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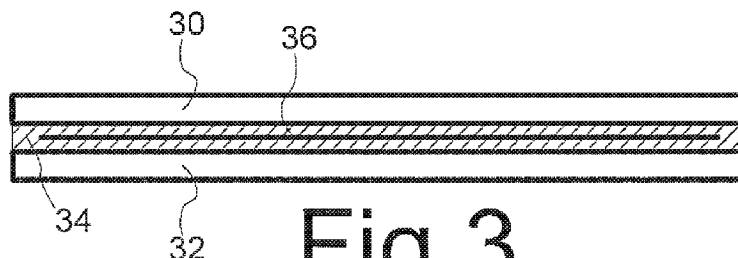
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(54) Title: BLAST AND FRAGMENT RESISTANT WALL SECTIONS USED INSIDE STRUCTURES LIKE SHIPS



**Fig.3**

(57) Abstract: A protective wall for use in a structure such as a ship comprises a first and second metal layer, with an armor plate in between and layers of elastomeric material between the armor plate and the first and second metal layer respectively. The first and second metal layer having a higher ductility than the armor plate, the armor plate being mounted between the first and second metal layer in a way that allows the first and second metal layers to stretch relative to armor steel plate at least in response to forces resulting from impact by fragments from an explosion. When an explosion occurs in a space bounded by the protective wall, the first and second metal layer deflect under the pressure pulses due to blasts, stretching relative to the armor plate. The armor plate blocks high speed fragments. The elastomeric material has a double function: it increases the resistance of the armor plate to fragments and it allows for separation of the armor plate from the first and second metal layer, allowing them to stretch.



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Title: Blast and fragment resistant wall sections used inside structures like ships

#### Field of the invention

The invention relates to blast and fragment resistant wall sections used inside structures like vehicles such as ships.

5

#### Background

US 6,706,406 discloses a ship hull design with hull plates formed from a pair of parallel ductile steel layers with an elastomer bonded to the steel layers in the space between the two layers. Voids may be provided in the elastomer, filled with rigid foam or light gauge steel. The elastomer arrests the development of cracks, which reduces hull damage during grounding or collisions.

15 When a ship is hit by an explosive projectile, the most noxious damage is due to the effect of explosion within the ship. The explosion leads to a pressure surge and high velocity fragments that can kill ship's personnel and create extensive damage to the ship's infrastructure.

20 One possible solution to the high velocity fragments problem is the use of armored bulkheads. Various technologies for manufacturing armored plates are known from the field of armored vehicles, such as use of hard grade steel, ceramics, fabrics of strong fibers or composites thereof. For example, an armor plate comprising a hard armor plate with an elastomer coating on the outside is known from an article titled "Elastomer-steel laminate armor", by C.M. Roland et al., published in Composite structures, 92 pages 1059-1064. By coating the plate, a layer is formed that has no rigidity of its own, but is attached everywhere to the armor plate, so that it stretches everywhere

25

together with the armor plate. The coating serves to increase penetration resistance. Roland et al note that the origin of blast and ballistic mitigation remains to be fully understood, but they mention energy absorption by rubber and strain delocalization. Roland et al note that a multi laminate structure  
5 may be used, which can be extended to using multiple layers may be introduced into the coating. Roland et al give examples of very thin layers in the coating like 0.25 mm aluminum and 0.33 thick low modulus PU-1. With such an thin aluminum layer in the coating, the coating attaches the aluminum layer everywhere to the armor plate.

10

However, many of these technologies are unattractive for use in ships, in view of the vast number of plates required in ships, which leads to concerns about weight and costs. This further means that it is desirable that the protective plates as much as possible perform structural functions in the  
15 ship, which may conflict with the behavior of conventional armor. For example hard materials are often brittle, and hence vulnerable to pressure surge. Moreover, it may be difficult to weld armor plates to other structures in a way that the welds support a structural function in a reliable way.

20

### Summary

Among others, it is an object to provide for improved blast and fragment protection in ships.

