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(54) Title: AN ARMOUR ELEMENT

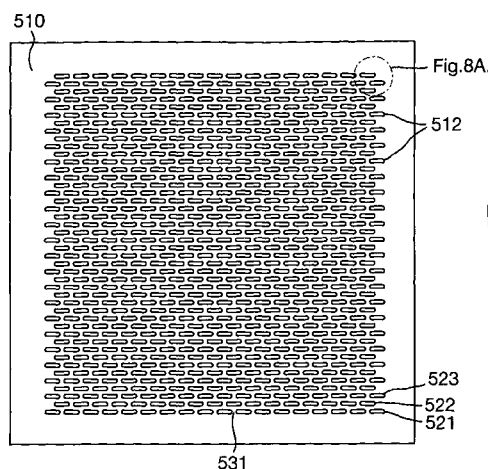


Fig. 1.

(57) Abstract: An armour element comprising a High-Hardness Steel having a plurality of slots passing through the element, such that the areal density of the slotted element is 55-65% that of the unperforated, monolithic plate. The slots are stamped before the final heat treatment to produce a High-Hardness Steel (greater than 500Hv).

## AN ARMOUR ELEMENT

This invention primarily relates to armour for vehicles, but the inventive concept can be applied to other situations, for example, ships or parts thereof, buildings, and even personal armour.

Perforated armours are known and can work well when fabricated from very hard, brittle metals such as High-Hardness Steel (HHS). In this specification High Hardness Steel means a steel having a hardness greater than 500Hv. A new steel known as Super Bainite Steel (SBS) has been described in

PCT/GB2009/050947 and its potential application to armour has been described in UK Patent Application 0914665.5 (both incorporated herein by reference).

Super Bainite Steel in accordance with PCT/GB2009/050947, is an example of HHS.

Super Bainite Steel is a carbide free bainite steel which comprises between 90% and 50% bainite, the rest being austenite, and in which excess carbon remains within the bainitic ferrite at a concentration beyond that consistent with equilibrium; there is also partial partitioning of carbon into the residual austenite. Such bainite steel has very fine bainite platelets (thickness 100nm or less). In this specification the expression "Super Bainite Steel" is used to refer to such fine bainite steel.

Brittle armour materials can suffer significant cracking under ballistic impact, reducing the multi-hit capability of the material. Perforations in these materials can limit crack propagation since each perforation acts as a 'firebreak' in a similar way to 'segmented' armours. Perforating a plate has the additional benefit of decreasing the overall mass of the plate.

Commonly, perforated armours (such as perforated steel known as MARS300 from Industeel) use circular perforations. The ability to make circular perforations of a small diameter is limited by the thickness of the plate and the difficulty of stamping small holes. Drilling, water jet cutting, laser cutting the holes in large plates is time consuming and thus not a particularly economic manufacturing process.

As a result of these fabrication problems, the diameter of the perforations may be larger than the core size of small arms projectiles. This means that a proportion of projectiles can go through the holes, and thus through the armour, without touching the armour material at any point.

5 Accordingly the present invention provides an armour element comprising high hardness steel provided with a plurality of slots passing through the element, said slotted element comprising no less than 55% the areal density of the unperforated, monolithic element.

10 Preferably the areal density of the slotted element is in the range 55% to 65% of the areal density of the unperforated, monolithic element. An areal density of less than 55% results in the webs between the slots being insufficiently strong to resist the impact of heavy caliber weapons, whereas an areal density of greater than 65% of the unperforated, monolithic element does not provide sufficient weight reduction to offset the increased cost of manufacturing of  
15 perforated armour.

Preferably the width of said slots is designed to be less than the core size of a projectile from the minimum caliber weapon capable of penetrating the hull of a vehicle; generally this is considered to be a 5.56mm caliber weapon with a projectile having a core diameter of 5mm. To prevent such a projectile passing  
20 through the slots in such an armour element, even by squeezing, the slots' width should be 4.9mm or less. Ideally the slot width is substantially 4.5mm, since slots having lesser width become increasingly difficult to manufacture by pressing without high tooling breakages rates, and as the slot width increases towards 4.9mm the statistical risk of a projectile from a 5.56mm weapon  
25 passing through the slot increases.

