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(54) Title: ARMOUR MATERIAL

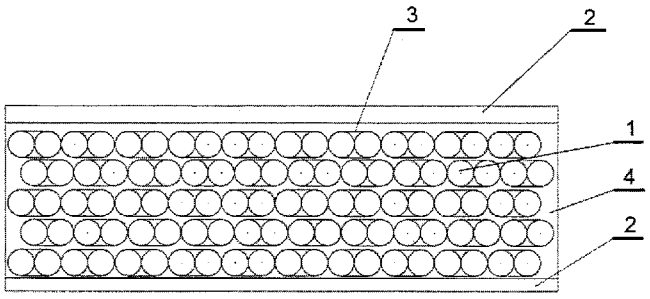


Fig.2

(57) Abstract: The ballistic material is made up of layers of rods arranged in rows, and the rods are arranged with an overlap, whereas the layers of the rods are joint inseparably with a warp (4) of a material undergoing solidification. The rods (1) are made of polyterephtalane-1,4- phenylenediamine fibres (PPTA), and/or carbon fibres, bundles thereof are impregnated with the warp and are twisted undergoing solidification. Individual rows of rods in a layer are arranged with an offset of rods of adjacent rows with an overlap close to 0.1 - 0.9 of the rod length, and between the rows of the layer an adjacent layer is laid of similarly offset rods such that the rods of the layers are also arranged with an overlap close to 0.1 - 0.9 of the rod length for each adjacent three rods adjoining by side surfaces.

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Armour material

The object of the invention is a ballistic material intended for providing enhanced ballistic resistance, resistance against projectile impact, of buildings protected with the armouring material.

The ballistic material is intended for providing or enhancing ballistic resistance of vehicles, aircrafts and watercrafts, and buildings.

There are known methods of ballistic armour production from fabric and appropriately bound fibres from the materials reaching high tensile strength of 0°, ±45° and 90° orientation with the identical quantity for each direction. Such materials are defined as a quasi-isotropic composite. Epoxy-carbon laminates of such a structure are used in aviation, partly forgoing the opportunity to obtain very strong resistance (that would be possible with parallel arrangement of all the UD layers) in favour of minimizing occurrence of problems related to application of materials of very strong anisotropy. Tensile and bending resistance tests of laminates are subject to similar conditions.

From the description NL8403529 an armour plate is known that comprises layers made up of aramid fibre (particularly Kevlar, RTM) embedded in a synthetic resin on a basis of epoxy resin. Moreover, the plate comprises layers of carbon fibres and/or metallic layer, alternatively on mineral basis, for example a base layer on a basis of Na2O, K2O or SiO2. A layer of carbon fibre may be placed at one or both sides of the aramid fibre layer. The aramid layers and/or carbon layers may form unidirectional strips. Longitudinal directions of fibres in consecutive layers may be arranged at an angle with each other. A metallic layer or layers may be placed on the aramid fibre layer and/or on the carbon fibre layer by way of flame spray.

In the known composite materials under dynamic loads typical for those that occur in the case of ballistic armour, anisotropy occurs in the resistance rates, flexibility coefficient with the very rapid kinetic energy load being applied on a small area thereof.

In the case of a ballistic material made up of fibres bound by a warp in the form of a plate with arranged on each other layers of fabric from highly resistant fibres or rods, a projectile launched exerts force on such armour in the direction it was moving prior to hitting the armour, but also radially, around the hit area. Such loads cause damage, tearing the laminate structure due to lateral expansion of the fibres. It is the most destructive factor damaging the composite ballistic armour.

It is known from the description of the invention EP2072945 a composite armour plate for protection against projectiles, which includes layers of parallel rods, whereas between the ends of axially arranged rods introduced are elements absorbing shock. Those may be materials in the form of films, fibres, strips or granules. The shock absorbing materials may also, according to other exemplary embodiments, be arranged between the rows of rods. The shape of the rods, convex or concave, is the object of the invention as well. The very rods may be of a variety of sizes and shapes, for example circle, ellipse or polygon. A rod of a length from 13 to 300 mm is made of a ceramic material, of aluminium oxide or another hard material such as boron carbide, silicon carbide, metallic material, hardened steel or sinters.

