United States Patent [19]

Clougherty

[11] **3,802,850**

[45] **Apr. 9, 1974**

[54] **GRADED IMPACT RESISTANT STRUCTURE OF TITANIUM DIBORIDE IN TITANIUM**

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[22] Filed: **Nov. 13, 1972**

[21] Appl. No.: **305,784**

[52] **U.S. Cl.**..... **29/182.2,** 29/182.3, 29/183.5, 89/36 A, 75/202, 75/208 R, 75/226, 75/208 CS

[51] **Int. Cl.** **B22f 3/14,** B22f 1/00

[58] **Field of Search**..... 29/182.2, 182.3, 182.5; 75/202, 208 R, 208 CS, 226; 89/36 A

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[57] **ABSTRACT**

A new product resistant to impact from foreign bodies including both erosion and collision has a graded structure with an outwardly facing surface prepared from a mixture of titanium and titanium diboride. For a specific purpose of ballistic impact resistance, a product has a graded structure wherein the exposed or impact receiving face has a composition corresponding to a mixture of titanium and boron in a range between the approximate equivalents of 25 to 60 percent titanium diboride and the remainder primarily titanium, while the inwardly facing surface is primarily titanium or a titanium alloy. The presently preferred process for producing the product comprises mixing powders of titanium and geometry titanium diboride in the desired graded grometry and hot pressing then, desirably with a sheet or structure of titanium or titanium alloy or a similar support material at the back surface.

11 Claims, 2 Drawing Figures

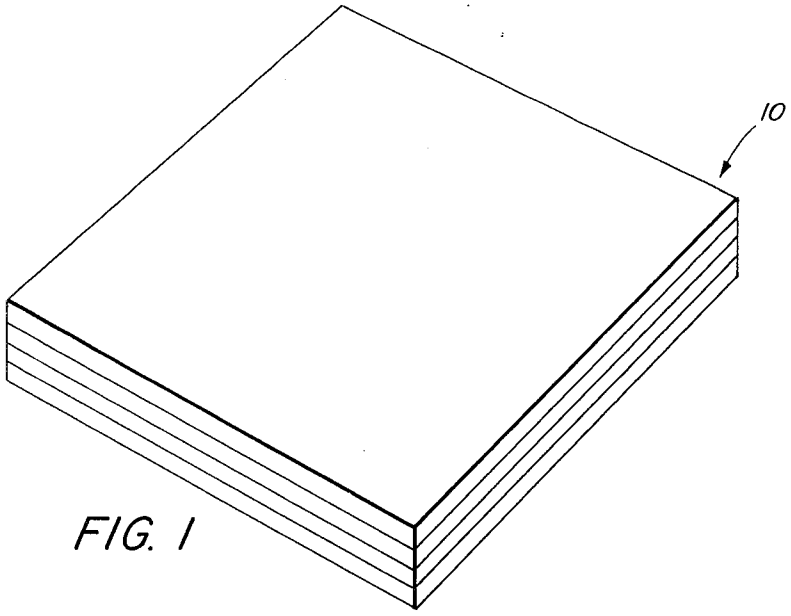


FIG. 1

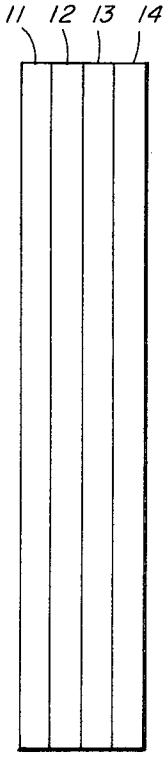


FIG. 2

GRADED IMPACT RESISTANT STRUCTURE OF TITANIUM DIBORIDE IN TITANIUM

BACKGROUND OF THE INVENTION

A number of types of materials have been employed in uses and applications where resistance to impact is desired. Depending on the intended use and application and the type of impact which is to be expected, a wide variety of criteria exist. For example, military applications of products resistant to ballistic impact are exposed to severe hazards such as penetration by armor piercing ammunition and also to exposure to high velocity fragmentation hazards. Other uses and applications of ballistic impact resistant products may be less severe and, for example, non-military security operations are not normally to be expected to be exposed to the hazard of armor piercing ammunition and seldom to fragmentation hazards such as artillery, grenades and the like. Furthermore, in many industrial and commercial uses and applications, greatly less severe hazards are to be expected. For example, in many commercial and industrial uses erosion, with or without thermal or mechanical shock and stress can be a very exacting problem. Thus extrusion dies, nozzles and the like suffer abrasion or erosion from impact by hard particles. Turbines have problems of thermal and mechanical stress combined with impact by foreign bodies.

Although the present invention has many forms and embodiments, the greatest amount of data and information relates to the very severe conditions and requirements in resistance to collision such as ballistic impact. Generally speaking, components or structures providing ballistic impact resistance are classified in two categories known as parasitic and structural. Parasitic ballistic impact resistance relates to situations in which shields or similar devices are carried or hung on a person or object to be protected. Structural ballistic impact resistance on the other hand, relates to uses and applications where the structure itself is exposed to the hazards and where the ballistic impact resistant product must, accordingly, be a part of the exposed structure. In each case, there are certain common properties which are desirable, such as strong resistance to impact, minimum weight, and, of course relatively moderate cost. In the case of structural ballistic impact resistance, however, an additional key characteristic is that the product itself should be structurally sound.