Ideally the ends of each slot are rounded as this helps reduce crack propagation.

Slots may be arranged in parallel rows, which are preferably offset such that the webs between slots in one row are aligned with the slots in an adjacent  
30 row. In order to provide desirable strength the pitch of the rows (the distance between the mid-point of one row and the mid-point of the next row) is greater than twice the width of the slots.

The length of the slot is determined by the wished for areal density. For an areal density of 60% and a slot width of 4.5mm, the slot length is 14mm, with a semi-circular end, in plan portion, of 2.25mm radius at each end of each slot if the pitch is set at 9.5mm.

5 It is beneficial to use the perforated armour element in accordance with the invention with some kind of additional rear panel, normally with an air gap between, such that in use the rear panel is provided between the armour element and the item to be protected. It is preferred that this rear panel comprises a spall  
10 liner material such as glass fibre sheets or Kevlar®. However, ultra-high molecular weight polyethylene (UHMWPE) is the preferred spall liner material. The spall liner aims to catch the fragments from the perforated plate and the fractured projectile. The projectile will hit some part of the armour and break off a small segment; this may be one single piece or several. The projectile core is also likely to be damaged. These fragments will have momentum, and as a  
15 result there will be multiple, slower impacts on the spall liner rather than a single, pointed bullet impact on the outer armour element.

The armour itself may be a single sheet covering the area to be protected, or several individual elements each comprising a sheet of armour material fixed in such a way as that between them they cover the area to be protected, or an  
20 armour may comprise a comparatively larger number of individual tiles comprising elements according to the invention placed together to protect the area concerned. Armour comprising a plurality of individual elements or tiles may have an advantage in that a damaged element may be easily replaced, armour made of a single element may be less easy to deal with should it be damaged.

25 The preferred method of manufacturing the armour elements is by stamping, although laser or water jet cutting can be used, but is slow.

An economic process for the manufacture of elements might comprise, forming an alloy comprising by weight percent: carbon 0.6% to 1.1%, manganese 0.3% to 4%, nickel up to 3%, chromium 0.5% to 1.5%, molybdenum up to 0.5%,  
30 vanadium up to 0.2%, silicon 0.5% to 2% , and the balance iron save for incidental impurities, cooling the steel from austenite to pearlite, and forming into sheets of the required thickness for the armour element, stamping the sheets to

form a plurality of slots, reheating the steel to an austenitic state and cooling sufficiently quickly to avoid the formation of pearlite from a temperature above its austenitic transition temperature to a transformation temperature above its martensite start temperature but below the bainite start temperature and holding  
5 within that temperature range until fully transformed to Super Bainite Steel. Preferably the manganese content is about 1%. This process has the advantage that the stamping occurs when the steel is in a soft pearlite form, before it is transformed into its high hardness state.

The invention will now be described, by way of example, with reference to the  
10 accompanying drawings in which:

figure 1 shows an armour element according to the present invention;

figure 1A shows detail of a part the element;

figure 2 shows a schematic section of an armour through an armour element according to the invention and a spall liner; and

15 figure 3 illustrates a manufacturing process used to make a Super Bainite Steel armour element according to this invention. .

In figure 1 an armour element 510 comprises a sheet of hard steel, typically this will be High-Hardness Steel (HHS) or Super Bainite Steel (SBS), having a hardness above 500Hv.

20 The element 510 has a plurality of slots penetrating though the element. The slots are aligned longitudinally with one another in a plurality of parallel rows 521, 522, 523 etc. such that the webs 531 between slots in one row 521, aligns with the middle of the slots in the adjoining row 522 to ensure reasonable support for the slots. In this case, which illustrates armour suitable to resist 5.56mm rounds, the  
25 slots 512 are 4.5mm wide and have parallel sides 514 each 14mm long. The end of the slots 516 are semicircular in plan and have a radius of 2.25mm. The pitch of the rows (i.e. the distance between the mid-point of one row and the mid-point of the next row) is just over twice the width of the slots - 9.5 mm. In this configuration the areal density of the slotted element is 60% that of the  
30 unperforated monolithic element. The areal density can be reduced further by increasing the length of the parallel sides 514, decreasing the separation of the slots in a row, or decreasing the pitch between rows. However, major changes

will reduce the areal density below 55% at which point the ability of the armour to resist impact is compromised. Changing the dimensions in the opposite direction will have the opposite effect and increase areal density, but above 65% areal density the benefits of the reduced armour weight are compromised by the cost of manufacture of perforated armour.