It is known from the patent description PL217284 a soft hybrid ballistic package intended particularly for bullet and/or fragment-proof jackets and armouring of parts of vehicles. An insert enclosed in a watertight and vapour-permeable case, is provided with a facing layer, which is made of a conventional ballistic material, and a reverse layer in the form of an arrangement comprising from 3 to 15 sheets of polypropylene fabric, replacing from 2 to 12 sheets of a ballistic material of the conventional insert, maintaining the assumed ballistic resistance class and original or reduced mass of the insert. The hybrid insert contains up to 30% by weight of polypropylene material.

In the plates made of laminates the fibres are distributed multi-directionally, but always parallelly or nearly in parallel to the plate surface being the ballistic armour. The plates have the highest resistance if the forces are exerted in the direction along the direction of the fibres arrangement.

Upon binding the fibres with the warp, laminated plates are formed thereof, flat or rounded. A property significantly restricting the application of the laminates is the susceptibility to stretch in the direction across the fibres. It is difficult to avoid a situation where some fibres used to form the laminate are stretched cross the fibre axis. Such a load causes rupturing of fibre and warp bond of the composite, which is particularly disadvantageous for the ballistic armour durability.

Moreover, there are air bubbles in laminates, which reduce the material strength rates, particularly in the case of loads on the plate made thereof under high kinetic energy exerted on a small area.

In the case when the plate is loaded with high kinetic energy exerted on the small area of the plate, which is a typical state of load in the case of ballistic armour, cracks caused by the projectile impact start joining the areas filled up with air. Long cracks are being formed along the fibre axis causing the load state tearing the plate being the ballistic armour, in the direction across or nearly across the fibre axis.

The ballistic structure is formed from layers of rods arranged in rows. The rods are arranged in a layer with an offset of rods of adjacent rows with an overlap close to 0.1 - 0.9 of the rod length, and between the rows of the layer an adjacent layer is laid of similarly offset rods such that the rods of the layers are also arranged with an overlap close to 0.1 - 0.9 of the rod length for each adjacent three rods adjoining by side surfaces. The layers of the rods are bound inseparably with a warp of a material undergoing solidification. The warp is a polymer resin, preferably a polyester resin or epoxy resin or phenol-formaldehyde resin. The rods are made up of polyterephtalane-1,4-phenylenediamine fibres (PPTA), and/or carbon fibres, bundles thereof are impregnated with the warp and are twisted undergoing solidification. It is advantageous if closely laid rods, adjoining by side surfaces are woven with carbon fibre and/or PPTA fibre and each two are so bound together in the inseparable manner with the material of the warp.

A big advantage of the solution is the fact that the rods are made up of twisted fibres, the rods that are arranged spatially and with an overlap. Twisting the rods creates the state in which the projectile hitting the plate made of the material encounters the fibres oriented at different

angles in relation to the direction of the projectile movement. Such arrangement of the fibres ensures twist of the fibre bundle along the fibre axes.

Additionally, twisting the fibres generates pressure between the fibres that leads to elimination of micro air bubbles from the material.

The above properties of the plate provide that the armouring made thereof has the ability to disperse high kinetic energy exerted on the small area thereof.

The object of the invention is illustrated in the embodiment in the drawing, wherein Fig. 1 presents a side view of the ballistic material and Fig. 2 a cross-section view.

The armouring material has the form of a plate inside which there are arranged in layers elements of a circular cross-section making up a rod 1. The rods are made up of arranged side by side fibres from polyterephtalane-1,4-phenylenediamine structure, PPTA in short, also known under the names "kevlar", "twaron" or "aramid" and of carbon fibres. In each element there are PPTA fibres and carbon fibres in possibly variable weight ratios. In one embodiment the ratios 80% by weight of PPTA fibres and 20% by weight of carbon fibres were applied as sufficiently advantageous.

