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Stiglich, Jr.

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[54] **ARMOR**

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[51] **Int. Cl.** **F41h 5/04**

[58] **Field of Search** ..... 109/49.5, 58.5, 80, 82, 109/83, 81, 84, 79; 29/182.7; 161/90, 404, 38, 37, 193, 194, 170; 106/43, 44; 89/36 A; 2/2.5; 75/202, 203, 206

[56] **References Cited**

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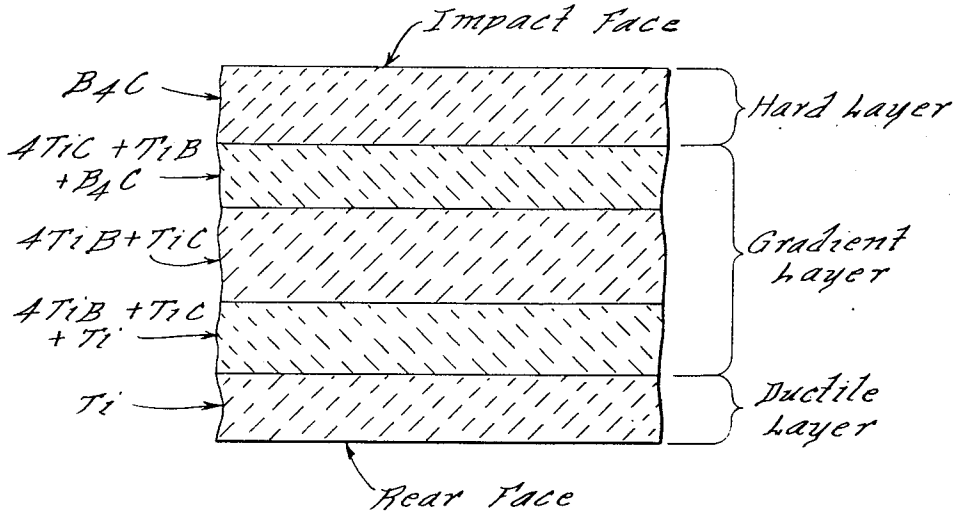
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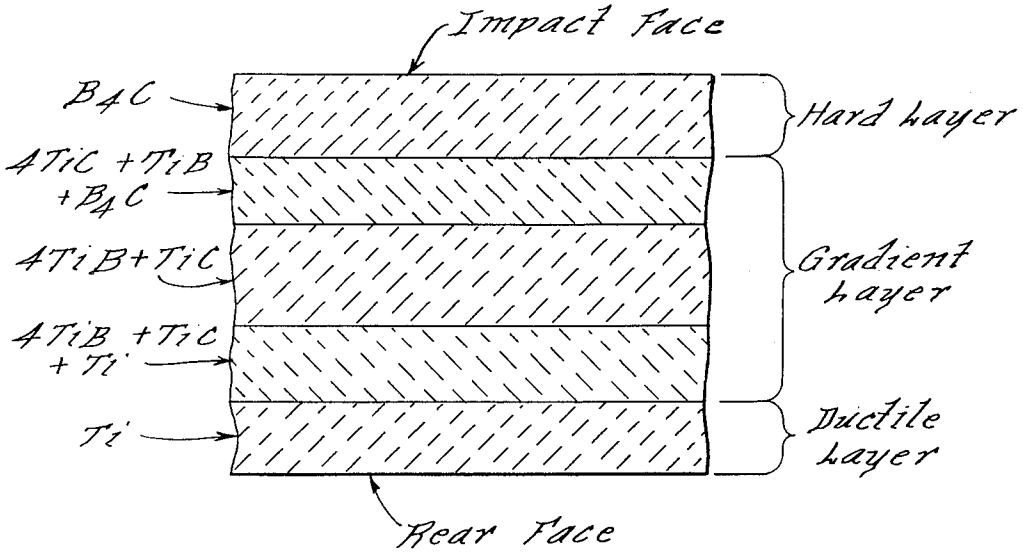
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[57] **ABSTRACT**

An improved armor having a hard layer comprised predominantly of boron carbide, defining a projectile impact face, and a ductile layer comprised predominantly of metallic titanium, defining a rear face, and a gradient layer having a controlled gradient of hardness and ductility interposed between said hard layer and said ductile layer and comprised of a ceramic alloy of TiB and TiC as discrete phases defining a matrix through which controlled amounts of particulated boron carbide and/or titanium are dispersed.

