COMPOSITE AUXETIC ARMOUR

Inventor: David Skertchly, Southampton Hampshire (GB)
Assignee: GLOBAL COMPOSITES GROUP LIMITED, Buckinghamshire (GB)

Appl. No.: 13/061,582
PCT Filed: Aug. 24, 2009
PCT No.: PCT/GB2009/051049
§ 371 (c)(1), (2), (4) Date: May 26, 2011

Foreign Application Priority Data
Sep. 4, 2008 (GB) 0816083.0

Publication Classification
Int. Cl.
F41H 5/04 (2006.01)
F41H 5/08 (2006.01)
F41H 1/02 (2006.01)

U.S. Cl. 89/36.02; 89/903; 89/904; 89/906; 89/917; 89/914; 89/922

ABSTRACT
A ceramic armour plate (1, 41, 50, 70) having auxetic reinforcement (2, 40, 51, 71). The auxetic reinforcement may be provided utilising auxetic fibres, auxetic knits or weaves, or lay-ups exhibiting auxetic behaviour. The auxetic reinforcement reduces cracking of the ceramic plate to improve multi-hit performance. The reinforcement may be provided as a layer (2, 40, 51) bonded to the surface of the ceramic plate (1, 41, 50) or as an integral part (71) of the ceramic plate (70).
200 — Impregnate reinforcement

201 — Place reinforcement in mould

202 — Place ceramic tile over reinforcement layer

203 — Place second reinforcement layer over tile

204 — Cure

205 — Remove from cure

206 — Apply spall liner

FIG. 2
Mix reinforcement fibre and thermoplastic strands

Place layer in mould

Place ceramic tile on layer

Place second layer over tile

Cure

Remove from cure

Apply spall liner

FIG. 3
Manufacture two reinforced plates

Lay up composite structure between plates

Cure

Apply spall liner

FIG. 6
Place auxetic reinforcement in mould

Fill mould with ceramic material

Add auxetic reinforcement to other mould surface

Press mould

Remove blank and fire

FIG. 8
COMPOSITE AUXETIC ARMOUR

BACKGROUND

[0001] This invention relates to improvements in armour and in particular to the improvement of ceramic armour using auxetic materials. The use of ceramic materials such as Aluminium oxide, so called high alumina ceramics, and Silicon carbide as armour is well known. The material is formed into plates to defend a person or object from impacts such as bullets or shrapnel. For example, plates may be formed into body armour for use in garments to protect people, or may be located on the outside of vehicles to protect that vehicle.

[0003] When a bullet or other item strikes the ceramic material the impact causes the bullet to fragment. The fragments may then be stopped either within the ceramic or by a spall liner before they harm the person or object being protected.

[0004] When a ceramic plate is struck by a projectile the plate typically cracks and shatters due to the impact. Locally this shattering/cracking absorbs some of the energy of the projectile, however once cracked the plate is less able to protect against further strikes and thus its effectiveness is significantly, or totally, reduced.

[0005] Ceramic armour having improved multi-hit capability is therefore desirable.

SUMMARY

[0006] The following presents a simplified summary of the disclosure in order to provide a basic understanding to the reader. This summary is not an extensive overview of the disclosure and it does not identify key/critical elements of the invention or delinate the scope of the invention. Its sole purpose is to present some concepts disclosed herein in a simplified form as a prelude to the more detailed description that is presented later.

[0007] There is provided an armour plate, comprising at least one ceramic plate, and a component which exhibits auxetic behaviour.

[0008] The ceramic plate may comprise the component which exhibits auxetic behaviour.

[0009] The component which exhibits auxetic behaviour may be comprised in a composite layer on a surface of the ceramic plate.

[0010] The composite layer may be formed on the surface during curing of the composite layer.

[0011] The composite layer may be bonded to the surface by an adhesive.

[0012] A composite layer may be formed on each surface of the ceramic plate.

[0013] The component exhibiting auxetic behaviour may be at least one auxetic fibre.

[0014] The component exhibiting auxetic behaviour may be a knitted or woven fabric.

[0015] The fabric may be formed of non-auxetic fibres.

[0016] There is also provided an armour panel comprising two or more armour plates as described herein separated by a composite structure.

[0017] There is also provided an item of armoured clothing comprising an armour plate or panel as described herein.