The fibres in the bundle are immersed in a bowl with a polyester resin or epoxy resin or phenol-formaldehyde resin. When the fibres making the bundle are saturated, they are twisted until a rod is formed of a diameter not smaller than 18 mm and not larger than 22 mm. The twisting consists in grasping both ends of an individual bundle of fibres and turning it in the perpendicular plane relate to the bundle axis. Obviously, it is possible to grasp permanently one end of the bundle, and the other end is being turned to the left or to the right in the plane perpendicular axis relate to the bundle axis. The fibres in the bundle are arranged in the form of a spiral, whereby the fibres laid in the centre of the bundle have a smaller diameter of the spiral than the fibres on the perimeter of the bundle. When the excess of the epoxy has been drained off the bundle is seasoned in the temperature 30 - 50 degrees Celsius. When the epoxy bonding the fibres has been gelled the relevant harness is achieved. Twisting the fibres advantageously leads to removal of the air bubbles that are therebetween and upon solidification makes the structure of multidirectional arrangement of the fibres in the element. In this manner, upon solidification of each bundle, the rods 1 are made.

Next, the rods are arranged in rows to create a layer, and similar layers are laid thereon. Above the first layer the second layer is laid. Each rod of the second layer is located above the point of joint of the side and face surfaces of the rods of the first layer. In other words, the rods are arranged with an overlap, similar to bricks in a wall.

The rods are arranged in a layer in rows with an offset of adjacent rows with an overlap close to 0.1 - 0.9 of the rod length, and between the rows of the layer an adjacent layer is laid of similarly offset rods such that the rods of the layers are also arranged with an overlap close to 0.1 - 0.9 of the rod length for each adjacent three rods adjoining by side surfaces.

The first layer is arranged on the plate 2 of 500 mm x 400 mm dimensions and 10 mm thick, made of a resin of Shore 90 hardness.

Each rod 1 is arranged such that the longitudinal axis thereof is in parallel to the plate edge of 500 mm long. The rods are arranged such that they are adjacent to each other by side surfaces. An additional reinforcement is provided in an exemplary embodiment where the closely laid rods, adjoining by the side surfaces, are bound each two in the inseparable manner, by weaving with the carbon fibre or a fibre made of PPTA upon solidification of the resin which they are impregnated with.

The braid 3 is made from the fibres of the material that the rods are made of or of the carbon fibre or of both those fibres in a similar weight ratio. Braiding of the rods together in pairs enhances the ballistic resistance of the material the plate is made of, particularly in the case of a projectile impact in the area between adjacent rods, adjoining by the side surface. The joints relate solely to the adjacent rods arranged in the same layer. The first layer comprises six rods, each arranged such that the longitudinal axis of each of them is in parallel to the side edge of the plate 500 mm long.

The rods 1, each 60 mm long each, are arranged one after another such that they adjoin by face surfaces perpendicular to the longitudinal centre axis. In each row there are eight rods, each 60 mm long. In the first horizontal, lowest laid layer there are 20 rows with eight rods 1 in each row. In the first layer there are arranged 160 rods adjoining by the face surfaces.

In the plate there are five horizontally arranged layers. In each of them there are 160 rods. In total, there are 800 rods in the entire plate, each 60 mm long.

The rods are arranged in the warp 4 and they made up the laminate structure, like rods and steel wire bundle located in the structure made of concrete make a material called reinforced concrete or ferroconcrete. The warp 4 is gelled, that is a hardened polyester resin, epoxy resin or phenol-formaldehyde resin filling spaces between the rods.

The layers arranged on each other are encapsulated with liquid resin PMC 790. The layers of rods are covered with a plate 3 of 500 mm x 400 mm dimensions and 10 mm thick, made of resin PMC 790 of Shore 90 hardness and such made ballistic material is left to season in the temperature 30 - 50 degree Celsius for approximately 48 hours.

Claims

1. A ballistic material is made up of layers of rods arranged in rows, and the rods are arranged with an overlap, whereas the layers of the rods are joint inseparably with a warp (4) of a material undergoing solidification, **characterized in that** rods (1) are made of polyterephtalane-1,4-phenylenediamine fibres (PPTA), and/or carbon fibres, bundles thereof are impregnated with the warp and are twisted undergoing solidification.

2. The ballistic material according to claim 1, **characterized in that** individual rows of rods in the layer are arranged with an offset of rods of adjacent rows with an overlap close to 0.1 - 0.9 of the rod length, and between the rows of the layer an adjacent layer is laid of similarly offset rods such that the rods of the layers are also arranged with an overlap close to 0.1 - 0.9 of the rod length for each adjacent three rods adjoining by side surfaces.