Figure 2 is a schematic cross section of the armour element 510 of figure 1 attached to a vehicle 550. The armour is bolted by bolts 544 to upstanding lugs 542 in the vehicle wall 552, the armour element is, in this case 8mm deep, and as can be seen the slots 512 penetrate through the element. Between the armour element and the vehicle a spall liner 546 is pinned with pins 548. This liner comprises ultra-high molecular weight polyethylene (UHMWPE). The spall liner's purpose is to catch the fragments from the perforated plate and the fractured projectile after a projectile has hit the armour element to prevent them from penetrating the vehicle wall 552. The armour element is separated from the spall liner 546 by an air gap 554.

Figure 3 illustrates the manufacturing steps of the armour element of figure 1 and 2. A steel is allowed to cool from a high temperature (above its austenite transition temperature) as large thick plates, often in stacks. The cooling rate is naturally about 2°C/ minute, which is sufficiently slow to enable a fully pearlite phase to form. The plates are then heated again to above 850°C to austenitise them. The hot material is passed through rolling mills to form strip steel, in this example, 8mm thick and coiled. Obviously the thickness can be greater or less than the range given to suit the armour requirement. The thermal capacity of the coil restricts the cooling rate sufficiently to ensure that pearlite is again formed as the material cools to ambient (room in this case) temperature (RT). This is conveniently achieved by allowing the coiled steel to cool in air naturally over 48 hours, for example. At this stage the coils can be de-coiled and cut into plates or reheated to anneal it before allowing it to cool to ambient temperature. Once back to ambient temperature, room temperature in this example, (RT in Figure 1B), it can be stamped with the slots before undergoing a final austenisation and the bainite transformation step. At this stage it is in individual pieces and cools after this austenitisation much more rapidly thus avoiding passing through the pearlite phase. Once it has reached a temperature of 190°C to 260°C, it is held

at that temperature to allow the bainite transformation step to be completed. The exact bainite transformation period required depends on the manganese content of the steel, the lower the manganese content the shorter the transformation time required. A preferred material containing about 1% manganese can be

5 transformed in 8 hours.

The rolling step may be carried out immediately during the initial cooling stage, coiled and allowed to cool further before decoiling, thus omitting two steps shown in the figure.

**CLAIMS**

1. An armour element comprising high hardness steel provided with a plurality of slots passing through the element, said slotted element comprising no less than 55% the areal density of the unperforated, monolithic element.
2. An armour element according to claim 1 wherein the areal density of the slotted element is in the range 55% to 65% of the areal density of the unperforated, monolithic element.
3. An armour element according to claim 2 wherein the areal density of the slotted element is substantially 60% of the areal density of the unperforated, monolithic element.
4. An armour element according to any one of claims 1 to 3 wherein the width of said slots is less than the core size of a 5.56mm caliber weapon projectile.
5. An armour element according to claim 4 wherein the width of said slots is 4.9mm or less.
6. An armour element according to claim 5 wherein the width of said slots is substantially 4.5mm.
7. An armour element according to any preceding claim wherein the ends of the slots are rounded.
8. An armour element according to any preceding claim wherein the slots are arranged in a plurality of parallel rows.
9. An armour element according to claim 8 wherein the slots in one row are offset against the slots in an adjacent row.
10. An armour element according to claim 8 or 9 wherein the pitch between adjacent rows is greater than twice the width of the slots.
11. An armour element according to any preceding claim wherein a rear panel is mounted between the armour element and the item which the armour element is protecting, said rear panel comprising a spall liner material.
12. An armour element according to claim 11 wherein the spall liner material is ultra-high molecular weight polyethylene (UHMWPE).