25

According to one aspect a protective wall for use in a structure such as a ship is provided, the protective wall comprising

- a first metal layer,
- an armor plate adjacent the metal layer, the first metal layer having a  
30 higher ductility than the armor plate, the armor plate being mounted in a way

that allows the first metal layer to stretch relative to armor plate at least in response to forces resulting from the pressure surge from an explosion;

- a layer of elastomeric material between the armor plate and the first metal layer.

5

When an explosion occurs in a space bounded by the protective wall, the first metal layer flexes under the pressure pulses due to blasts, stretching relative to the armor plate. The armor plate blocks high speed fragments. The elastomeric material has a double function: it increases the resistance of the armor plate to fragments and it allows the armor plate to be kept in position relative to the first and second metal layer under normal circumstances, without causing significant load transfer from the layers to the armor plate during blast or impact loading. The elastomeric material need not fill the entire space between the armor plate and the first metal layer.

15

In an embodiment, the wall comprises a second metal layer, the armor plate being located between the first and second metal layer, the first and second metal layer having a higher ductility than the armor plate, the armor plate being mounted between the first and second metal layer in a way that allows the first and second metal layers to stretch relative to armor steel plate at least in response to forces resulting from impact by pressure surge from an explosion; the protective wall comprising layers of elastomeric material between the armor plate and the first and second metal layer respectively. Thus, the wall provides protection in spaces on either side of the wall against explosions on the other side of the wall. The elastomeric material need not fill the entire space between the armor plate and the metal layers.

25

The first and second metal layer may be fixed parts of the structure, which may be a ship or a land vehicle for example, the first and second metal

layer taking up at least part of the normal operational forces that arise due to use of the structure. The wall may be a bulkhead of a ship for example.

5 In an embodiment the protective wall comprises a plurality of layers of armor plate and layers of elastomeric material. This increases protection against fragments.

#### Brief description of the drawing

10 These and other objects and advantageous embodiments will become apparent from a description of exemplary embodiments using the following figures.

Figure 1 shows the position of a bulkhead in a ship

Figure 2 illustrates a response of the bulkhead to an explosion

15 Figure 3 shows a cross-section of a bulkhead

Figure 4 shows a detail of an attachment of the bulkhead

Figure 5 shows a cross-section of a further bulkhead

#### Detailed description of exemplary embodiments.

20

Figure 1 shows the position of a bulkhead 10 in a ship, between two longitudinal wall sections 12, which may be hull sections. The plane of bulkhead 10 extends perpendicularly to the keel line of the ship. Bulkhead 10 is designed to provide for protection in a space 14 adjacent bulkhead 10 on one side of bulkhead 10 against the effects of the explosion of a projectile with high explosive within the ship on the other side of bulkhead 10.

25 Figure 2 illustrates the desired effect of the pressure surge associated with such an explosion: bulkhead 10 flexes from the side A on which the explosion occurs to the other side B, absorbing explosive energy in the form of stretching energy.

30

Figure 3 shows a cross-section of bulkhead 10. Bulkhead 10 comprises a pair of ductile metal layers 30, 32 with elastomeric material 34 between ductile metal layers 30, 32 and an armor steel plate 36 "floating" between ductile metal layers 30, 32. As used herein, "floating" means that the coupling between armor steel plate 36 and ductile metal layers 30, 32 allows ductile metal layers 30, 32 to stretch independently of armor steel plate 36 under influence of forces with force amplitudes as induced by explosions. A floating presence may be realized by the absence of a direct fixed attachment of armor steel plate 36 to ductile metal layers 30, 32, or at least by a limitation of direct fixed attachment to a point or line. A floating presence of armor steel plate 36 may be realized when substantially all contact between armor steel plate 36 and ductile metal layers 30, 32 is mediated via elastomeric material 34. A floating armor steel plate 36 may rest on a rib of a ductile metal layer 30, 32 for example, without being fixedly attached to the rib. As used herein, fixedly attached includes attachment by welding, rivets, bolts etc. that resist forces that arise during explosions, whereas not fixedly attached includes contacts that allow for relative sliding motion at least when exposed to forces that arise during explosions. Spot welds or small bolts (e.g. M3 bolts or less) may be used

Ductile metal layers 30, 32 may be made of steel of a known standard ship building steel quality, for example of steel types Steel 37 or Steel 52 (as is well known the standards for Steel 37 etc, specify the material properties and many manufacturers supply steel that meets these specifications; in the more modern EN 10028-3 standard Steel 37 and Steel 52 are also known as S235 and P355 respectively, but the terms Steel 37 and Steel 52 are still well known to skilled persons in the ship building industry).

