FLEXIBLE PROTECTIVE ARMOUR MATERIAL AND METHOD OF MAKING SAME

Louis E. Gates, Jr., Inglewood, Calif., assignor to Hughes Aircraft Company, Culver City, Calif.
Filed Dec. 22, 1967, Ser. No. 692,852

Int. Cl. B32b 5/16
U.S. Cl. 161—43

9 Claims

ABSTRACT OF THE DISCLOSURE

The disclosure herein pertains to protective dilatant fluid insulation material or flexible fluid dilatant armor material for insulation and protection of personnel and equipment from intense sound rays, heat, light, and high velocity projectile impact. Such protective material comprises a relatively fluid material and suspended medium therein resistant to radiant energy or particle (shrapnel and bullet) penetration.

This invention relates to fluid armor material and preferably relatively flexible insulation and armor material for the protection of personnel and equipment. More particularly, the invention relates to encapsulation of small particulate materials suspended in a fluid, and to flexible compositions which show dilatant behavior when subjected to the high velocity impact of shell and shrapnel. The property of dilatancy of fluid suspensions is very often known to be a detriment in industry and particularly to be avoided. It is with the useful application thereof with which the present invention is concerned.

Two major material characteristics are required to stop bullets and shrapnel. Material must absorb the kinetic energy of the projectile and it must distribute the energy over the widest possible area with the least amount of damage to the material and to the object to be protected. Hereinafore, it has been the practice to utilize thick, heavy plates of metal or ceramic material, or sand bags, and the like in front of the object to be protected. It will be recognized how unsatisfactory such protection is when used as wearing apparel or for other uses where weight is a problem.

Accordingly, it is an object of this invention to provide an improvement in lightweight protective armor and particularly in the method for providing lightweight flexible protective armor material for the protection of personnel and equipment.

Another object of this invention is to provide for improved encapsulation of flexible protection armor material with dilatant fluid-like suspensions of energy-absorbing fine particulates in a highly packed and discontinuous phase therein.

Another object of this invention is to provide lightweight insulating structural arrangement resistant to penetration by sound, radiation and the energy of projectile penetration in clothing, block, sheet, strip or tape form, including laminations thereof and any of the like forms which can serve as lightweight personnel and equipment protective inclosure mediums.

An essential object of this invention is to provide a method for making use of a substantially fluid mixture of particulate material having the property of dilatancy upon high shear rate impact as portable insulation and protective armor or armor for personal and equipment.

Further objects and advantages will be apparent from the following non-limiting description of the invention in conjunction with the drawings wherein:

FIG. 1 is an open-end wide view illustrative of the containment of dilatant material in thin cross-section of block, sheet, film or tape form;

FIG. 2 is an isometric view in side and end cross-section of a flexible cellular protective section of structure of a character as embodied herein;

FIG. 3 is an open-end view isometrically illustrative of a multiple panel armor structure adapted to contain multiple dilatant mixtures, as embodied herein;

FIG. 4 is an isometric view of laminated structure modifying FIG. 1 and FIG. 3.

While I do not wish to be limited by theory or any explanations, the following conjectures are illustrative of mechanisms of action. The basic described compositions in encapsment form, as provided, are applicable to the control of acoustic wave propagation by impedance mismatching mechanism. The description is also illustrated by a technique of attrition of projectiles with dilatant material or dilatant mixtures.

For personnel armor, it is primarily required that the dilatant mixture and particularly combined dilatant constituents be energy absorbant, non-toxic, and yield non-toxic decomposition products when struck and heated by the impact of hot projectiles. Where mask protection is provided or non-personnel contact protection is possible, other or even somewhat potentially toxic mixtures may be used. In either case, a portable encapsulation of the particulates is preferred with the combined fluid (carrier) and the particulates in discontinuous phase. Such condition is provided by particulate solids in combination with a liquid or combination of liquids, elastomer or soft flexible plastic such as a lightly cross-linked or vulcanized elastomer, or flexible plastic, which normally appear relatively stationary or as a very viscous fluid at rest. When serving as a carrier, such composition, containing a high content of fine particulates, as described, behaves as a solid under high viscosity pressure converting the kinetic energy of impact into thermal energy.

The preferred continuous phase medium of the dilatant mixture or composition must possess the desired physical properties such as high boiling point, viscosity that is relatively insensitive to temperature, and a dipole moment that may be greater than 1.5, Delby units.