13. An armour element according to claim 11 or 12 wherein an air gap is provided between the armour element and the rear plate.
14. A method of manufacturing an armour element in accordance with any preceding claim comprising the steps of:
- 5 a) forming a steel comprising by weight percent: carbon 0.6% to 1.1%, manganese 0.3% to 4%, nickel up to 3%, chromium 0.5% to 1.5%, molybdenum up to 0.5%, vanadium up to 0.2%, silicon 0.5% to 2% , and the balance iron save for incidental impurities;
- b) cooling the steel from austenite to pearlite;
- 10 c) forming into sheets of the required thickness for the armour element;
- d) stamping the sheets to form a plurality of slots;
- e) reheating the steel to an austenitic state and cooling sufficiently quickly to avoid the formation of pearlite from a temperature above its austenitic transition temperature to a transformation temperature above
- 15 its martensite start temperature but below the bainite start temperature and holding within that temperature range until fully transformed to super bainite.
15. An armour element substantially as hereinbefore described with reference to the accompanying drawings.
- 20 16. A method of manufacturing an armour element substantially as hereinbefore described by reference to the accompanying drawings.

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Fig.1.

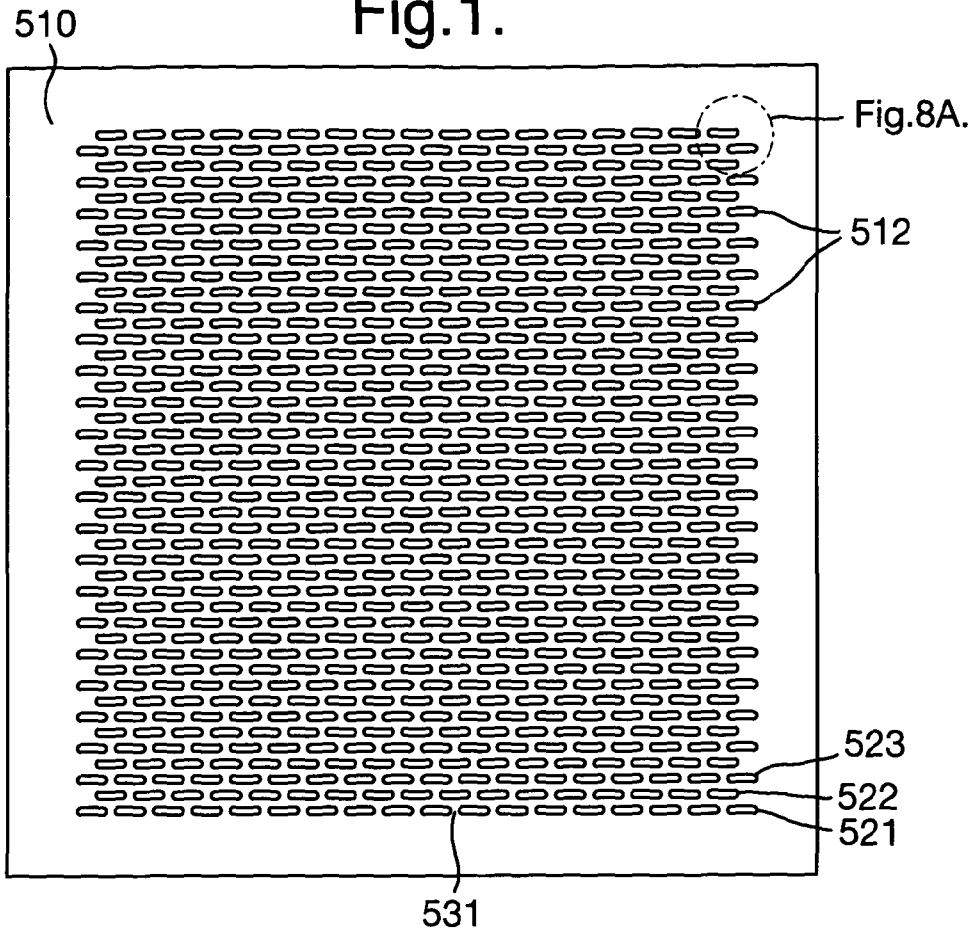


Fig.2.

