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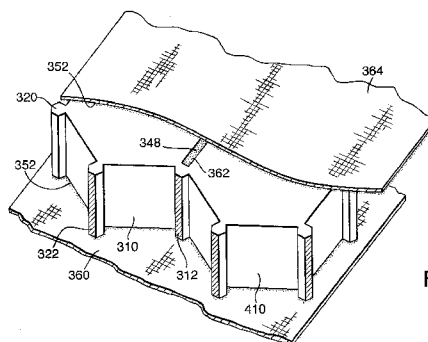


Fig. 7.

(57) Abstract: A steel armour comprising between 90% and 50% bainite, the rest being austenite, 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. In one embodiment of the invention the bainite comprises in weight percent: carbon 0.6 to 1.1%, silicon 1.5 to 2.0%, manganese 0.5 to 1.8%, nickel up to 3%, chromium 1.0 to 1.5%, molybdenum 0.2 to 0.5%, vanadium 0.1 to 0.2 %, balance iron save for incidental impurities. In particular it was noted that excellent properties were obtained if the manganese content is about 1% by weight. By forming the steel as a pearlite sheet the elements of the panel can be formed easily by cutting or stamping before final transformation to bainite. Cutting may also occur after final transformation using water-jet or laser cutting. Alternatively hot forging elements is described. The invention notes that such armours may have holes or slots to fragment incoming projectiles.



Armour

Description

[0001] This invention relates to armour systems and elements therefore and their manufacture. Although intended primarily for vehicles, the invention can be used in other ways, for example, personal body-armour, armouring buildings and vulnerable parts of ships, for example the bridge, to protect them against piracy.

[0002] In

Patent Citation 0001: WO WO 2006/103431 A (THE SECRETARY OF STATE FOR DEFENCE). 2006-10-05.

an armour panel comprising a layer of ceramic armour elements and spacing means is characterised in that the spacing means comprises a lug on a side of a ceramic armour element arranged to co-operate with an adjacent ceramic armour element. The element of this publication is, in fact, is a three dimensional object having two faces substantially opposed to each other and having at least three sides joining the faces. Alternatively, the two faces may be circular and joined by one side. The spacing means provides substantially uniform spacing for formation of a bond line between sides of adjacent ceramic armour elements in the panel, a bond line being a layer of adhesive is formed between sides of adjacent ceramic armour elements.

[0003] An embodiment of WO2006/103431 utilises a hexagonal element shape which incorporates a lug on each side of the hexagonal element. When the ceramic armour element is rotated 60° through the axis of symmetry of the hexagonal transverse cross section of the ceramic armour element, the position of the lugs on the ceramic armour element is substantially the same. The lugs may be an integral part of the element moulded as part of the element. This hexagonal element shape with integral lugs has the advantage that assembly of the ceramic armour elements in the panel is simplified. When a panel is being assembled, elements are configured to tessellate. The hexagonal symmetry of the elements means that elements can be fitted into the array with minimal effort required for proper orientation to ensure tessellation.

[0004] The invention of WO2006/103431 has the further advantage that the lugs separate adjacent elements evenly, thus the requirement of an independent spacing means between each element can be dispensed with. The lugs on the element and the spacing provided between elements facilitate in-plane adhesive infusion and allow for adhesive to be distributed evenly between the elements without any voids. The element shape has the advantage that there is no need for the addition of extra material to fill interstitial voids between elements, as for example the small spheres in
Patent Citation 0002: US 3523057 B (BUCK). 1970-08-04.

[0005] Patent Citation 0003: WO WO 2010/013054 A (THE SECRETARY OF STATE FOR DEFENCE). 2010-02-04.

, published after the priority date hereof, describes a carbide free bainite steel which comprises between 90% and 50% bainite, the rest being austenite, 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 for such steel.

[0006] It has now been found that the processes described in Super Bainite Steels of PCT Patent Application PCT/GB2009/050947 make for the easy and economic manufacture of armour elements, for example elements of the kind described in WO2006/103431. Furthermore a hardness of 630Hv and more is obtained readily. The elements can be constructed with thicknesses of about two thirds of the ceramic elements described in WO2006/103431 more cheaply yet giving similar performance.

[0007] In this specification the word "element" in relation to armour means a component of the armour. It may, for example, comprise a tile which may or may not be physically linked to another tile, a shaped item or element of the kind described in WO2006/103431, or a sheet forming part of the armour.

[0008] In the present invention armour is characterised in that it comprises a plurality of elements of Super Bainite Steel.

[0009] Preferably the Super Bainite Steel comprises by weight percent: carbon 0.6% to 1.1%; manganese 0.3% to 1.8%; nickel up to 3%; chromium 0.5% to 1.5%; molybdenum up to 0.5%; vanadium up to 0.2%; sufficient silicon and or aluminium to render the bainite substantially carbide free; with the balance being iron save for incidental impurities.

[0010] Such steels can be very hard, 550HV to 750HV.

[0011] Silicon is preferred to aluminium both on cost grounds and for ease of manufacture, for armour steels aluminium would not, therefore, normally be used. The practical minimum silicon content is 0.5% by weight and it should not exceed 2% by weight. Excess silicon renders the process difficult to control.

[0012] Preferred ranges of some of the other constituents of the Super Bainite Steel, by weight percent, are: manganese 0.5% to 1.5%; chromium 1.0% to 1.5%; molybdenum to 0.2% to 0.5%; vanadium 0.1% to 0.2%.

[0013] By varying the manganese content, it has been found that the processing time can be varied as described in WO2010/013054, the higher the manganese content the longer the processing time. However, from a practical point of view it has been found that a manganese content of about 1% by weight percent provides a sensible compromise, producing a very hard product highly suitable for armour elements. In reality, the

manganese content, even if 1% by weight percent is aimed for, will vary between about 0.9% and 1.1% by weight percent, thus in this context of this invention, the word “about” implies a possible variation of + or -10% from the quoted figures.