As indicated, the suspending medium is preferably a fluid but may be an elastomer or soft plastic matrix such as polyethylene, vinyl resin, polybutadiene, or polydi-methylsiloxane or mixtures thereof and the like. The dipolar fluid may be ethylbromomcaetate, polyethylene glycol, glycercine, glycerine and water, perfluorocarbons, fluorododebenzene, and the like, mixtures thereof, with the fluid material preferably having a specific gravity nearly identical to the particulate material suspended therein.

The nature and reasons for dilatancy are not fully known or understood and the compositions may vary for different stress purposes; for example, under proper conditions, other organic and inorganic compounds and compositions may be used as the permanent suspending medium for the particulate material. For example, such other carriers as very low non-flammable fluid materials as esters, amine, amides, nonflammable hydrocarbons, silicone oils, silanes, suitable oils, and organic and inorganic fluids which provide with the particulate material, dilatant properties under conditions of high stress or high shear rates, may be utilized. The particulate material may be powdered ceramic or otherwise powdered silica, mica, vermiculite, quartz, and other powdered silicate or powdered crystalline vitreous mineral as borosilicates of aluminum of the tourmaline group, the garnet group, leucite group, and other group of titanium dioxide, clay, alumina, zirconia, and the like, or dilatant mixtures thereof, in small particulate form. Included here-with are such dilatant fluid particle suspension as sometimes occurs in mixing paints and in plastics fabrication.
wherein catastrophic galling and wreckage of mixing machinery occurs. Also, there may be mixed therein natural or synthetic fibers which in admixture with a thick fluid or plastic serves to increase shear strength and to block small openings and prolong, prevent or delay the escape of the dilatant mixture therethrough.

The instant mixture is a multiple permanent suspension of a high concentration of powdered particles obtained by combining fluid material and particles with nearly identical specific gravities. For example, as herein described, the silica powder material can be suspended in glycerine and water, ethyl tribromonitate (2.2 g./c.c.) or fibers in mixtures (1.925 in c.c.) or a diluent mixture of particulate solids and fluent carrier material.

The fluent material preferably has a specific gravity approximately the same as the particle material, to provide for the prevention of projectile penetration.

I may alternatively desire to encase other portable flexible dilatant fluid mixtures of the fine particulates in a dry or wet state, in thin portable flexible film forms, as described and illustrated, or in alternately laminated and multiple layer forms having a multiple dilatant property under conditions or high stress and shear forces. In such instances, I may desire to use water or other liquid or semi-solid as the fluid medium. In such instances, the dilant mixture is relatively packed with a solid powdered particle content, and is similarly adapted as a protective portion of flexible wearing apparel, or for lining of airplane cockpits and other flexible lining or encasement protective measures. As contemplated herein, the dilant mixtures suitably encased in flexible articles of apparel, or made up into articles of apparel, provide increased measures of protection to life and limb.

To provide the dilatant property, the bulk density of a dilatant composition is prepared very close to maximum theoretical packing density of the powder material which is preferably in the form of substantially uniform diameter approximately spherical particles comprising the bulk of solids content, with or without smaller diameter particles filling interstices between the larger particles.

Closely packed spheres in a relatively disperse particulate phase exhibit the highest dilancy, with the property of moving in the carrier in point to point contact with other particulate material when subjected to the energy of an impact force. For example, when the suspension consists on the order of 300 mesh particulate material in a close packing ratio, then the total interface area in 1 cc. of mixture becomes about 580 sq. cm., as is provided, for illustration, in the following illustrative dilatant mixtures. The utilized herein, the particle size may range from colloidal to nominally 100 mesh.

In making effective use of the particulate suspension armor material, different characteristics of energy absorption and distribution can be achieved by varying fluid viscosity (within limits of formability and dilatant behavior), varying average particle size, particle size distribution, particle density and fluid-particle ratio. Greater assurance of protection is preferably provided by utilizing a plurality of relatively thin layers of dilatant mixtures with the same or different properties to augment energy dissipation. For example, in personal armor as in protective clothing or in padding, wrapping, shielding, or encasing equipment, as oil lines, gas tanks, etc., with sheet, pad, strip and tape forms, laminated or overlapping layers of the dilatant mixtures, as embodied herein, can be provided. For example, two or more films of dilatant non-shattering, or liquid-filled alternate mixtures thereof and of the same or different dilatant properties, as embodied herein, provide beneficial armor.