9 Claims, 1 Drawing Figure




Impact face
B_4C
$4TiC + TiB + B_4C$
$4TiB + TiC$
$4TiB + TiC + Ti$
Ti
Hard Layer
Gradient Layer
Ductile Layer
Rear Face

ARMOR

BACKGROUND OF THE INVENTION

A variety of materials and structural arrangements have heretofore been used or proposed for use in the fabrication of armor systems for resisting penetration by projectiles. More recently increased emphasis has been placed on lightweight armor systems which are comprised primarily of ceramic materials, such as alumina and boron carbide, which form extremely hard projectile shattering media. Further work with lightweight monolithic ceramic armor systems has revealed that such materials are inadequate by themselves due to their inability to absorb sufficient energy resulting in spallation of the monolithic armor plate and possible damage as a result of the secondary missiles produced.

In order to overcome the foregoing deficiencies, various energy-absorbing back-up materials have been employed including, for example, resin impregnated fiberglass and woven roving serving as the energy-absorbing medium. The resultant composite armor systems, while more effective than the monolithic ceramic armor materials, are nevertheless deficient in many respects, including the difficulty and high cost associated in their fabrication, the limitations on the configurations and sizes of armor that can be conveniently produced, as well as the difficulty of uniting the hard impact ceramic material to the energy-absorbing back-up material.

Many of the problems associated with such composite armor materials have now been overcome by the adoption of so-called "gradient armor systems" of the type described in U.S. Pat. No. 3,633,520, granted to Jacob J. Stiglich, Jr., on Jan. 11, 1972. In accordance with the teachings of the aforementioned U.S. patent, the hard bullet-shattering medium and the energy-absorbing medium are combined in one integral plate by employing an alumina matrix through which fine-sized molybdenum particles are dispersed. The concentration of the molybdenum particles is controlled so as to progressively increase in the direction toward the rear or back-up face of the armor. Ballistic testing of the gradient armor material has been observed to lengthen the total time during which an interaction between the projectile and armor system occurs, increasing the time period before the formation of the initial cracks in the armor system.

The present invention also pertains to gradient armor systems and constitutes a still further improvement over materials and processing techniques heretofore known.

SUMMARY OF THE INVENTION

The benefits and advantages of the present invention are achieved by a gradient armor having a projectile impact face and a rear face, between which is interposed an intermediate stratum comprised of a matrix composed of discrete phases of TiB and TiC, herein referred to as a "ceramic alloy," having dispersed therethrough controlled quantities of particulated boron carbide and/or metallic titanium. The concentration of the boron carbide in the matrix normally increases in a direction toward the impact face, providing a hard and brittle impact surface; while the concentration of metallic titanium in the matrix increases in a direction toward the rear face of the gradient armor, increasing the ductility and energy-absorption properties thereof.

The rear face of the gradient armor matrix can also be united with metallic alloys, such as titanium and steel alloys, as may be desired, in order to further enhance the energy-absorption properties thereof, as well as to facilitate a mounting of the armor on a structure.

In its process aspects, the present invention provides for a fabrication of a gradient armor material by employing particulated mixtures of boron carbide and titanium, which are hot-pressed forming an integral matrix having controlled gradations in composition. The use of stoichiometric proportions of boron carbide and titanium in a selected stratum or region of the powder layers produces an in situ solid state diffusion controlled reaction to produce the ceramic alloy composed of discrete phases of TiB and TiC. It is further contemplated that the layers of powder mixture can be integrally bonded to a back-up plate of a selected metal alloy or of a powdered mixture of a metal alloy during the hot-pressing operation.

Still further benefits and advantages of the present invention will become apparent upon a reading of the description of the preferred embodiments, taken in conjunction with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

The drawing comprises a magnified fragmentary cross sectional view of a typical gradient armor embodying the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now in detail to the drawing, a gradient armor material is illustrated comprising three basic layers; namely: a hard layer comprised substantially entirely of ceramic or intermetallic compounds and defining the hard and brittle impact face of the armor; a ductile layer having a relatively high percentage of metallic phases therein in order to provide high energy-absorption characteristics and which defines the rear face of the armor; and a gradient layer or intermediate stratum, which itself may comprise a plurality of individual layers containing controlled proportions of boron, carbon and titanium to provide for a controlled variation in the hardness and ductility characteristics of successive layers on moving in a direction from the impact face to the rear face of the armor.

In accordance with the arrangement as shown in the drawing, the front of the shock wave created upon impact of a projectile against the impact face of the armor becomes broken or dispersed as a result of its travel through regions of different material since its velocity will vary as the composition varies. In addition, the wave, upon movement from one gradation to a next gradation of material, will lose energy as a result of the absorption of energy during wave travel through the transition regions between adjacent composition gradients. The gradient armor material is further characterized as being of substantially 100 percent density which is attained by use of controlled conditions during the hot-pressing process as subsequently to be described.