- [0014] Super Bainite Steel armours comprising a plurality of elements made with constituents within the preferred ranges have been found to have extremely fine bainite platelets (platelet thickness on average 40nm or less thick and usually above 20nm thick) and hardness of 630HV or greater and are substantially free of blocky austenite.
- [0015] In one particularly advantageous configuration the elements are maintained in a fretwork construction within the armour by maintaining narrow uncut bridges between adjacent elements. In use the bridges help to maintain the elements in place, but will fail on the impact of an armour piercing round on one of the adjacent elements preventing the spread of the impact effects to adjacent elements. If necessary, the bridges can be made less deep than the elements themselves by partially cutting them through so that the bridges will break preferentially to avoid transmission of shocks from one element to another.
- [0016] A further advantage of providing weakened bridges is that armour comprising a plurality of elements can be sold to vehicle manufacturers or other end users mounted in large fretted sheets to be broken or cut to the final shape or configuration as required.
- [0017] Providing holes in the elements has advantages for some applications, as the holes deflect and break up armour piercing rounds, and will lighten an armour panel formed of such elements considerably. These holes can be round or in the form of slots or other suitable shape and formed by stamping, drilling, or laser or water-jet cutting while the steel is in a pearlite form by stamping or by laser or water-jet cutting once the final Super Bainite Steel is formed. If a forging process is used to manufacture elements the holes can be formed during the forging.
- [0018] An armour panel may comprise a layer of armour elements and bridges means associated with one element in which the bridges join the element to adjacent elements. An element may comprise a three dimensional object having two faces substantially opposed to each other and having at least three sides joining the opposed faces. The bridges provide substantially uniform spacing between elements in which spacing a bond line is formed between sides of adjacent armour elements in the panel. A bond line is a layer of material between sides of adjacent armour elements. In this embodiment the panel may additionally be formed of material other than Super Bainite Steel.
- [0019] In the embodiment described in the preceding paragraph rectangular or hexagonally shaped elements are convenient. For ease of manufacture with hexagonal elements joined by bridges, it has been found that the bridges are best placed at the angles

formed between the lateral sides

[0020] The bridges create space for a controlled uniform bond line between the elements, equivalent to the width of the bridges. A bond line formed between the elements limits energy transfer from one element to adjacent elements by providing a means for energy absorption. Known armours do not have bond line achieved by the use of elements with bridges. In this embodiment, because of the reduction in energy transfer between elements, there is a high probability that armour elements in the panel remain intact and adjacent armour elements remain bonded to a backing plate. The shock absorbing properties of a panel made in accordance with this invention has the advantage that a plate or film of synthetic material for shock absorbing does not have to be added separately, as in, for example **GB 2149482 A** (HARRY) 12/06/1985 .

[0021] This invention has the further advantage that the bridges ensure that adjacent elements are evenly separated, thus there is no requirement for independent spacing means between each element. The bond line thus formed facilitates in-plane infusion of bond line material and allows it to be distributed evenly between the elements without any voids.

[0022] In a further embodiment, the invention the elements are hexagonal incorporating a lug on each side of such hexagonal elements. When the armour element is rotated 60° through the axis of symmetry of the hexagonal transverse cross section of the armour element, the position of the bridges on the armour element is substantially the same. In this form the elements are configured to tessellate. The hexagonal symmetry of the elements means that elements can be fitted into a frame with minimal effort required for proper orientation to ensure tessellation.

[0023] A method of manufacture of armour according to the invention includes the steps of:

[0024] cooling sufficiently a steel sufficiently quickly to avoid the formation of pearlite from a temperature above its austenitic transition temperature to a temperature above its martensite start temperature but below the bainite start temperature;

- holding the steel at a temperature within that range for a sufficiently long period to transform it to Super Bainite Steel;
- cutting the steel to form armour comprising a plurality of elements.

[0025] The cutting may be by laser or water-jet or other appropriate means.

[0026] In a still further aspect of the invention a method of manufacturing armour comprises:

- initially cooling a steel having 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 into a fully pearlite state;
- forming the steel into a plurality of elements;

- reheating the steel to a fully austenitic state;
- cooling sufficiently quickly to avoid the formation of pearlite from a temperature above its austenitic transition temperature to a temperature above its martensite start temperature but below the bainite start temperature;
- holding the steel at a temperature within that range for a sufficiently long period to transform it to Super Bainite Steel.

[0027] The steel may be reheated into an austenite form and cooled to a pearlite form on one or more occasions prior to forming into a plurality of elements. Likewise it may be annealed in the pearlite form prior to formation of the elements.

[0028] In para [0026] elements may be formed by stamping, laser or water-jet cutting, or other suitable cutting means.

[0029] If the armour steel is to have holes or slots these can also be formed while the steel is in a pearlite state. Cutting elements, holes and slots is substantially easier and quicker when carried out while the steel is in a pearlite form than when the steel is transformed to its final super bainite condition. The significant advantage of using Super Bainite Steel rather than other hard steels to manufacture armour elements is the possibility of forming an intermediate pearlite condition wherein the steel is much more easily worked than in its final transformed condition.

[0030] In another aspect of the invention, a method of manufacture of armour according to the invention includes the step of hot forging billets of steel into armour elements whilst at temperature above its austenitic transition temperature.

[0031] In all these processes greatest hardness is achieved if the manganese content of the steel is about 1% by weight. It is to be understood that 'about' in this context means + or - 10%.

[0032] For practical purposes the maximum temperature at which transformation takes place in this invention is 300°C or less, but preferably it is in the range 190°C to 260°C.