DESCRIPTION OF THE DRAWINGS

[0018] Embodiments of the present invention will now be further described, by way of example, with reference to the figures, wherein:

[0019] FIG. 1 shows a cross-section of a structure according to an embodiment of the invention;

[0020] FIGS. 2 and 3 are flow-charts of methods of manufacturing an embodiment of the invention;

[0021] FIGS. 4 and 5 show cross-sections of structures according to embodiments of the invention;

[0022] FIG. 6 is a flow-chart of a method of manufacturing an embodiment of the invention;

[0023] FIG. 7 shows a cross-section of a structure according to an embodiment of the invention; and

[0024] FIG. 8 is a flow-chart of a method of manufacturing the embodiment shown in FIG. 7.

DETAILED DESCRIPTION

[0025] The detailed description provided below in connection with the appended drawings is intended as a description of the present examples and is not intended to represent the only forms in which the present example may be constructed or utilized. The description sets forth the functions of the example and the sequence of steps for constructing and operating the example. However, the same or equivalent functions and sequences may be accomplished by different examples.

[0026] FIG. 1 shows a cross-section of a composite structure according to an embodiment of the current invention.

[0027] Reinforcement layers 2 are bonded to a ceramic plate 1 and spall liner 3 is an optional layer applied to the back surface of the structure. Reinforcement layers 2 comprise a composite material incorporating an auxetic component. The auxetic nature of the reinforcement reduces the propagation of cracks in the ceramic plate when it is struck by a projectile. This limits the area of damage to the locality of the impact, thereby improving the multi-hit capability of the armour.

[0028] Auxetic materials have a negative Poisson's ratio and thus when a tensile stress is applied to an auxetic structure, its size in a direction perpendicular to the applied stress increases (in contrast to conventional materials whose size reduces when a tensile stress is applied).

[0029] Reinforcement layers 2 are intimately bonded to the ceramic plate such that the layers are mechanically bound together. When a projectile strikes the armour, and hence the ceramic plate, the consequent deformation of the plate is transferred to the reinforcement layer. The deformation causes tensile stresses in the auxetic component which expands in a direction perpendicular to the stress. That expansion resists the propagation of cracks in the ceramic plate, and thus the amount of cracking that occurs for a particular projectile strike is reduced.

[0030] The reduction in crack propagation results in the structural integrity of the plate after a strike being improved and therefore the multi-hit capability may be improved compared to prior-art armours of comparable materials. The addition of a composite layer having auxetic reinforcement may therefore improve the performance of ceramic armour.

[0031] The auxetic component may be in the form of auxetic fibres included in place of, or in addition to, conventional reinforcement fibres. For example, the composite layer may
be a conventional fibre-glass/epoxy resin composite, with additional auxetic fibres. Alternatively the composite layer may utilise only auxetic fibres in a suitable matrix. PCT publication number WO2000/053830 discloses a manufacturing technique for auxetic fibres.

0032] The auxetic component may also be a knitted structure having auxetic behaviour (see for example PCT publication number WO2008/016690), or an auxetic woven fabric (see for example European publication number EP1786962).

0033] The auxetic component may be provided by a unidirectional lay-up of auxetic or non-auxetic fibres. It has been shown that auxetic behaviour can be obtained with certain fibre orientations, even if the fibres themselves are non-auxetic (see e.g., Stat. sol. (b) 244, No. 3, 883-892 (2007), E. H. Harriott, A. Bezazi, F. Scarpa, K. Alderson and A. Alderson).

0034] FIG. 2 shows a flow-chart of a method of manufacture of the structure shown in FIG. 1.

0035] At step 200 reinforcement fibres are pre-impregnated with a suitable matrix material. The reinforcement includes the auxetic component in one of the forms described above. At step 201 the layer is placed in a mould and at step 202 a ceramic plate is placed over the reinforcement layer. At step 203 a further reinforcement layer incorporating an auxetic reinforcement and suitable matrix is placed on the ceramic plate. At step 204 the structure is cured in an appropriate fashion determined by the materials and structure utilised. For example, a vacuum bag may be applied around the structure, and cure may be performed at a pressure and temperature of 90 psi and 135°C for 1 hour.

0036] At step 205 the structure is removed from the curing process and at step 206 a spall liner may be applied if required.

0037] The resulting structure is a ceramic plate with a reinforcement layer incorporating an auxetic component bonded to each surface. As will be appreciated, this method, with suitable modification, is also applicable to the manufacture of a plate with reinforcement on only one surface.