Steel 37 and Steel 52 have a limited tensile strength (plates fail at engineering stress of less than 550MPa and hence also less than 600MPa) and a large deformability (more than 25% engineering strain (elongation) before rupture). Standard measurements for measuring tensile strength are known

per se. The strength of a material is expressed in terms of the stress at which the material fails. This involves subjecting a piece of material to a tensile force, the force defining a tensile stress on the piece as the force divided by the cross-sectional area of the piece in a plane perpendicular to the direction of the force.

5 The strength is the maximum stress that the material is able to resist, i.e. the stress reached before the piece of material fails e.g. by necking. Because no high demands are placed on this strength, other building materials such as aluminum or titanium may also be considered. Similar performance can be achieved when the outer ductile steel layers are replaced with ductile metals  
10 such as aluminium and titanium. This may be applied to land vehicles requiring a similar combination of blast and fragment resistance. Ductile metal layers 30, 32 may have a thickness between 1-15 millimeter, and preferably between 4-7 millimeter. The material of armor steel plate 36 may be of material with the yield stress and tensile strength of known commercially  
15 available ARMOX 500 or ARMOX 600 for example. Such materials have a strength to resist at least 1000 MPa and up to 2500 MPa local tensile stress, which may be realized for example by metallurgical techniques such as adding carbon processing the steel to increase internal stresses. Armor steel plate 36 may have a thickness between 5-15 millimeter or, more narrowly, between 1-  
20 10 millimeter. The overall thickness of bulkhead 10 may be in the range of 5-150 millimeter and preferably between 60-120 millimeter. Various types of elastomeric materials may be used, for example one of the types described in the article by C.M. Roland et al. cited in the preceding. A rubber layer may be used for example.

25 Figure 4 shows a cross-section of a detail of an attachment of bulkhead 10 to a structural element 42 of the ship, such as a longitudinal wall section 12, a girder in longitudinal wall section 12 or similar structural elements such as a ceiling or floor (or decks) or girders in the ceiling or floor. More generally, a structural element is any elements of the ship's structure  
30 that mediates forces that keep the ship from deforming or falling apart during

normal operation. Structural element 42 may be made of ductile steel, of a material similar to that of ductile metal layers 30, 32. The attachment comprises a connection piece 40 with a T-shaped cross-section, which may be of the same material as ductile metal layers 30, 32. The foot of the T of  
5 connection piece 40 is welded to structural element 42. In an embodiment wherein bulkhead 10 has an elongated shape, at least the parallel pair of sides of bulkhead 10 that are closest to each other are attached to the structure of the ship are attached according to this T profile. In an embodiment the top of the T may be an insert plate with a thickness that is necessarily larger than  
10 the sum of the thickness of layers 30 and 32. For example when the floor to ceiling distance is smaller than the wall to wall distance, the T may be attached to the floor and ceiling. This prevents excessive deformation during explosions. Ductile metal layers 30, 32 are welded to the top bar of the T connection piece 40, at a single or few points only for positioning, in a manner  
15 not suitable for significant load transfer. Preferably, armor steel plate 36 is only coupled to connection piece 30 via elastomeric material 34. Armor steel plate 36 is not fixedly attached directly to connection piece 40, or at most at a single point.

Bulkhead 10 may be assembled in situ when the ship is built. In  
20 embodiment ductile metal layers 30, 32 are first welded to a structural element 42 via connections pieces 40, leaving a space between the layers. Elastomeric material 34 is applied to armor steel plate 36 (this may be done at a prefab stage) and the armor steel plate 36 with applied elastomeric material 34 is inserted between the ductile metal layers 30, 32 that have been welded  
25 into the ship's structure. In this way heat damage to elastomeric material 34 during welding can be avoided.