[0033] The invention will now be described in more detail with reference to the accompanying drawings in which:

[0034] Figure 1 shows an perspective view of Super Bainite Steel armour element shaped as shown in WO2006/103431 but made by forging in accordance with the present invention;

[0035] Figure 2 is a diagram of an array of hexagonal elements as shown in figure 1;

[0036] Figure 2a is a diagram of detail of a section of the array of figure 2 showing the co-operation of two elements;

[0037] Figure 3 is a cut away view of the interior of an armour panel utilising the elements shown in figures 1 and 2;

[0038] Figure 4 shows a portion of a of a Super Bainite Steel armour according to the present invention, in plan;

- [0039] Figure 5, is a perspective view of a Super Bainite Steel hexagonally shaped armour element with bridges to the next elements;
- [0040] Figure 6 is a plan view of a number of elements of the kind shown in figure 5 comprising part of an armour panel in accordance with the present invention;
- [0041] Figure 7 is a cut away view of the interior of an armour panel utilising the elements shown in figures 5 and 6;
- [0042] Figure 8 illustrates an armour manufacturing process used in conjunction with the present invention;
- [0043] Figure 9 illustrates an alternative armour manufacturing process used in conjunction with the present invention;
- [0044] Figure 10 shows a temperature/time/transformation diagram for a preferred steel according to the invention showing the impact of varying the manganese content; it should be noted that precise diagrams will vary according to the composition of the steel;
- [0045] Figure 11 shows a temperature/time/transformation diagram for a preferred steel according to the invention having 1% manganese showing the impact of varying the carbon content; it should be noted that precise diagrams will vary according to the exact composition of the steel; and
- [0046] Figure 12 shows a temperature/time/transformation diagram for a Super Bainite Steel used in connection with the invention and having 1% manganese showing the impact of varying the chromium content. It should be noted that precise diagrams will vary according to the exact composition of the steel.
- [0047] In figure 1 a Super Bainite Steel element 10 is of the form of a tile which is hexagonal in shape when looking at the element in the direction indicated by Z. Element 10 has lugs 12, 14, 16, 18, 20, 22 on each of its sides. The element has a flat lower face 24 and a convex upper face 26. The convex upper face 26 will dissipate energy from initial impact of a projectile thereon over a greater area than if the element had a flat upper face.
- [0048] Figure 2 shows an array of hexagonal Super Bainite Steel elements including an element 10 as shown in figure 1 and identical adjacent elements 100, 110, 120, 140, 150. The hexagonal array is arranged such that the lugs 12, 14, 16, 18, 20, 22 on element 10 separate element 10 from adjacent elements 100, 110, 120, 130, 140, 150. Lugs 101, 111, 121, 131, 141, 151, on adjacent these elements 100, 110, 120, 130, 140, 150 are arranged to be on the opposing half of the sides of these elements 100, 110, 120, 130, 140, 150, when compared with element 10. There is a continuous space 48 in the entire array of hexagonal elements between the sides of the elements allowing for adhesive flow and ingress and formation of a layer of adhesive between the sides of elements.

- [0049] Figure 2a shows a detail of a section of the array of hexagonal elements showing the co-operation of two elements. Here the line X through the centre of the sides 11 and 21 defines the left-hand halves and the right-hand halves of the sides 11 and 21. From the perspective of element 10, element 10 has a lug 14 on the right-hand half of the side 11 separating side 11 from the opposing lugless left-hand half of the side 21 of adjacent element 100. From the perspective of the element 100, element 100 has a lug 101 on the right-hand half of side 21 separating it from the opposing lugless left-hand half of the side 11 of element 10.
- [0050] A number of Super Bainite Steel elements are assembled to co-operate as in Figure 2a to form an entire panel in a close packed hexagonal array as in Figure 2. A confinement frame 32 is used to keep the individual elements in position while being assembled as described in figure 3. A bond line 48 is formed between the elements. The confinement frame 32 is removed after fabrication.
- [0051] Figure 3 shows a cut away view of the interior of the armour panel of Figure 2. The panel consists of a backing plate 60 with elements 100 and 110 etc adhered on their lower surfaces (24 in figure 1) to the backing plate 60 by a layer of adhesive 52. In this example the backing plate material is GFRP (glass fibre reinforced plastic). Bond line material adhesive 62 fills the bond line 48 between elements 100, 110 etc., Bond line material 62 may be the same as adhesive 52 or an alternative may be used. In practice it has been found that elastomeric material made from recycled vehicle tyres makes an ideal bond line material. When set, the panel (with the confinement frame 32 removed) is encapsulated in further adhesive 52 which bonds an aramid and/or glass reinforced fibre layer 64 to elements 100, 110 etc. on their upper surfaces (26 in figure 1)
- [0052] A standard panel as described above contains fixing points to fix the panel to the article to be protected. Panels are assembled to include fixing elements (not shown). Fixing elements are essentially modified steel hexagons having the same dimensions as a Super Bainite Steel element, adapted to facilitate a bolt and adapted to enable lugs of adjacent elements to co-operate with the fixing element. Fixing elements are incorporated into the panel at any position, the position being determined prior to assembly of the panels. The panel will normally be mounted such the lower surfaces of the elements during assembly (24 in figure 1) face toward the object to be protected, and the upper surfaces during assembly (26 in figure 1) face away from the object to be protected towards potential incoming projectiles.
- [0053] Hot forging is an ideal way to produce individual the individual Super Bainite lugged tiles shown in figures 1 to 3. It is a well established process used extensively in the automobile industry and offers the advantage that forged parts are normally stronger than either cast or machined parts as the metal is pounded into shape, where it creates a grain flow that follows the component shape which results in a stronger part. Advant-

ageously for a hot forged component the steel is heated to at least 900°C, into its austenite form prior to forging (see para [0064]). The armour tile thus formed could be cooled and fed directly into an oven held at between 190 °C and 260 °C to transform them from austenite into Super Bainite Steel. Other means of holding the steel within the required temperature range for the transformation will be clear to those skilled in the field.

[0054] In figure 4 an armour sheet 200 is shown comprising a plurality of rectangular Super Bainite elements 212.

[0055] Each element is supported in a fret-like construction by retaining uncut portions between them to form bridges 216. The thickness of the elements may typically be between 6 and 8mm, but there is no reason why thicker or thinner elements to suit the particular application should not be made. The processing times and parameters to make the Super Bainite Steel are adapted to suit following the principles described below. Stamping or drilling is carried out when the sheet is in a pearlite form as described in figure 8, laser or water-jet cutting can be carried out while the sheet 210 is in pearlite form or by laser or water-jet cutting after it has been transformed to Super Bainite Steel as described in either figures 8 or 9. Stamping, laser and water-jet cutting are well known processes in the metal working industry and do not require further explanation here.