With reference to the drawings, for example, there is illustrated in FIG. 1 a use of a multiple suspension of dilatant particles in dilatant mixtures. Herein, is provided a protective dilatant strip material in multiple layer or laminate form in container package 10 having an exposed side wall 11 of fluid-tight flexible strip or sheet material subject to projectile penetration. As illustrated, the package or container 10 can be provided as a U-shaped flexible strip having a front wall 11 and enclosure back wall 12 with an inner spacer wall 13. The side walls 14 and 15 are provided as molded portions integral with wall 11 and having into turned edges 16 and 17 respectively, each of which the backing 12 is adapted to be inserted and held in place. This strip material 10, for personnel protection, is preferably a high strength, reinforced flexible material, as fiberglass or cloth fabric impregnated with a resins mixture of polystyrene, otherwise polybutadiene, vinyl resin, plasticized styrene, or the like. For projectile protection, the sheet material can be reinforced aluminum foil or other thin high strength flexible metal sheet material. Behind the exposed side 11 and in spaced relationship therewith is the backside wall 12 preferably of heavy or thick flexible plastic or flexible strong heavy woven fluid-tight elastomer impregnated fabric serving as a shield to prevent particle penetration and absorb a part of the dissipated energy, as of a projectile which may enter wall 11. The spacing between the front wall 11 and the back wall 12 may be provided with one or more strong thin divider spacer walls 13 forming two or more compartments between the outer walls 11 and 12. Enclosure caps (not shown) are provided to fit over and seal the ends of the walls 11, 14, 15 and backing 12. As will now be self-evident, various encasement cover the plurality of films or laminations thereof of can be provided, including laminating independently prefabricated or encased flexible film packs, or providing a single flexible dilatant film thickness on the order of a transportable film of from a few centimeters to a few inches thick. Single and multiple dilatant films in hunting apparel, used to line airplane cockpits and encasement wrapping of oil lines, gas tanks, and the like subject to damage by high velocity projectiles and shrapnel, provide useful protective measures.

Within the compartments, as illustrated, there is placed a viscous, flexible, fluent dilatant composition, as contemplated herein and illustrated by the mixtures of finely powdered silica and glycerine. This type dilatant mixture is not literally a fluid, as such, but when encased in flexible film form, has been discovered to be capable of stopping high velocity projectiles within a short distance. The same and other suspension compositions as herein contemplated are also highly effective in absorbing sound, radiation, cutting off the intensity of light rays, and distributing impact force.

For example, a solid-liquid mixture composed of:

<table>
<thead>
<tr>
<th>Percent</th>
<th>Silica powder</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>80</td>
</tr>
<tr>
<td>Glycerine</td>
<td>16</td>
</tr>
<tr>
<td>Water</td>
<td>4</td>
</tr>
</tbody>
</table>

was prepared by simply mixing and the mixture used to fill and be sealed within the two compartments divided by spacer 13. For example, in preparing a laminated structure, as provided, the dilatant mixture 18 is first placed or spread at the base, adjacent wall 11, of the flexible container 10. The spacer wall 13 is positioned thereagainst and a second dilatant mixture 19 spread or poured thereover. If desired, this is repeated for the desired number of layers and the backing 12 is then pressed into position against the opposite layer. In the illustrations, the retainer into turned edges 16 and 17 of walls 14 and 15, respectively. When molded of an elastomer which is relatively hard, the walls 14 and 15 are sufficiently flexible to permit the backing 12 to be slipped under the retaining edges 16 and 17. In a completely flexible or semi-flexible structure the backing 12 may be completely sealed with a suitable adhesive or other fastening means.
Caliber 22 long rifle lead bullets fired into such flexible films of dilatant material were flattened and shred-
down. For shells of higher caliber, a somewhat greater thickness, or further plurality of layers, of such dilatant material, may be prepared.

As a further demonstration of the applications of such dilatant material, a 30-caliber armor piercing bullet was fired into a thin film formed of an unconfined polyethylene bag containing 2500 grams of the above dilatant ma-
terial. The bag was broken but the bullet was deflected 30 degrees and rotated broadside, after striking the dilatant mixture, thus affording protection from a direct hit.

Several similar additional experiments were conducted to discover some approximate composition limits for such packaged flexible fluid armor of optimum dilatancy and found to be:

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica powder</td>
<td>79 to 83</td>
</tr>
<tr>
<td>Glycerine</td>
<td>13 to 16</td>
</tr>
<tr>
<td>Water</td>
<td>3 to 6</td>
</tr>
</tbody>
</table>

In addition, mixtures of high content powdered silica (over 75%) with acetone and N-dimethylformamide were prepared and pronounced dilatancy was obtained in enclosed and confined batches of such mixtures. These composition mixtures are illustrative of less preferred fluent carrier materials showing high impact dilatancy with which care must be taken, as indicated.