In accordance with the process for preparing the gradient armor, mixtures of controlled composition of boron carbide and titanium powders are prepared. The boron carbide suitable for use in accordance with the practice of the present invention may be derived from either the so-called "melt process," such as described in U.S. Pat. No. 2,155,682, or by the so-called "solid

state reaction process," as described in U.S. Pat. No. 2,834,651. The boron carbide material may range within the permissible atomic ratios of the boron/carbon phase field, wherein the boron content will range from about 76 percent by weight up to about 89 percent by weight of the composition. Conventionally, boron carbide corresponding to the formula B_4C, in which the boron to carbon atomic ratio is 4:1 and contains about 78 percent by weight boron, is the most common and preferred material.

The boron carbide powder is of an average particle size less than about 200 microns and preferably of an average particle size of less than 50 microns. While particles less than 1 micron can be satisfactorily employed, additional precautions must be exercised in the handling of such extremely fine-sized powders due to dusting problems and the like. Since the formation of the ceramic alloy is achieved through a solid phase diffusion controlled reaction, the smaller the particle size, the greater the surface area, and thereby the greater the efficiency and rate of reaction. In this regard, particle configuration which maximizes surface area, while concurrently permitting the attainment of 100 percent density using reasonable hot-pressing pressures, are preferred. The source of the boron carbide will in part dictate the particular configuration of the powder particles. For example, boron carbide powders derived from the solid state reaction process are of an equiaxed configuration resembling jagged spherical particles.

The titanium metallic powder also is preferably of an average particle size less than 200 microns, while average particle sizes of less than 50 microns have been found particularly suitable. As in the case of the boron carbide powder, particle configuration is not critical, although those configurations are preferred which maximize surface area without detracting from compaction of the powder mixture during hot-pressing.

The boron carbide and titanium powders are mixed or blended in the desired proportions consistent with the hardness and energy-absorbing characteristics desired for each specific layer. As shown in the drawing, the hard layer comprises substantially 100 percent compounds devoid of any metallic phases to achieve optimum hardness in the region defining the projectile impact face. For this purpose, the hard layer may be composed of the ceramic alloy comprising discrete phases of TiB and TiC, as well as the foregoing ceramic alloy matrix with boron carbide dispersed therethrough in an amount up to an extreme wherein the hard layer comprises substantially 100 percent boron carbide. The ductile layer, on the other hand, is comparatively high in metallic phases and may be comprised of about 50 percent by volume up to 100 percent metallic titanium. The inclusion of a minimum of about 50 percent by volume of metallic titanium enables the formation of high-strength bonds of the gradient armor to other metal supporting structures such as by diffusion bonding or by welding, or the like. It is also contemplated that the ductile layer defining the rear face of the armor may include discrete phases of alternative metallic powders, as well as solid metal plates, which are united to the gradient layers during the hot-pressing operation. For example, in addition to titanium powders, titanium alloy powders and steel powders, as well as plates of titanium alloy and steel, for example, can be employed as the energy-absorbing ductile back-up layer. A typical titanium alloy comprises one containing 6 percent aluminum, 4 percent vanadium and the balance titanium.

A stratum of the gradient layer shown in the drawing is comprised of a ceramic alloy, which is formed by admixing stoichiometric proportions of boron carbide and metallic titanium, which undergo a controlled solid phase diffusion reaction during which no melting of any of the constituents occurs in accordance with the following chemical reaction:

$$5Ti + B_4C \rightarrow 4TiB + TiC$$

The foregoing reaction and in situ formation of the hard and dense ceramic alloy occurs during the hot-pressing of the powder mixture at a temperature of at least about 1,000°C. up to the temperature at which an incipient melting of the titanium (1,730°C.) occurs. While temperatures less than about 1,000°C. can be employed, the time required to complete the solid state diffusion reaction is inordinately long and usually is commercially unacceptable due to the length of time of the pressing cycle. On the other hand, temperatures at which an incipient melting of titanium occurs are unacceptable and temperatures approaching 1,700°C. are less desirable due to the tendency to promote the formation of titanium diboride (TiB_2). Particularly advantageous results are obtained employing moderate temperatures that is, temperatures of about 1,100°C. to about 1,400°C. at which dies comprised of materials such as tungsten carbide can be employed instead of graphite, which is required at higher temperatures. Tungsten carbide dies are less fragile and more wear-resistant than graphite die and, accordingly have a longer useful operating life and also maintain dimensional accuracy of the resultant hot-pressed armor part over longer time periods.

The reaction is also promoted by the pressure applied to the powder particles, which preferably is at least 1,000 psi, with the maximum pressure being dictated by press and die strength limitations.

The duration of the hot-pressing reaction will vary on such factors as the particular temperature used, the shape and size of the boron carbide and titanium particles, and the pressure employed. Generally, time periods of about two hours to about three hours at temperatures of about 1,000°C. and at pressures above 1,000 psi are usually satisfactory for completing the solid phase diffusion reaction and the formation of the ceramic alloy containing TiC and TiB as the primary constituents which are dispersed in a matrix comprised of discrete phases of these constituents.