[0056] Optionally, the elements may have holes 214 cut through, this again may be done by stamping or drilling when the sheet is in a pearlite form as discussed with reference to figure 8, or by laser or water-jet cutting carried out while the sheet is in pearlite form or after it has been transformed to Super Bainite Steel as described in either figures 8 or 9. The space created between the elements forms a bond line 248, which can be filled with an elastomer in the same way as described with reference to figure 3.

[0057] Alternatively the holes 214 may be replaced by slots.

[0058] Figure 5 shows a Super Bainite Steel armour element 310 of hexagonal cross-sectional shape when looking at the element in the direction indicated by X; the element is part of an armour panel. The armour element 310 has bridges 312, 314, 316, 318, 320, 322 at the angles of each side to join element 310 to adjacent elements (not shown in figure 5). The bridges are at the corners of the sides rather than at intermediate points along the sides as cutting the elements out with the bridges in this position is easier. The element has flat lower and upper faces 324 and 326.

[0059] Figure 6 shows an array of hexagonal armour elements of the kind described with reference to figure 5 including element 310 and identical elements 410, 420, 430, 440, 450, 460. These elements all form part of an armour panel. The array is arranged such that the bridges 312, 314, 316, 318, 320, 322 on element 310 join it to adjacent elements 410, 420, 430, 440, 450, 460. There are spaces between the sides of the

elements forming bond lines 348, allowing for ingress of an elastomeric bond material, such as adhesive, or material from recycled tyres.

[0060] The elements shown in figures 5 and 6 may have one or more holes between the lower and upper faces 324 and 326 respectively. These holes are formed in the element at the time of the manufacture of the armour panel. Figure 7 shows a cut away view of the interior of the armour panel of figures 5 and 6. The panel consists of a backing plate 360 with armour elements 310 and 410 adhered to the backing plate 360 by a layer of adhesive 352. The backing plate material is GFRP (glass fibre reinforced plastic). The material 352 used to bond the armour to the backing plate 360 and the material poured over the Super Bainite Steel elements 310, 410, to ingress into bond lines 348 can be the same or different, as described previously with reference to figure 3. An example of suitable adhesive for the purposes of panel assembly would be toughened epoxy or toughened epoxy resin. Rubberised material 362 recovered from recycled automobile tyres is a very suitable material with which to fill the bond lines 348. When set, the array is encapsulated in further adhesive 352 which bonds an aramid and/or glass reinforced fibre layer 364 to elements 310, 410 etc. The panel will normally be mounted such the lower surfaces of the elements during assembly (324 in figure 5) face toward the object to be protected, and the upper surfaces during assembly (326 in figure 5) face away from the object to be protected towards potential incoming projectiles.

[0061] The armour panels described in figures 4 to 7 have fixing elements (not shown) to fix the panel or array to an article to be protected. Fixing elements are elements as described but having a hole to receive a bolt. Fixing elements are incorporated into the panel at any position as convenient.

[0062] Figure 8 illustrates a manufacturing process for an armour panel of the present invention. Typically, in the production process steel having the required composition 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, 6 to 8mm thick and coiled. Obviously the thickness can be greater or less than the range given to suit the end customer's 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 and before allowing it to cool to ambient temperature. Once back to ambient temperature, room temperature in this example, (RT in

Figure 8), the elements can be stamped or cut from the plate. Any bridges portions between elements are formed as part of the stamping or cutting process, at this stage. If holes and/or slots are required in the elements, these can be stamped or drilled at this stage. The steel then undergoes the final austenitisation 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 transformed in 8 hours.

[0063] It is preferred that the bainite transformation temperature is 260°C or less; the transformation temperature must be above the martensite start temperature. However, transformation temperatures up to 300°C may be used with steels having manganese content towards the lower end of the range specified (below about 0.7% by weight), or with very low carbon content (less than 0.7% by weight). However, it has been found that Super Bainite Steels made in this way have a lower hardness and may be less desirable for the purpose described in this invention.

[0064] In figure 9, the steel used to make the elements is hot rolled whilst in an austenitic phase, either immediately after casting from a hot melt or possibly after heating into the austenite phase for homogenisation or deformation. The rolled steel is then be cut into plates and air cooled. The rate of cooling is such that the plates will reach the transformation temperature at an appropriate point to allow transformation to Super Bainite Steel to occur. This can take place in a temperature controlled air recirculation furnace or other suitable environment. In this instance there is no intermediate pearlite phase, but with modern laser or water-jet cutting techniques the elements can be cut from the final Super Bainite Steel sheet, to form the structures shown in figures 1 to 7. If cutting is in a sheet of transformed Super Bainite Steel, water-jet cutting may be preferred for most application as this does not alter the phase of the steel at or near the cut. If laser-jet cutting is used, the heat generate near the cut may raise the temperature of the steel in that area sufficiently to soften it, however, for some armour applications this may have an advantage as bridges may be more ductile than the elements themselves and help absorb shock energy on one element without it being passed to the next.

[0065] For most applications, it is preferred that the bridges be retained between elements as shown in figures 4 to 7, but alternatively elements having lugs may be formed, and subsequently assembled into armour panels as shown in figure 3. For this latter situation, an alternative manufacturing process is preferred, following generally the

cycle shown in figure 9. In this process billets of steel are heated to above their austenite transformation temperature and hot forged to the required shape, and then cooled sufficiently quickly to avoid transformation to pearlite to a temperature above the martensite start temperature but below 260°C and transformed in the same way as described with reference to figure 9 to Super Bainite Steel.