In another embodiment, one of the ductile metal layers 30 is first attached to a connection piece like that of figure 4, for example by welding. Next armor steel plate 36 or a plurality of such plates 36 is or are placed, for  
30 example on supporting ridges on the ductile metal layer 30. Armor steel plate



36 may be placed between stiffeners on ductile metal layer 30 for example. A layer of armor steel plate 36 may be constructed in situ from a series of strips of armor steel plate 36. Subsequently, the other ductile metal layer 32 is attached to the connection piece, for example by welding.

5           In a further embodiment the other ductile metal layer 32 is formed from a series of strips that are each welded to the connection piece and/or to stiffeners on the first attached ductile metal layer 30. In these embodiments a prefabricated armor steel plate 36 may be used, which is provided with elastomeric material 34. Alternatively, the elastomeric material 34 may be added during  
10 assembly as well. The connection piece may subsequently be welded to the ship's structure, or this may be done at an earlier stage, e.g. before the first ductile metal layer 30 is attached to the connection piece.

          In operation, bulkhead 10 combines the effect of the deformability of ductile metal layers 30, 32 on protection against pressure pulses with  
15 fragment protection by armor steel plate 36. When a fragment hits bulkhead, it will typically penetrate one of ductile metal layers 30, 32 and cause armor steel plate 36 to exhibit "plugging", i.e. local shearing through the thickness. Because armor steel plate 36 "floats" between ductile metal layers 30, 32, its inhibiting effect on deformation of ductile metal layers 30, 32 during pressure  
20 pulses is reduced. Elastomeric material 34 makes it possible to mount armor steel plate 36 between ductile metal layers 30, 32 with a minimal effect on the deformability. Alternatively, armor steel plate 36 may be kept in place by means of local stiffeners, such as ribs on ductile metal layers 30, 32 (not shown), without being directly fixedly attached to these stiffeners. In addition  
25 elastomeric material 34 increases the resistance of armor steel plate 36 against explosion propelled fragments. Part of this may be due to reduction of notch effect on armor steel plate 36 by fragments, reducing the otherwise predominant failure mechanism through thickness shearing.

          Figure 5 shows a cross-section of a further bulkhead, with a  
30 plurality of layers of armor steel plates 36a-c between ductile metal layers 30,

32 with elastomeric material 34 between ductile metal layers 30, 32 and armor  
steel plates 36a-c and between the layers of armor steel plates 36a-c. By  
splitting armor steel plate 36 of the embodiment of figure 3 into multiple  
layers with intermediate elastomeric material a higher protection can be  
5 realized at the same or lower weight.

Armor steel plate 36 of the embodiment of figure 3 or each layer of  
armor steel plates 36a-c of the embodiment of figure 5 may be provided in the  
form of a plurality of strips parallel to the main plane of bulkhead 10 and  
separated by elastomeric material. In this way a better deformability may be  
10 realized. The strips in different layers of armor steel plates 36a-c may be offset  
relative to each other, so that spaces between strips in one layer are backed up  
by strips in the other. Horizontal or vertical strips may be used. A plurality of  
strips may be used over the height or width of the wall. As used herein,  
“strips” may be elongated rectangular elements, but the term strip cover any  
15 shape and height/width ratio.

In an experiment a wall of 6 millimeter thick ductile metal layers  
30, 32 of Steel 52, and a double ARMOX-600T double sheet of armor steel 36  
was made, with volume between the ductile metal layers 30, 32 and armor  
steel 36 filled with polyurethane rubber adhered to armor steel 36. Fragments  
20 Simulating Projectiles (known in the art as FSP's) with a mass of 39 grams  
were fired at the wall with a 29 millimeter canon with speeds up to 1850 m/sec  
to simulate fragments. Up to this speed penetrations of the wall could not be  
obtained. At 1831 m/sec the first ductile layer was penetrated. The sheets of  
ARMOX were dented and cracked but the cracks opened insufficiently to allow  
25 remains of the projectile to pass through. The back ductile layer was only  
deformed.