0038] FIG. 3 shows a flow chart of an alternative method of manufacturing the structure shown in FIG. 1.

0039] At step 300 reinforcement fibres, for example glass fibres, are mixed with thermoplastic strands (for example polypropylene). As described above, the auxetic effect may be provided by the use of auxetic fibres, an auxetic knit/weave or an auxetic lay-up. If auxetic fibres are utilised these may be provided as a proportion of the thermoplastic strands, but the material of the auxetic strands must be selected such that they are not affected by the curing process used to melt the strands which will form the matrix. At step 301 the layer is placed in a mould and at step 302 a ceramic tile is placed over the layer. At step 303 a further layer of mixed fibres and strands is placed over the tile and at step 304 the structure is cured in an appropriate fashion determined by the materials and structures utilised. For example, a vacuum bag may be applied around the structure and cure may be performed at a pressure and temperature of 90 psi and greater than 185°C respectively for 1 hour.

0040] At step 305 the structure is removed from the curing process and at step 306 a spall liner may be applied if required.

0041] FIG. 4 shows a cross-section of a composite structure according to an embodiment of the invention.

0042] In the structure shown in FIG. 4 reinforcement layers 40 incorporating an auxetic component are bonded to a ceramic plate 41 using an adhesive 42. The structure shown in FIG. 4 may be formed by producing the reinforcement layers 40 using known techniques and subsequently bonding them to the surfaces of the ceramic plate 41. The reinforcement layers may be bonded using any suitable adhesive, for example a 2-part epoxy. The structure may also be manufactured by co-curing the reinforcement layers 40 and adhesive 42, which may be a more efficient method of production. The reinforcement layers may utilise any of the structures described above.

0043] The spall liner 43 may be bonded to the second reinforcement layer using adhesive.

0044] FIG. 5 shows a cross-section of a multi-layer armour according to an embodiment of the invention.

0045] Two ceramic plates 50 with an auxetic reinforcing component 51 are formed around a composite structure 52. Multiple layers of ceramic material 50 may have performance advantages in certain situations, for example in resisting blast impacts, and may also have advantages in manufacturing. The composite structure 51 may be structural elements such as beams or honeycomb, or may be fillers such as fibres with auxetic or non-auxetic properties.

0046] Each reinforcement layer 51 includes an auxetic component as described previously. The auxetic component may be provided throughout each reinforcement layer, or may be provided in only selected plies of those layers, for example only in the ply adjacent to the ceramic plates. Such distributions of the auxetic component may also apply to the other embodiments described herein.

0047] Not all of the reinforcement layers necessarily include an auxetic component, and embodiments may be provided which only have an auxetic component in some of the layers. As will be appreciated the multi-layered principles of this embodiment may be applied to various structures having a combination of layers.

0048] FIG. 6 shows a flow-chart of a method of manufacturing the structure shown in FIG. 5. At step 600 two reinforced plates are manufactured as described in one of the foregoing methods. At step 601 the plates are laid up with the composite structure using conventional techniques. The structure is then cured at step 602 and a spall liner applied at step 603 if required. As will be appreciated the structure could be co-cured to simplify the manufacturing process.

0049] FIG. 7 shows a cross-section of a reinforced ceramic plate 70 according to an embodiment of the current invention. In this structure a ceramic plate 70 is formed with an integral auxetic component 71. The auxetic component 71 may be provided using any of the means described hereinbefore, for example an auxetic knit structure, auxetic weave or auxetic fibres providing that they are capable of resisting the firing temperature of the ceramic which is typically 1250°C.

0050] The reinforcement of the structure shown in FIG. 7 provides reinforcement and crack reduction due to the mechanisms described above, and may therefore exhibit improved multi-hit resistance.

0051] FIG. 8 shows a flow-chart of a method of manufacturing the structure shown in FIG. 7.

0052] At step 800 an auxetic reinforcement is placed on a first surface of the ceramic plate mould. The auxetic reinforcement is formed of a material that can resist the temperatures associated with firing the ceramic plate. For example, carbon fibre woven into an auxetic knit structure may be suitable.

0053] At step 801 the mould is filled with the ceramic material, typically as a powder or slurry but in some imple-
ments the mould filling may be by melt infusion or chemical vapour infiltration particularly where the desired matrix required is Silicon carbide. In this example a low cost high alumina ceramic known as Grez ceramic may be utilised. At step 802 a further reinforcement layer is applied to the other mould surface and the mould is closed. The mould is then pressed at step 803 to form the ceramic to shape and to integrate the reinforcement within, but close to the surface of, the ceramic material. Alternatively the reinforcement may be spread through the thickness of the ceramic material, or may be applied only at one surface of the plate.