- [0066] Where the elements are of particularly thick plate, say more than 100mm thick, the final transformation may be carried out by reducing the temperature from the austenite phase to a temperature just above the bainite transformation temperature and holding the plate at that temperature to ensure that it is uniform throughout the plate before lowering the temperature to one below the maximum bainite transformation temperature to allow final transformation to occur. If this is not done there is a risk that the plate will not transform throughout to Super Bainite.
- [0067] The temperature/time/transformation diagram for Super Bainite steel used for armour according to the invention showing the effect of varying the manganese content is shown in figure 10.
- [0068] The final transformation from austenite to bainite is shown for thin plate (typically 6 to 8 mm) thick by curve 2. Here individual plates are air cooled, by separation of the plates; the cooling rate is typically 80°C/min for example. This avoids transformation to pearlite. If necessary the cooling rate should be controlled accordingly. The bainite transition for 0.5% by weight manganese is shown by the line 10, for 1.0% by weight manganese by line 612, and for 1.5% by weight manganese by line 614. Quenching will convert the material to martensite, the martensite start temperatures are shown by lines 620, 622 and 624 for 0.5%, 1.0% and 1.5% by weight manganese respectively. Failure to maintain the transformation temperature within the range indicated by curves 610, 612 or 614 as appropriate for adequate periods may risk partial transformation to martensite. The curves 630 (for 0.5% by weight manganese), 632 (for 1% by weight manganese) and 634 (for 1.5% by weight manganese) indicate transformation to pearlite which is to be avoided in the final transformation stage of the process. The bainite start temperature is the temperature above which bainite will not form. In figure 10, for bainite curves 610, 612 and 614 the bainite start temperature is represented by the flat uppermost portions of each curve.
- [0069] As the thickness of the plate increases, the greater the chance of the slower cooling at the centre of the plate allowing a partial pearlite phase to form at the centre and a less homogeneous structure is obtained. This can be avoided by following a cooling curve such as that marked 3, which is for a 1% by weight manganese steel in accordance with invention. In this case the temperature is reduced to one marked 4A just above the bainite transition start temperature 612 and held just above that transition temperature until the temperature within the plate is uniform. At that point (4B) the temperature is

reduced to a point 5 within the transformation range and held within that range to allow the transformation to bainite to take place.

[0070] In figure 11 the bainite temperature/time/transition curves for 0.6% by weight carbon is shown by the line 660, for 0.7% by weight carbon by line 662, and for 0.8% by weight carbon by line 664. Quenching will convert the material to martensite. The transition temperatures are shown by lines 650, 652 and 654 for 0.6%, 0.7% and 0.8% by weight carbon respectively. Similarly failure to maintain the transformation temperature within the range indicated by curves 660, 662, or 664 as appropriate for adequate periods will risk partial transformation to martensite. Curves 670, 672 and 674 show the pearlite transitions for carbon contents of 0.6%, 0.7% and 0.8% by weight respectively. The bainite start temperature is the temperature above bainite will not form. In figure 11, in curves 660, 662 and 664, the bainite start temperature is represented by the flat uppermost portions of each curve.

[0071] Figure 12 similarly shows the bainite temperature/time/transition curves for 0.5% by weight chromium (line 690), for 1.0% by weight chromium (line 692), and 1.5% by weight chromium (line 694). Quenching will convert the material to martensite the transition temperatures are shown by lines 680, 682 and 684 for 0.5%, 1.0% and 1.5 by weight chromium respectively. Failure to maintain the transformation temperature within the range indicates by curves 690, 692, or 694 as appropriate for adequate periods will risk partial transformation to martensite. Curves 700, 702 and 704 show the pearlite transitions for chromium contents of 0.5%, 1.0% and 1.5% by weight respectively. The bainite start temperature is the temperature above bainite will not form. In figure 12, for bainite curves, 690, 692 and 694 the bainite start temperature is represented by the flat uppermost portions of each curve.

Claims

- [0001] Armour characterised in that it comprises a plurality of elements of Super Bainite Steel.
- [0002] Armour according to claim 1 characterised in that the Super Bainite Steel comprises 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%; sufficient silicon and or aluminium to render the bainite substantially carbide free; and the balance iron save for incidental impurities.
- [0003] Armour according to claim 2 characterised in that the Super Bainite Steel includes silicon in the range about 0.5% by weight to about 2% by weight, and no aluminium.
- [0004] Armour according to claim 2 or 3 characterised in that the manganese content of the Super Bainite Steel is in range of about 0.5% by weight to 1.5% by weight.
- [0005] Armour according to any one of claims 2 to 4 characterised in that the chromium content of the Super Bainite Steel is in the range of about 1.0% by weight to 1.5% by weight.
- [0006] Armour according to any one of claims 4 to 7 claim characterised in that the molybdenum content of the Super Bainite Steel is in the range of about 0.2% by weight to 0.5% by weight.
- [0007] Armour according to any one of claims 4 to 8 characterised in that the vanadium content of the Super Bainite Steel is in the range of about 0.1% by weight to 0.2% by weight.
- [0008] Armour according to any one of claims 2 to 5 characterised in that the manganese content of the Super Bainite Steel is about 1% by weight.
- [0009] Armour according to any preceding claim having an average bainite platelet thickness of the Super Bainite Steel is below 40nm.
- [0010] Armour according to any preceding claim characterised in that one or more elements has one or more holes therethrough.
- [0011] Armour according to claim 10 characterised in that the holes comprise slots.
- [0012] Armour according to any preceding claim having one or more bridges between adjacent elements.
- [0013] Armour according to claim 12 characterised in that the sides of elements are uniform spaced apart and a bond line is formed between the sides of the adjacent armour elements.
- [0014] Armour according to claim 12 or 13 characterised in that the bridges are at corners formed between adjacent sides of elements.
- [0015] Armour according to claim 12, 13 or 14 characterised in that in which the