This compared favorably with experiments with a wall of 20  
millimeter Steel 52, which was penetrated at speeds higher than 1096 m/sec. A  
combination of two walls of 10 millimeter Steel 52 at 32 mm spacing, was  
30 penetrated at speeds higher than 1512 m/sec. A combination of 6mm Steel 52-7

mm Armox600T 6 mm Steel 52, with 9 and 16 mm spacing was penetrated at speeds higher than 1196 m/sec.

Although embodiments have been described wherein ductile metal layers 30, 32 are provided on both sides of armor steel 36, it should be appreciated that in other embodiments a ductile metal layer on one side may be omitted. This may mean that less protection is provided against fragments from the side where no ductile metal layer is present. But this may not be needed when this space itself is protected against projectiles, or contains other means to slow down fragments.

In an embodiment the structure is assembled by attaching a first metal layer to a connection piece, mounting an armor plate coated on both sides with elastomeric material between on the first metal layer attached to the connection piece, attaching a second metal layer to the connection piece and/or the first metal layer and over the armor plate, the first and second metal layer having a higher ductility than the armor plate. This makes it possible to assemble the wall easily within a ship for example.

In another embodiment structure is assembled by at least part of the structure with a wall comprising a first and second metal layer attached to elements of the structure, and inserting an armor plate coated on both sides with elastomeric material between the first and second metal layer, the first and second metal layer having a higher ductility than the armor plate. This makes it possible to assemble the wall on site.

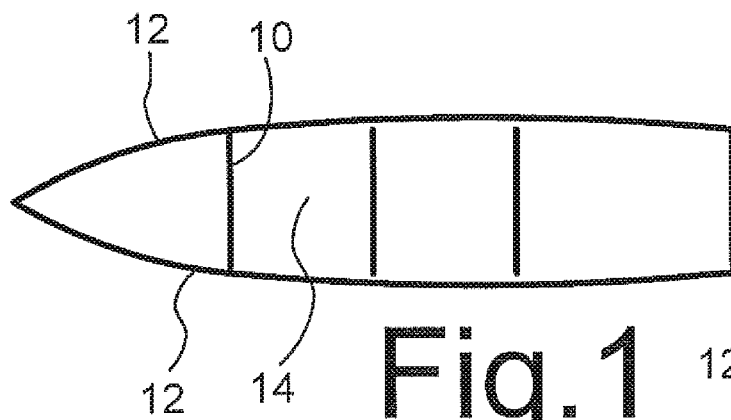
Claims

1. A protective wall for use in a structure such as a ship, the protective wall comprising
- a first metal layer,
  - an armor plate adjacent the metal layer, the first metal layer having a
- 5 higher ductility than the armor plate, the armor plate being mounted in a way that allows the first metal layer to stretch relative to armor plate at least in response to forces resulting from a pressure surge from an explosion;
- a layer of elastomeric material between the armor plate and the first metal layer.
- 10
2. A protective wall according to claim 1, comprising a second metal layer, the armor plate being located between the first and second metal layer, the first and second metal layer having a higher ductility than the armor plate, the armor plate being mounted between the first and second metal layer in a
- 15 way that allows the first and second metal layers to stretch relative to armor steel plate at least in response to forces resulting from impact by fragments from an explosion; the protective wall comprising layers of elastomeric material between the armor plate and the first and second metal layer respectively.
- 20
3. A protective wall according to claim 2, comprising a plurality of layers of armor plate successively between first and second metal layer, the layers of elastomeric material lying between the layers of armor plate and between the layers of armor plate and the first and second metal layer respectively.
- 25
4. A protective wall according to claim 2 or 3, wherein first and second metal layer are made of steel.