At step 804 the ceramic blank is removed from the mould and fired according to conventional techniques. For example the blank may be fired at 1250° C. for 20 minutes.

The resulting structure is a ceramic plate with integral auxetic reinforcement which may have the improved multi-hit capability described previously.

The armour plates described hereinbefore may be formed in any suitable dimensions as required by the application. The plates maybe utilised in personal body armour, in vehicle armour or for any other structure or device. The plates may be formed in any shape or contour suitable for the required use and the parameters of the structures are defined according to the protection required for that use.

Reference has been made to ceramics in general and specific examples of suitable ceramics may be Aluminium oxide (high alumina) and silicon carbide.

Any suitable matrix may be utilised for the reinforcement layers, for example thermoplastics, thermosetting plastics, ceramics or metals.

Any suitable fibres may be utilised which will resist processing in the reinforcement layer, for example glass fibre, carbon fibre, aramid fibres and polyethylene fibres.

The reinforcement may be provided over the whole area of the ceramic plate, or may be provided over only part of the plate. Furthermore, the reinforcement may be provided in more than one discrete region. Where reinforcement is provided on both surfaces of the plate it may be provided in different regions on each surface, or over the whole surface on both sides. The thickness, amount or type of auxetic reinforcement may be varied over the area of the ceramic plate, or on the different sides of the plate.

Multiple composite layers incorporating auxetic, and/or conventional reinforcement may be provided on each of the surfaces.

The reinforcement techniques described herein may also be applied to the spall liner, which may be auxetically reinforced. Also, such reinforcement may be provided in isolation of reinforcement at the ceramic layers. Furthermore, the spall liner could be provided using auxetic knitted or woven fabrics in the absence of a matrix.

Any range or device value given herein may be extended or altered without losing the effect sought, as will be apparent to the skilled person.

It will be understood that the benefits and advantages described above may relate to one embodiment or may relate to several embodiments. It will further be understood that reference to ‘an’ item refers to one or more of those items.

The steps of the methods described herein may be carried out in any suitable order, or simultaneously where appropriate. Additionally, individual blocks may be deleted from any of the methods without departing from the spirit and scope of the subject matter described herein. Aspects of any of the examples described above may be combined with aspects of any of the other examples described to form further examples without losing the effect sought.

It will be understood that the above description of preferred embodiments is given by way of example only and that various modifications may be made by those skilled in the art. The above specification, examples and data provide a complete description of the structure and use of exemplary embodiments of the invention. Although various embodiments of the invention have been described above with a certain degree of particularity, or with reference to one or more individual embodiments, those skilled in the art could make numerous alterations to the disclosed embodiments without departing from the spirit or scope of this invention.

1. An armour plate, comprising:
   at least one ceramic plate; and
   a component which exhibits auxetic behaviour.

2. An armour plate according to claim 1 wherein the ceramic plate comprises the component which exhibits auxetic behaviour.

3. An armour plate according to claim 1 wherein the component which exhibits auxetic behaviour is comprised in a composite layer on a surface of the ceramic plate.

4. An armour plate according to claim 3 wherein the composite layer is formed on the surface during curing of the composite layer.

5. An armour plate according to claim 3, wherein the composite layer is bonded to the surface by an adhesive.

6. An armour plate according to claim 3, wherein a composite layer is formed on each surface of the ceramic plate.

7. An armour plate according to claim 1 wherein the component exhibiting auxetic behaviour is at least one auxetic fibre.

8. An armour plate according to claim 1 wherein the component exhibiting auxetic behaviour is a knitted or woven fabric.

9. An armour plate according to claim 8 wherein the fabric is formed of non-auxetic fibres.

10. An armour panel comprising two or more armour plates separated by a composite structure, wherein the two or more armour plates each comprise at least one ceramic plate and a component which exhibits auxetic behaviour.

11. (canceled)

12. An item of armoured clothing comprising:
   a piece of clothing associated with at least one armour plate, wherein the at least one armour plate comprises at least one ceramic plate and a component which exhibits auxetic behaviour.

13. An item of armoured clothing according to claim 12, comprising two or more armour plates separated by a composite structure.

* * * * *