- elements comprise a fret like structure.
- [0016] Armour as claimed according to any preceding claim characterised in that the elements are hexagonal.
- [0017] Armour according to any one of claims 1 to 11 characterised in an element has a lug on a side said lug separating said side from the side of an adjacent element.
- [0018] Armour as claimed in claim 17 characterised in that the elements have a lug on each of their sides.
- [0019] Armour as claimed in claim 18 characterised in that the lugs on each side of a first element are entirely on one hand (left or right) of the sides of the first element, the lugs on adjacent sides of a second element are entirely on the opposing hand of the sides of said second element when compared to the first element.
- [0020] Armour as claimed in claim 19 characterised in that the in that the lugs on each side of a first element are entirely on one hand of the sides of the said first element, the lugs on the sides of an adjacent second element are entirely on the opposing hand of the sides of said second element when compared to the first element and when the first element is rotated 60° about an axis of symmetry the position of the lugs on said first element in relation to the second element is substantially the same.
- [0021] Armour according to any one of the previous claims characterised in that an elastomeric materials encapsulates the elements.
- [0022] Armour according to claim 21 characterised in having a bond line between adjacent elements filled with , at least in part, recycled material from vehicle tyres.
- [0023] Armour according to any preceding claim characterised in that individual elements are disposed between two layers.
- [0024] Armour according to any preceding claim characterised in that one surface of the elements is convex surface.
- [0025] A method of manufacture of armour characterised in that it includes the steps of forming austenite steel having a composition according to any one of claims 2 to 7, cooling the steel sufficiently quickly to avoid the formation of pearlite to a temperature above its martensite start temperature but below the bainite start temperature and holding the steel with that temperature range for up to a week to transform to Super Bainite.
- [0026] A method of manufacture of armour according to claim 25 characterised in that it additionally includes the step of cutting individual elements.
- [0027] A method of manufacture of armour according to claim 26 characterised in that it additionally includes the step of forming a sheet of pearlite steel prior to trans-

formation to Super Bainite and cutting said pearlite sheet to form armour elements.

- [0028] A method of manufacture of armour according to any one of claims 26 or 27 characterised in that it includes the step of forming bridges between the elements.
- [0029] A method of manufacture of armour according to claim 28 characterised in that it additionally includes the step of rendering said bridges more ductile than the elements.
- [0030] A method of manufacture of armour according to claim 26 characterised in that it includes the step of raising the temperature of the sheet sufficiently to austenitise it and transforming from austenitized sheet to Super Bainite Steel.
- [0031] A method of manufacture of an armour according to any one of claims 25 to 30 characterised in that it additionally includes the step of the formation of one or more holes or slots in one or a plurality of elements.
- [0032] A method of manufacture of an armour according to claim 25 characterised in that armour elements are hot forged when the steel is austenitic.

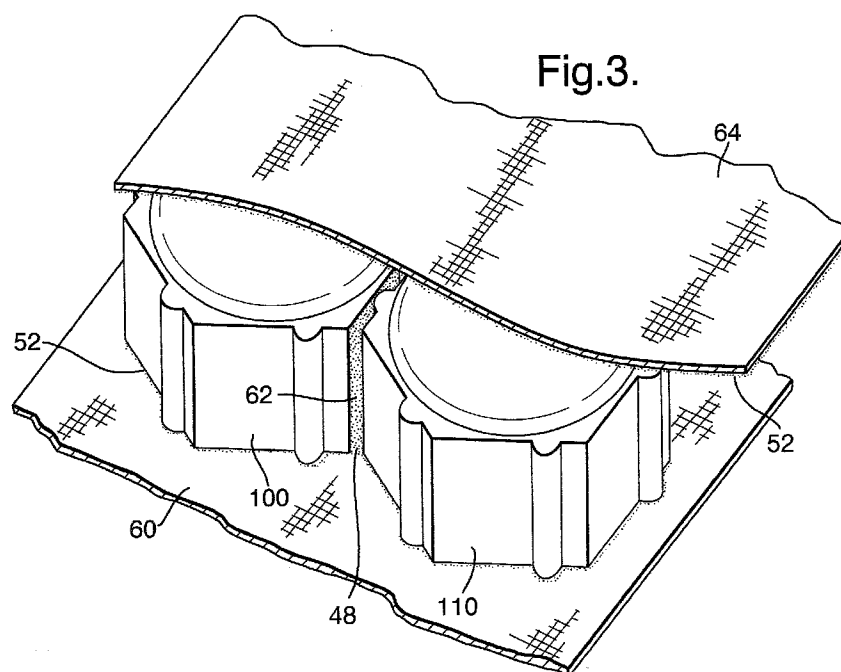
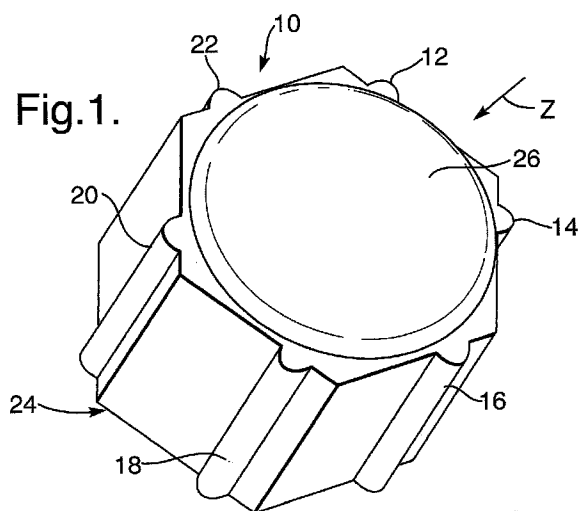


Fig.2.