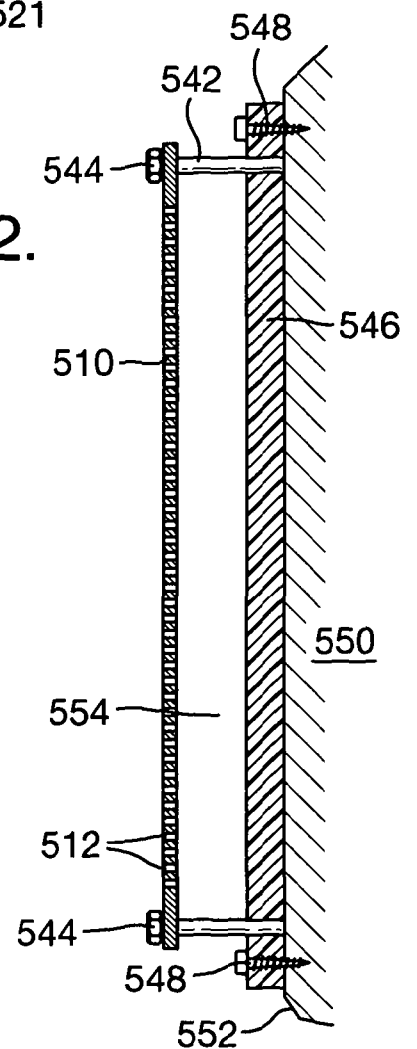


Fig.1A.

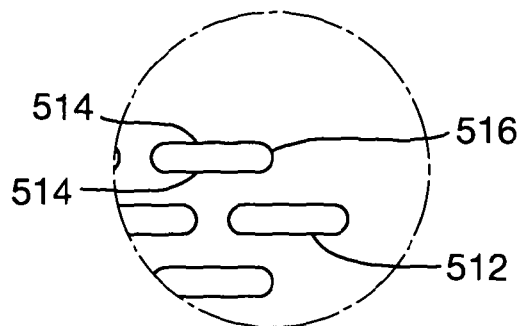
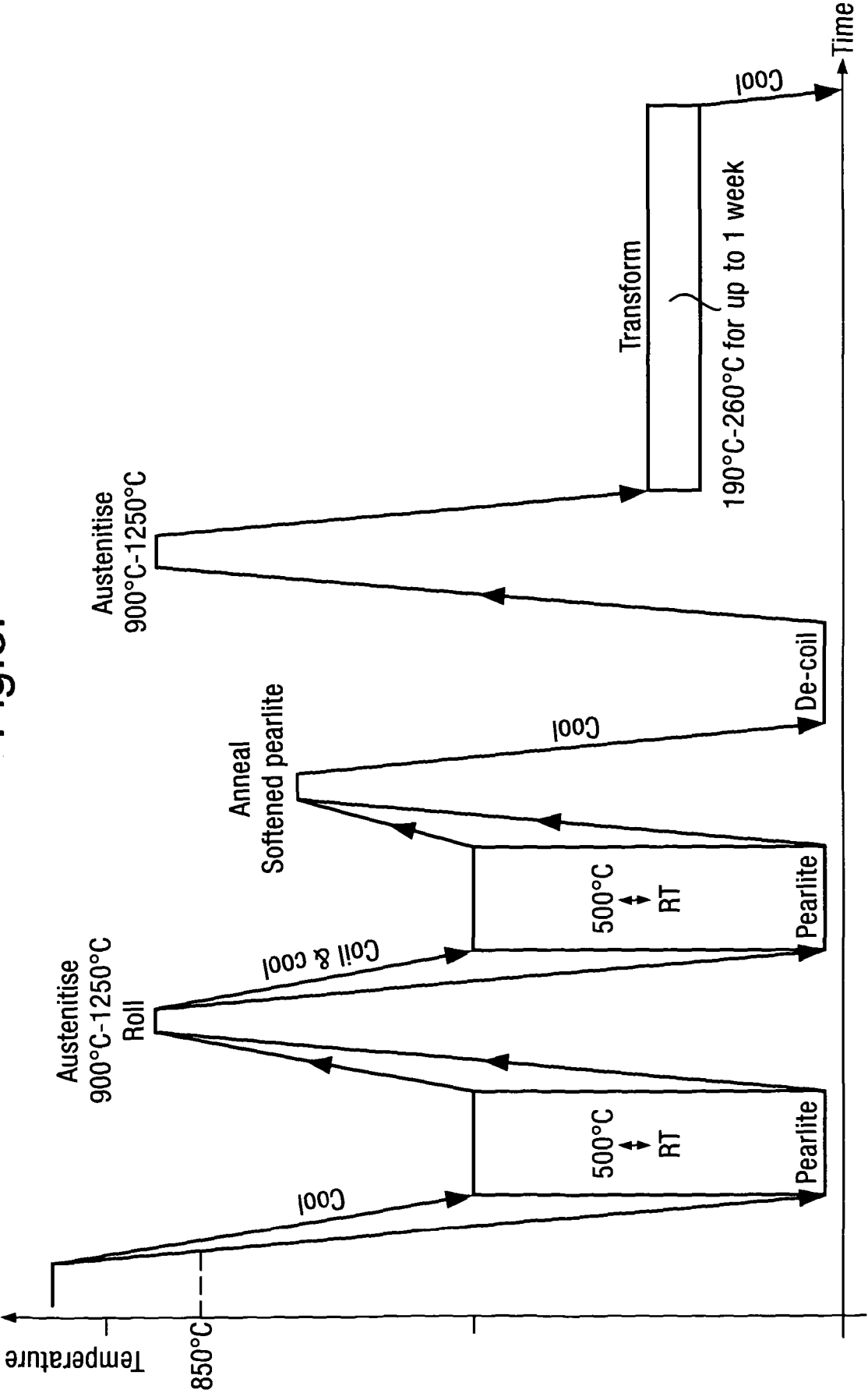