The amount of a small amount of metal or metal ox-
ide material in particle form in the proportion of about 0.1% to 1%, for example, ferric oxide particles, con-
tained in such fluid mixtures, appear to improve the di-
latancy property of the mix. In addition, other approxi-
mately spherical fine particle size powders, such as finely ground silicate glasses and the like containing bismuth trioxide, lead oxide and the like may be used. Further comparable films of dilatant mixtures may be prepared of high concentrates of powdered material as powdered garnet, graphite, alumina, chromium oxide, cobalt oxide, titanium dioxide, ceramic material and mixtures of such material, and the like contained in fluid, elasto-
mer or soft plastic matrices and preferably encased in laminated form as contemplates, described and exempli-
fied herein. In addition, as alternative structure, a self-
supporting flexible film of a thermoplastic elastomer, or mixture thereof, when mixed with or having incorporated therein over 75% of the fine particulates, such as a mixture of polyethylene and silica powder, fabricated in sheet form likewise forms a high impact dilatant mixture in single and laminated form. For example, polyethylene or other suitable elastomer composition when mixed in a molten or solvent state with, for example, a high con-
centration, over 75% of material such as silica powder and the like, and formed as flexible sheet material, may be fabricated in single or laminated form as protective articles of clothing, or otherwise provided in tape, strip, block or other suitable form, with or without the backing material adhered or secured thereto, as illustrated, or by a suitable rubber, plastic or other adhesive. As will be obvious, it is not expected that all of the protective means, as provided herein, will serve indefinitely without the necessity of renewal or change. However, dependent upon the particular conditions to be permanently, tem-
porarily, or momentarily guarded against various films and film combinations of the dilatant compositions with high concentration of granular particulates therein retaining a relatively fluent condition, as embodied herein, can be prepared.

A somewhat different structural arrangement affording separate cells for holding the dilatant material is pro-
vided for in FIG. 2. Therein, a moisture-proof shock absorb ing pad 19 serves as a backing, or the innermost covering sheet, for a plurality of separate cells 20 con-
taining a dilatant material as herein provided and covered by a face sheet 21. The protective pad 19 is preferably a flexible laminated composite of ceramic platelets bonded together with plastic, rubber, or coated, fluid-tight fabric to which the intermediate platelets by suitable heat seal or bonding means such as a plastic, rubber, or other sealant inert to the dilatant carrier ma-
terial. The cells 20 are formed, for example, preferably of a suitable flexible high strength metal, or plastic such as natural or synthetic rubber-like material conventionally formed or molded in a honeycomb-like form with the cells in closely adjacent and abutting relationships for attenu-
ation of shock wave effects and absorption of impact energy. After the cells 20 are filled with the dilatant material, the facing 21 is sealed thereover by a suitable heat seal or relatively inert plastic adhesive. Preferably each of the cells are in independently sealed relationship. By care being used in the selection of proper fluid ma-
terial, container material therefor and sealing material being comparatively and relatively inert to or insoluble in the dilatant material or in application, the selection thereof is as the operator may desire.

In an application of the dilatant material there is illustr-
ated in FIG. 3, the open end of a thin panel structure comprised of outermost flexible or rigid side walls 25 and 26 divided by one or more flexible or rigid spacer walls 27 affording a plurality of closely adjacent compartment encasements adapted to contain and confine dilatant mixtures as embodied herein. The top and base walls 28 and 29 seal the respective sides of walls 25 and 26. Suitable end closure walls (not shown) are used to seal the dilatant mixtures 18' and 19' within the closely adjacent compartments, as shown. The divider wall 27 may or may not be in sealed relationship with respect to the compartments formed on either side thereof and the relative walls in contact therewith. When such enca-
sement means is formed of a flexible thermoplastic or ther-
omolding resin, the contacting edges thereof may be heat sealed to encase and enclose the dilatant fluid and powder solids mixture in film form therein. A flexible article of clothing made to contain such dilatant material, by the molding of a hollow rubber or suitable plastic article and sealing therein of one or more flexible films of dilatant mixture, with or without the separate compart-
ments and modifications, as embodied herein, would ap-
pear unnecessary for further detailed description.

In forming the structure of FIGS. 1 and 3, the inner divider wall or walls may be modified as illustrated in FIG. 4. Therein, the divider wall 30 is molded or formed of flexible fabric or plastic, or of solid dilatant material, as elastomer, plastic, vulcanized rubber, and the like, or less preferably of ceramic or metal with addi-
tional divider side strips 28 extending along the sides thereof and adapted to be in sealed or bonded relation-
ship with the closure walls 30, 31, 32, and 33 thereof. Suitable end closure walls (not shown) are provided in rela-
tively sealed relationship with the closure walls and spacer means.