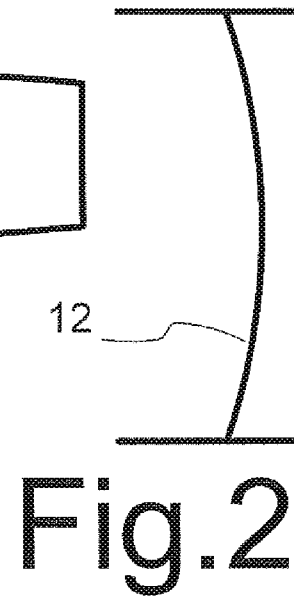
5. A protective wall according to claim 4, wherein first and second metal layer are made of steel types Steel 37 or Steel 52.
- 5 6. A protective wall according to claim 4 or 5, wherein first and second metal layer have a thickness in a range between 1-15 millimeter.
7. A protective wall according to any one of the preceding claims, wherein at least one of first and second metal layer are made of titanium or aluminum.
- 10 8. A protective wall according to any one of the preceding claims, wherein the armor plate has a yield stress and tensile strength corresponding to ARMOX 500 or ARMOX 600.
- 15 9. A protective wall according to claim 8, wherein armor plate has a thickness in a range between 1-10 millimeter.
10. A protective wall according to any one of the preceding claims, wherein the first and second metal layer each have a tensile strength of less than 600
- 20 MPa and the armor plate has a tensile strength of more than 1000 MPa.
11. A structure comprising a protective wall as claimed in claim 1, wherein the first and second metal layer are fixedly integrated in the structure.
- 25 12. A structure according to claim 11, comprising a connection piece with a first and second face, the first and second metal layer being attached to the first face, the second face being attached to a wall, ceiling or floor element of the structure.
- 30 13. A structure according to claim 11 or 12, wherein the structure is a ship.

14. A structure according to claim 13, wherein the wall is a bulkhead of the ship.
- 5 15. A method of assembling a structure, comprising attaching a first metal layer to a connection piece, mounting an armor plate coated on both sides with elastomeric material between on the first metal layer attached to the connection piece, attaching a second metal layer to the connection piece and/or the first metal layer and over the armor plate, the first and second metal layer  
10 having a higher ductility than the armor plate.
16. A method of assembling a structure, comprising assembling at least part of the structure with a wall comprising a first and second metal layer attached to elements of the structure, and inserting an armor plate coated on both sides  
15 with elastomeric material between the first and second metal layer, the first and second metal layer having a higher ductility than the armor plate.

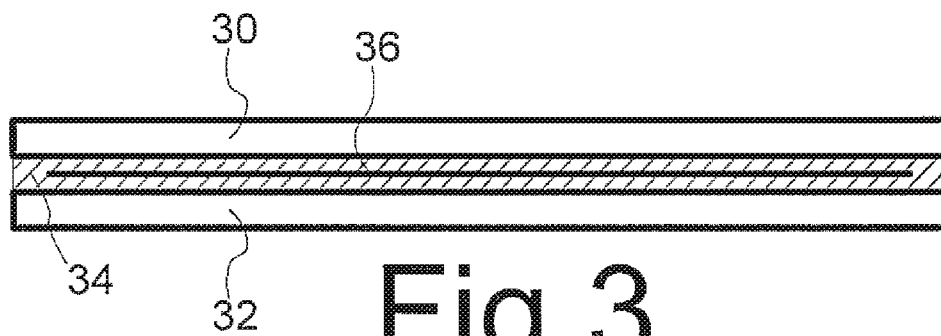
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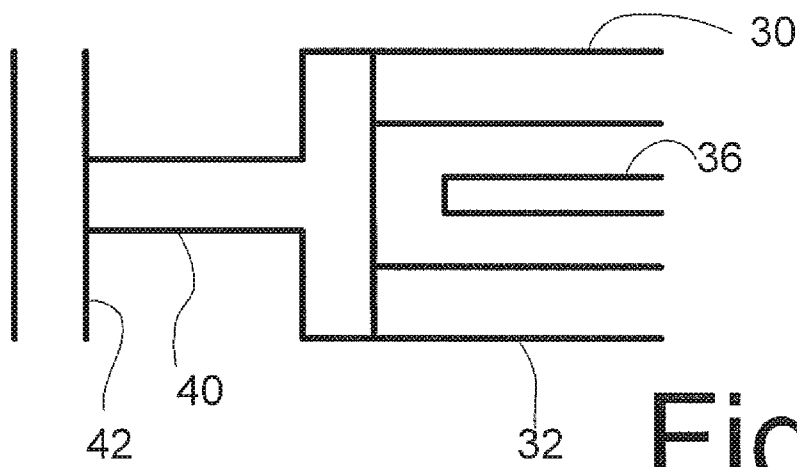
**Fig. 1**