Fig.3.



# INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2011/001079

A. CLASSIFICATION OF SUBJECT MATTER  
INV. F41H5/04 F41H5/02  
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
F41H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EP0-Internal, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                      | Relevant to claim No. |
|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| X         | EP 0 423 004 A1 (CREUSOT LOIRE [FR])<br>17 April 1991 (1991-04-17)<br>abstract<br>page 1, line 1 - page 3, line 32<br>figure 2                          | 1-13                  |
| X         | -----<br>US 7 191 694 B1 (GONZALEZ RENE G [US])<br>20 March 2007 (2007-03-20)<br>column 2, lines 28-41<br>page 5, line 18 - page 6, line 23<br>figure 4 | 1-13                  |
| X         | -----<br>EP 0 505 239 A1 (CREUSOT LOIRE [FR])<br>23 September 1992 (1992-09-23)<br>column 2, line 1 - column 4, line 52<br>figure 1<br>-----<br>-/--    | 1-10,14               |



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

25 October 2011

Date of mailing of the international search report

04/11/2011

Name and mailing address of the ISA/

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# INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2011/001079

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                        | Relevant to claim No. |
|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| X, P      | <p>WO 2011/023988 A2 (SECR DEFENCE [GB];<br/> BAXTER ANDREW GEORGE [GB]; BROWN PETER<br/> [GB]) 3 March 2011 (2011-03-03)<br/> paragraphs [0054] - [0063]<br/> figures 4,8<br/> -----</p> | 1-12,14               |

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/GB2011/001079

### Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claims Nos.: 15, 16  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:  
see FURTHER INFORMATION sheet PCT/ISA/210
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

### Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

#### Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

**FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210**

Continuation of Box II.2

Claims Nos.: 15, 16

Rule 6.2(a) PCT

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guideline C-VI, 8.2), should the problems which led to the Article 17(2) declaration be overcome.

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2011/001079

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date      |
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| -----                                     |                     |                            |                          |
| WO 2011023988                             | A2                  | 03-03-2011                 | NONE                     |
| -----                                     |                     |                            |                          |