When the enclosure containing the dilatant mixture is formed of flexible fabric, plastic, foil and the like in block, flexible sheet, strip or tape form, with or without the provision of an adhesive coating on either or both surfaces (not shown), for example, a coating of pressure sensitive-type adhesive, as disclosed in Pat. No. 2,156,380, of natural or synthetic rubber, the dilatant mixture encased therein can be laminated, wrapped and overlaid by an object to be protected. When used to wrap about oil lines, gas tanks and other vulnerable structure, for such improved protection as the dilatant composition af-
Fords, a conventional adhesive material inert to such fluid materials, may be used. Otherwise, when the dilatant is encased in a flexible plastic container as herein described, being a thermosetting resin composition, the dilatant may be used to wrap and enclose an element or body which gen-
erates heat and thus setting the laminated dilatant con-
tainer with retention of the dilatant property of the pow-

3,649,426
der mixture contained therein. For more stringent protective conditions, the confined dilatant composition is used as lining material for armament structure and as an aid in support of ceramic, metal and other shieldings subject to projectile penetration and breakage.

For personnel armor, in stopping projectile penetration, it is important that the constituents be energy absorbent and yield non-toxic decomposition products when struck and heated by impact of projectiles.

In several experiments with various dilatant mixtures, bullets fired into containers thereof penetrated only a short distance, and embedded therein or otherwise settled harmlessly to the bottom of the container.

To make effective personnel use of the above compositions in clothing, a vest, for example, constructed of heavy fabric or plastic having an intermediate body, as described, of a soft plastic matrix which behaves as a fluid and in which are suspended fine particles of solids, provides impact protection against small arms, shrapnel and harmful radiation.

While illustrative embodiments as disclosed herein may be modified within the scope of this invention and as will now occur to those skilled in the art, I intend to be bound only by the scope of the claims.

What is claimed is:

1. The method of preparing and providing protective armor of particulate material in a relatively fluent or dilatant mixture comprising the steps of:
   (a) mixing a dilatant fluid and powder solid mixture containing,
      (1) over 75% solid particulates selected from the group consisting of silica, mica, vermiculate, quartz, or other crystalline vitreous particulate powder material of a particle size in the range of from colloidal to about 100 mesh and contained in a discontinuous closely packed particulate phase in
      (2) a continuous relative fluid phase vehicle therefore, and
   (b) encasing the said dilatant mixture in a container with retention of said particulate material in solidly packed relationship in said relative fluid phase.

2. The method of claim 1 including the steps of encasing said dilatant mixture in a multiple of separate compartments in closely adjacent relationship.

3. The method of claim 1 wherein the fluid phase vehicle is a liquid to viscous fluid with the said particulates in high packed density and relatively therein in a fluid mixture state having the property of dilatancy upon high shear rate impact.

4. The method of claim 1 wherein said dilatant mixture comprises a fluid glycerine material and particulate silica in combination with particulates of metal oxide.

5. The method of claim 1 wherein said fluid vehicle is polar and the mixture contains natural or synthetic fiber material.

6. A flexible armor material having resistance to the passage of harmful radiation and shell and shrapnel projectiles comprising a prefabricated encased fluid of dilatant material consisting of over 75% particulate fluent powder solids in a closely packed flexible discontinuous relationship in a fluid vehicle and providing an encased viscous, flexible, fluent dilatant mixture.

7. The structure of claim 6 wherein the same film comprises a fluid vehicle containing the particulate solids and each have substantially the same specific gravities.

8. The structure of claim 6 wherein the said flexible armor material comprises a laminate of flexible plastic films each having over 75% powder solids therein and said powder solids in said fluid vehicle having a fluent behavior under impact of said projectiles.

9. The structure of claim 6 wherein the power solids are essentially ceramic.

References Cited

UNITED STATES PATENTS

1,213,118 1/1917 Lynch ---------------- 161—43
3,324,768 6/1967 Eichelberger ---- 161—404 UX
2,738,297 3/1956 Plastershammer ----- 89—36 AX
2,806,509 9/1957 Bozzacco et al. ----- 161—162 X
1,266,196 5/1918 Bentley ---------- 89—36 UX
2,348,130 5/1945 Hardy, Jr. -------- 89—36 A
3,431,818 3/1969 King -------------- 161—404 UX

FOREIGN PATENTS

569,802 1/1959 Canada ************ 156—276
1,081,464 8/1967 Great Britain ------- 161—404

PHILIP DIER, Primary Examiner

U.S. Cl. X.R.

161—87, 162, 404; 89—36; 109—84; 156—276