3. The ballistic material according to claim 1, **characterized in that** the warp (4) is a polymer resin, preferably a polyester resin or epoxy resin or phenol-formaldehyde resin.

4. The ballistic material according to claim 1, **characterized in that** closely laid rods, adjoining by side surfaces are woven with a fibre (3) of carbon and/or fibre of polyterephtalane-1,4-phenylenediamine (PPTA) and each two are bound together with the material of the warp (4) in the inseparable manner.

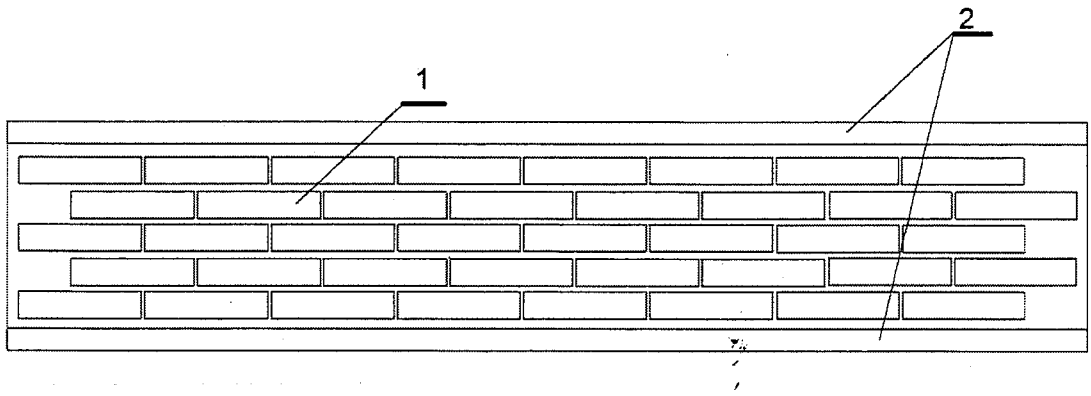


Fig.1

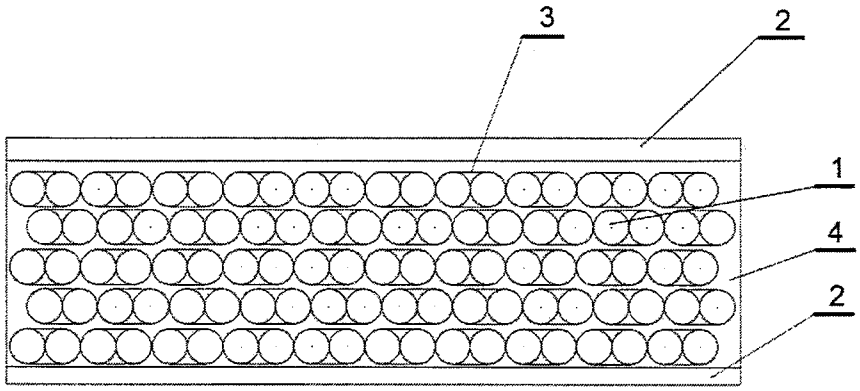


Fig.2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/PL2018/050010

A. CLASSIFICATION OF SUBJECT MATTER

F41H5/00 (2006.01), F41H7/00 (2006.01); C08J5/06 (2006.01), C08J5/10 (2006.01), F16J15/22 (2006.01), B32B5/02 (2006.01), D04H1/00 (2006.01)

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)

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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)

EPODOC,WPI (via EPOQUENET), Database of the Polish Patent Office, ESPACENET

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JPS63149437 A (TOYOTA MOTOR CORP [JP]) 1988-06-22	1-4
A	EP2072945 B1 (KRAUSS MAFFEI WEGMANN GMBH [DE]) 2011-01-26	1-4
A	RS20050418 (A) (DRAGIC MILE, [YU]) 2006-12-15	1-4
A	GB1260111 (A) (ROLLS ROYCE, [GB]) 1972-01-12	1-4

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search	Date of mailing of the international search report
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