The ceramic alloy is further identified by the following X-ray diffraction pattern data for the TiB and TiC phases, respectively.

TiB X-Ray Diffraction Pattern Lines (CuK_α Radiation)

hkl	Relative Intensity	$2\theta\beta$ (Degrees)
101	weak	24.47
200	medium	29.22
201	strong	35.25
011		
111	strong	38.32
210	strong	41.75
102	strong	42.18
211	medium	46.36
301	medium	48.82
112	medium	52.04

400	medium	60.52
020		
401	weak	63.60

TiC X-Ray Diffraction Pattern Lines (CuK_α Radiation)

hkl	Relative Intensity	$2\theta\beta$ (Degrees)
200	strong	41.78
111	strong	35.98
220	medium	60.57
311	weak	72.8

The relative intensities of the X-ray diffraction pattern lines will depend on the actual percentages of the two phases present and the proximity of adjacent peaks in the pattern. The locations of the peaks as set forth in the foregoing tables are typical of the observed X-ray diffraction patterns obtained on ceramic alloys produced by the solid phase diffusion reaction of stoichiometric proportions of boron carbide and titanium in accordance with the method aspects of the present invention. The presence of titanium diboride (TiB_2), as well as unreacted or excess boron carbide (B_4C) and/or titanium, is also detected at times depending on the particular temperature and pressure conditions under which the reaction is carried out.

The hardness of the ceramic alloy substantially devoid of any titanium diboride and free unreacted titanium and boron carbide is approximately 2,500 knoop/100 gram.

In the practice of the process, the desired number and quantity of powder mixtures of controlled compositions are uniformly blended, such as by ball milling, muller mixing and the like, and are thereafter deposited in the form of individual overlying layers in a suitable die cavity. The specific thickness of each layer and the number of layers employed is controlled consistent with the ballistic performance desired. The thickness of the individual layers and the number used is preferably controlled so as to provide a relatively smooth as opposed to an abrupt transition in composition and in attendant physical properties on moving in a direction from the impact face of the armor to the rear or back-up face.

After the appropriate number of powder layers have been deposited in the die cavity, which may further include a metal powder or homogeneous metal plate as the ductile or back-up layer, the die is placed in a heating chamber and the press plunger is inserted in preparation for the hot-pressing operation. Heating is preferably performed in a vacuum although other inert atmospheres can be satisfactorily employed which prevent a contamination of the heated particulated mixture with nitrogen and oxygen. Upon attaining the prescribed pressing temperature, which may range from about 1,000°C. up to 1,730°C., and preferably from about 1,100°C. up to 1,400°C., pressure of upwards of about 1,000 psi is applied by the plunger to the powder in the die cavity and the pressure is maintained for a time period sufficient to enable completion of the in situ solid phase diffusion reaction, as well as a densification of the powder to 100 percent theoretical density and the formation of an integrally-bonded matrix having controlled gradients of varying hardness and ductility throughout.

While it will be apparent that the invention herein disclosed is well calculated to achieve the benefits and advantages as hereinabove set forth, it will be appreciated that the invention is susceptible to modification, variation and change without departing from the spirit thereof.

What is claimed is:

1. A gradient armor having a projectile impact face and a rear face and an intermediate stratum interposed therebetween, said intermediate stratum comprised of a matrix of a ceramic alloy composed of discrete phases of TiB and TiC having dispersed therethrough controlled quantities of particulated metallic titanium, the concentration of said titanium in said matrix increasing in a direction toward said rear face.

2. The gradient armor as defined in claim **1**, wherein said matrix further includes particulated boron carbide dispersed therethrough, the concentration of said boron carbide increasing in a direction toward said impact face.

3. The gradient armor as defined in claim **1**, wherein the concentration of the particulated said metallic titanium in the region adjacent to said rear face ranges from about 50 percent up to about 100 percent by volume.

4. The gradient armor as defined in claim **1**, wherein a region of said intermediate stratum contains said ceramic alloy in the stoichiometric ratio of 4TiB for each part TiC.

5. The gradient armor as defined in claim **1**, wherein said particulated titanium is of an average particle size of less than about 200 microns.

6. The gradient armor as defined in claim **2**, wherein said particulated boron carbide is of an average particle size of less than about 200 microns.

7. The gradient armor as defined in claim **1**, wherein said particulated titanium is of an average particle size less than about 50 microns.

8. The gradient armor as defined in claim **2**, wherein said particulated boron carbide is of an average particle size of less than about 50 microns.

9. The gradient armor as defined in claim **2**, wherein said boron carbide has a boron to carbon atomic ratio of substantially 4:1.

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