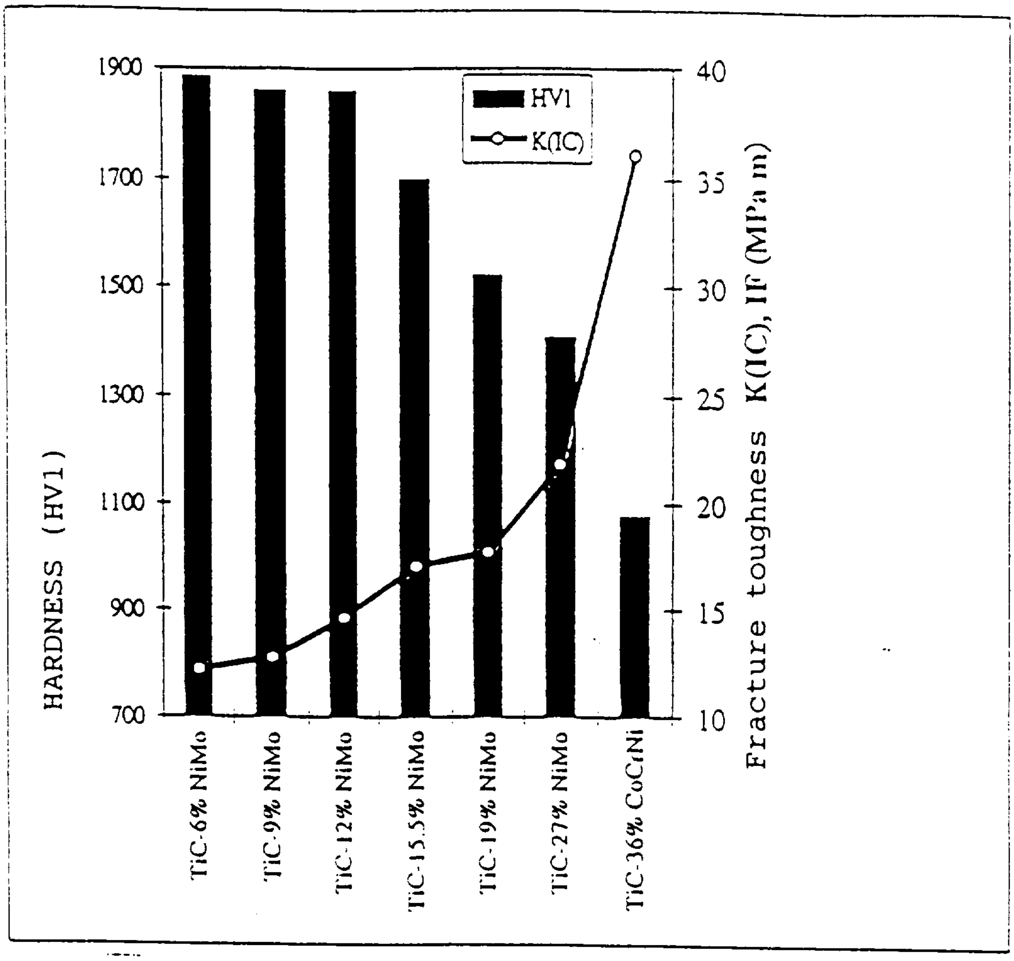
HARDNESS (HV1)
1900
1700
1500
1300
1100
900
700
HV1
K(IC)
40
35
30
25
20
15
10
Fracture toughness K(IC), IF (MPa m)
TiC-6% NiMo
TiC-9% NiMo
TiC-12% NiMo
TiC-15.5% NiMo
TiC-19% NiMo
TiC-27% NiMo
TiC-36% CoCrNi

Fig. 1

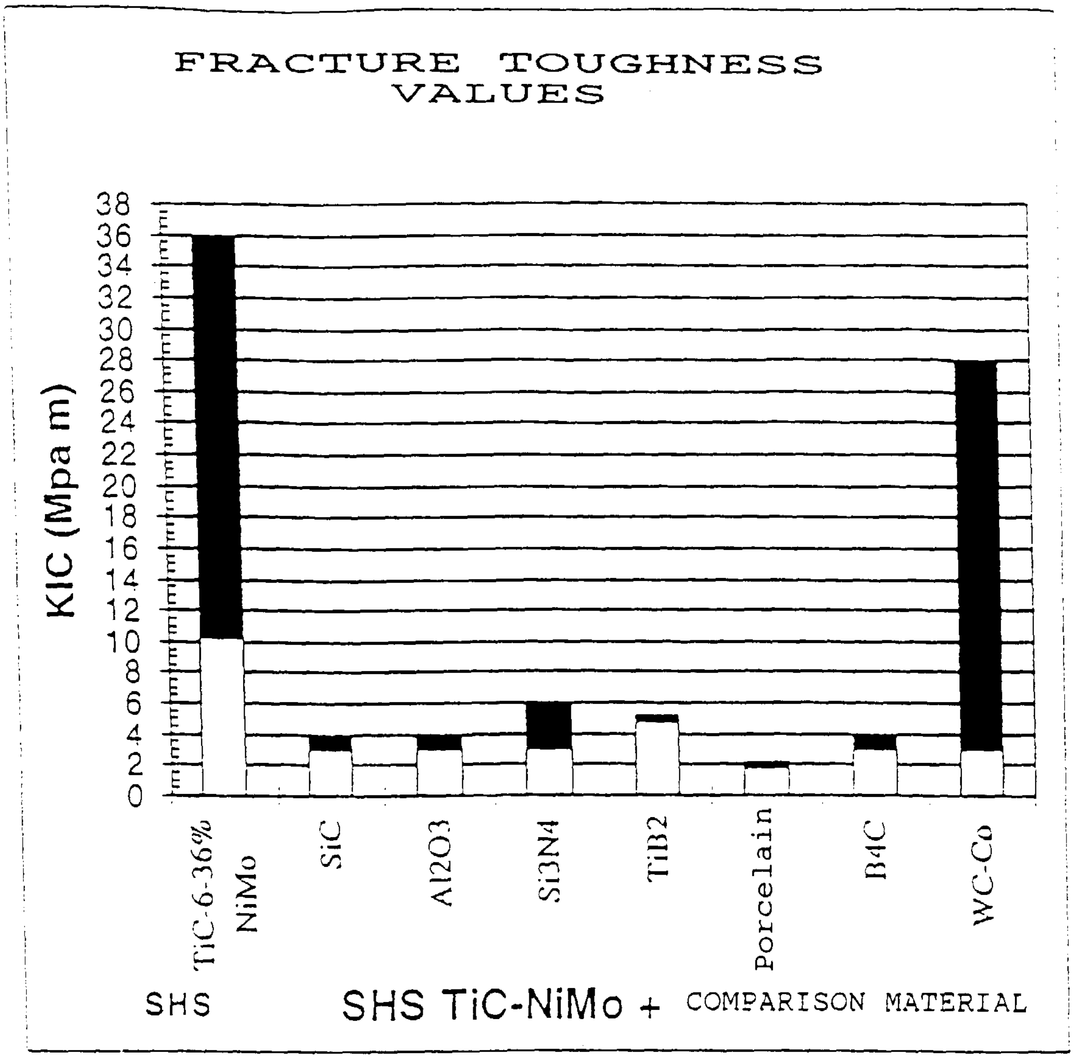
FRACTURE TOUGHNESS VALUES
KIC (Mpa m)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
TiC-6-36% NiMo
SiC
Al2O3
Si3N4
TiB2
Porcelain
B4C
WC-Co
SHS
SHS TiC-NiMo + COMPARISON MATERIAL

Fig. 2