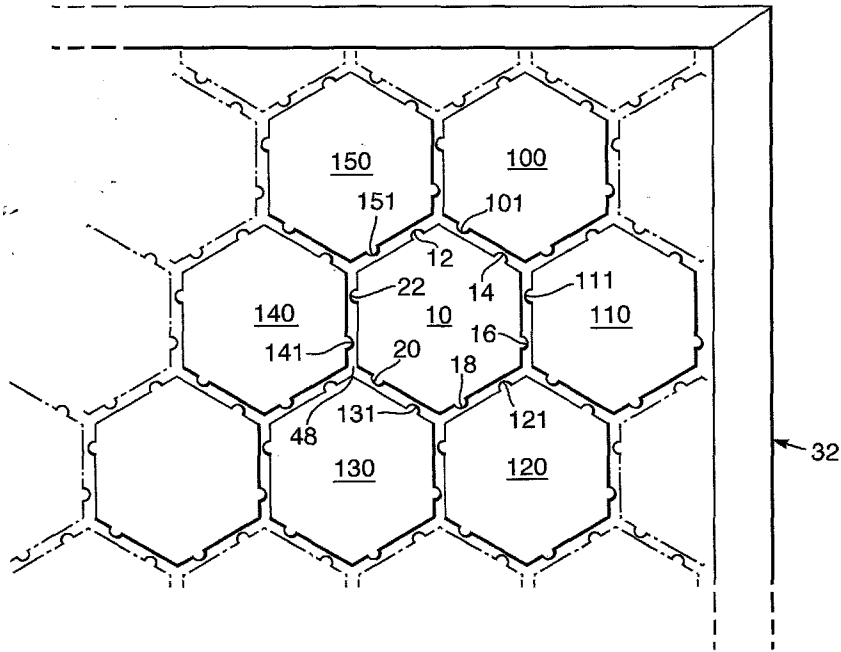


Fig.2a.

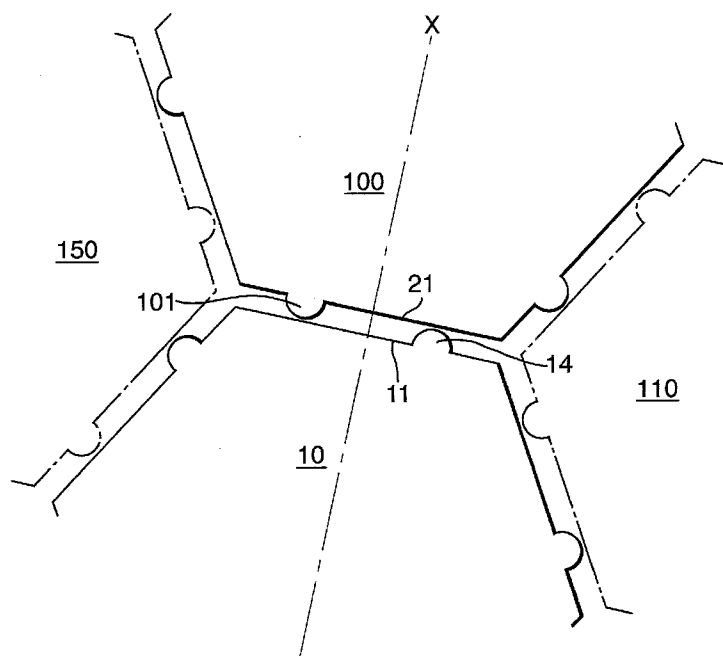
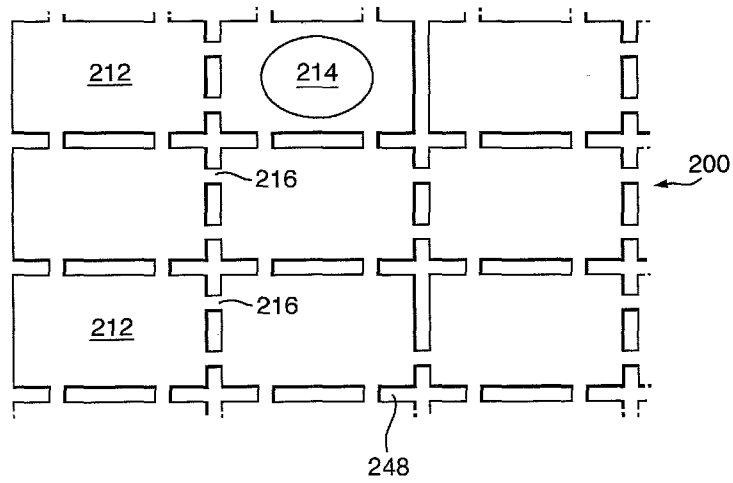


Fig.4.



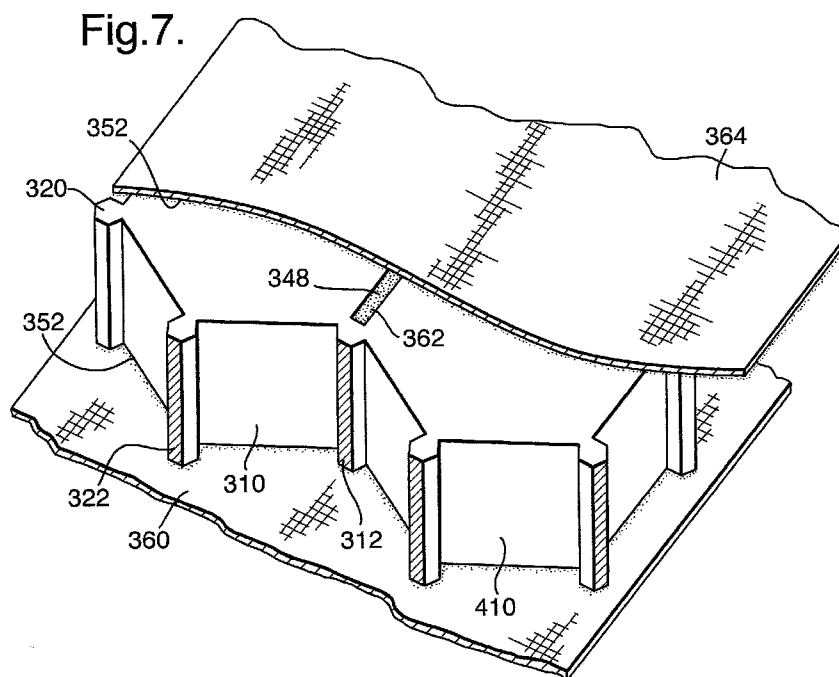
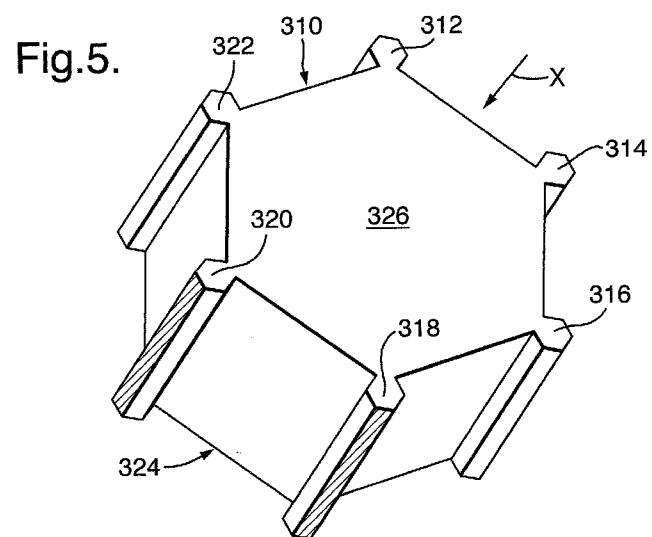