**Fig. 2**



**Fig. 3**



**Fig. 4**

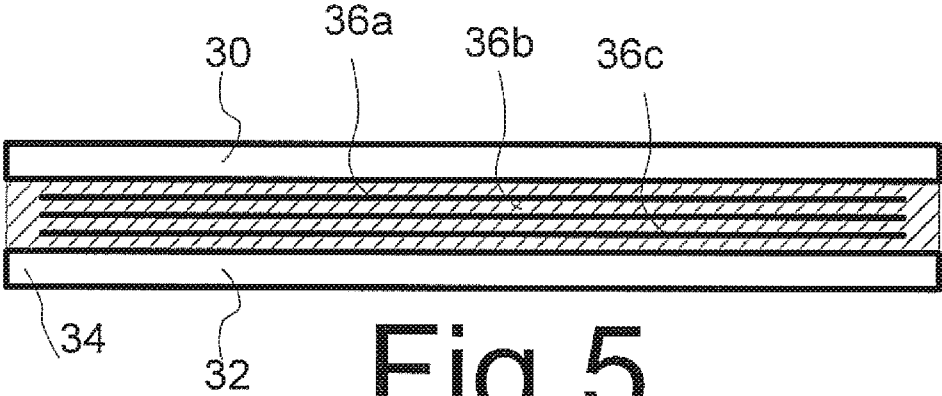


Fig.5



# INTERNATIONAL SEARCH REPORT

International application No

PCT/NL2012/050448

## A. CLASSIFICATION OF SUBJECT MATTER

INV. F41H5/04 B32B15/06  
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 B32B

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 practicable, 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         | ROLAND C M ET AL: "Elastomer-steel laminate armor",<br>COMPOSITE STRUCTURES, ELSEVIER SCIENCE LTD, GB,<br>vol. 92, no. 5, 1 April 2010 (2010-04-01),<br>pages 1059-1064, XP026834464,<br>ISSN: 0263-8223<br>[retrieved on 2009-10-04]<br>cited in the application<br>the whole document<br>page 1062, right-hand column, lines 4-10 | 1                     |
| A         | US 6 706 406 B1 (KENNEDY STEPHEN J [CA])<br>16 March 2004 (2004-03-16)<br>the whole document<br>-----<br>-/--                                                                                                                                                                                                                       | 1-16                  |



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

14 August 2012

Date of mailing of the international search report

24/08/2012

Name and mailing address of the ISA/

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Authorized officer

Hutton, David

## INTERNATIONAL SEARCH REPORT

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| C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                                                                                            |                       |
|------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Category*                                            | Citation of document, with indication, where appropriate, of the relevant passages                                                                         | Relevant to claim No. |
| X                                                    | US 6 216 579 B1 (BOOS STEPHEN J E [CA] ET AL) 17 April 2001 (2001-04-17)<br>examples<br>-----                                                              | 1, 11                 |
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| A                                                    | GB 122 370 A (WILLIAMS WILLIAM ARTHUR) 23 January 1919 (1919-01-23)<br>the whole document<br>-----                                                         | 1-16                  |
| A                                                    | US 2007/111621 A1 (BARSOU ROSHDY GEORGE S [US] ET AL) 17 May 2007 (2007-05-17)<br>the whole document<br>paragraphs [0027], [0031]; figures 5(a-c)<br>----- | 1-16                  |
| A                                                    | US 2008/223203 A1 (RAVID MOSHE [IL] ET AL) 18 September 2008 (2008-09-18)<br>the whole document<br>paragraphs [0010], [0011]<br>-----                      | 1-16                  |
| A                                                    | US 2004/035076 A1 (SCHILT ANDRE [NL]) 26 February 2004 (2004-02-26)<br>figures<br>-----                                                                    | 1-16                  |

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