Fig.6.

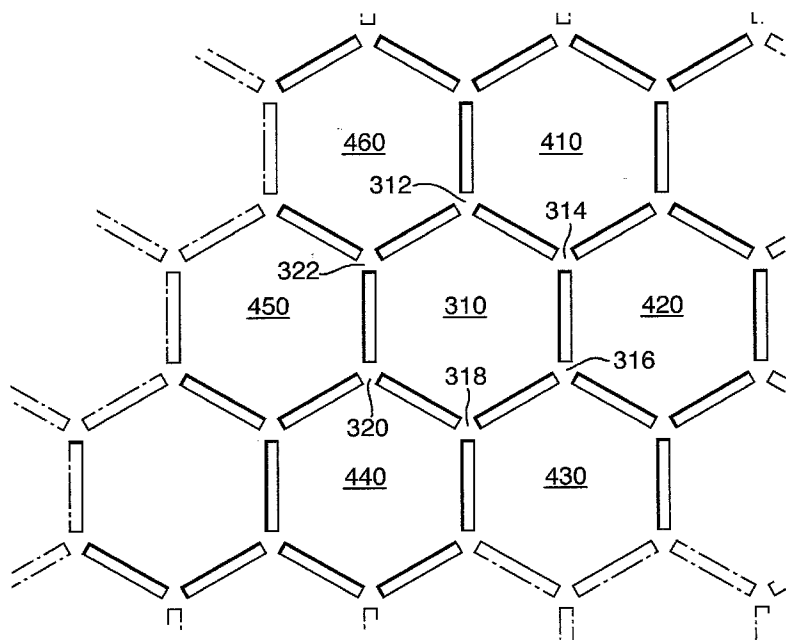


Fig.8.

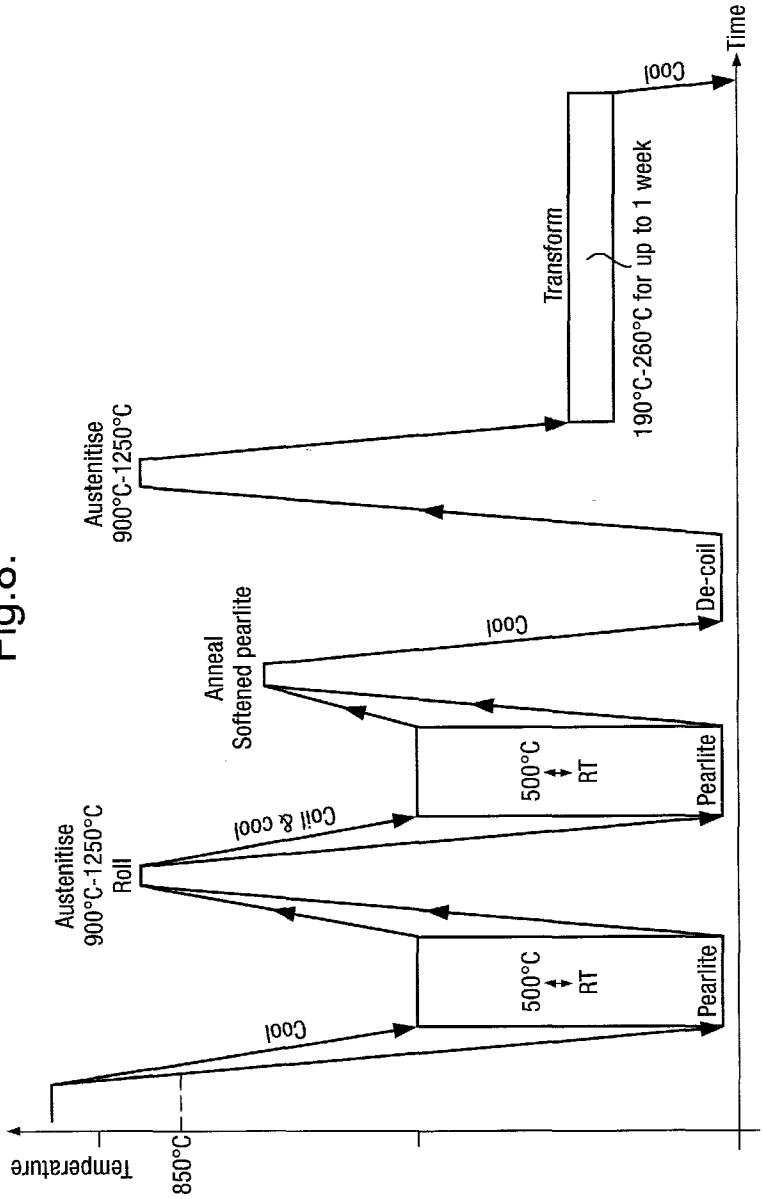


Fig.9.