For structural ballistic impact resistance generally intended for resisting armor piercing ammunition, it is usual to employ a structural material such as a dual hardness steel which is a roll bonded product of two different types of steel. Such a product is relatively heavy, particularly in view of the need to employ quite thick as well as strong dual hardness steel, resulting in an areal density of 12 pounds per square inch to be effective against 30 caliber armor piercing ammunition. In addition, steel offers limited protection against high speed fragmentation impact.

For parasitic ballistic impact resistance, it is usual to employ materials such as alumina, silicon carbide, boron carbide and the like, using these with plastic back-up, the assembly being characterized by relatively good resistance to fragmentation and other impact. They are, however, not satisfactory for structural ballistic impact applications.

Accordingly, there are shortcomings in the best of the known materials and products for ballistic impact resistance and there are no products which satisfactorily offer the combined protection separately provided by parasitic and structural ballistic impact resistance products, and there are equal problems in products for industrial and commercial use.

GENERAL STATEMENT OF THE INVENTION

According to the present invention, a product useful for many commercial, industrial and security applications including both structural and parasitic ballistic impact resistance comprises a formed or shaped article having a structure including a graded composition of titanium and boron. The outer surface of the article, or the impact receiving face, is characterized by extremely high degree of hardness and has a relatively higher proportion of boron. The inner surface or the one positioned away from the exposure to the hazard of ballistic impact has a relatively low proportion of boron and may be nearly or entirely titanium in the absence of boron. Desirably, this product is supported on a structural support base, particularly where structural ballistic missile protection is sought. The presently preferred structural support base is titanium metal or titanium alloy. This graded structure, or geometry, has proven greatly more effective at least in certain severe tests than the best material or structure previously known; moreover, these severe tests occur at precisely one point of greatest practical utility.

The new products are substantially better in ballistic impact resistance specifically with reference to high powered armor piercing ammunition than is the usual structural product previously preferred, namely, dual hardness steel, and at the same time, they are effective against low velocity non-armor piercing ammunition and high velocity fragments. In other words, the products according to the present invention appear to outperform the current products in the hazard exposures in which such prior products are generally employed.

The new products are relatively light in weight or bulk density as compared with prior structural products; and because of their better performance, thinner and lighter protection can be used to increase their ballistic impact resistance in terms of effectiveness per unit weight. The products of the present invention are about as light in weight as prior parasitic ballistic impact resistant products. At the same time, they need not compete against such prior light weight parasitic ballistic impact resistant products because they are suitable structural products. The result is that compared with existing products, they offer the best of both worlds.

The nature of the invention can be more readily understood with reference to the drawings, in which:

FIG. 1 is a perspective view of a plate of graded structure according to one form of the invention.

FIG. 2 is a cross section of the plate of FIG. 1.

SPECIFIC NATURE OF THE INVENTION

In the figures, there is illustrated in FIG. 1 a shaped graded structure **10** according to one embodiment of the invention. This shaped structure may be of any shape or form, as desired, and may for example, be a plate of armor, a turbine blade, an extrusion die, or any other object as is normally encountered in commercial, industrial or security use. For simplicity of illustration, the structure **10** is shown as a plate. Generally speaking, in addition to ballistic missile resistive structures

and other shaped articles named herein, this shaped article may be of any of the structures for which refractory ceramics are employed.

In FIG. 2, the graded structure of a presently preferred embodiment of the plate of FIG. 1 is diagrammatically illustrated. The structure or plate 10 comprises a base 11, a first layer 12, called herein an interface layer, a second layer 13, called herein an intermediate layer, and a surface or exposed layer 14. Layer 13 may in practice be a plurality of layers.

The presently preferred procedure for the production of the shaped hot pressed ballistic impact resistant products according to the present invention comprises mixing powders of titanium metal and titanium diboride in graded geometry as diagrammed in FIG. 2, wherein the highest concentration of titanium diboride is at the exposed or impact receiving face and the highest concentration of titanium metal is at the back or support areas, and hot pressing this mixture either with or without a support metal backing. In preparing and mixing the materials for the graded structure according to the present invention, it is preferred to employ titanium powder and titanium diboride powder. In the first place, no advantage has been found or would be expected as a result of the use of titanium powder and boron powder, while at the same time, it is believed that some advantages result from the use of titanium diboride powder. In the hot pressing step, it is believed that there is a large degree of chemical reaction between the titanium powder and the titanium diboride powder with which it is mixed, although this reaction may not be complete. It is probable therefore, that in the mixed layers which are at least layers 13 and 14 of FIG. 2, there are large quantities of a titanium-boron composition corresponding to TiB.

In the compositions in the various layers which include boron or titanium diboride, it is more useful to one skilled in the art for many reasons to consider the proportions in terms of the percentage by weight of titanium which has been mixed with an amount of titanium diboride as a starting material to form the resulting hot pressed layer. Accordingly, this mode of presentation is included in the specification and the claims. A composition whose proportions correspond to TiB is a composition prepared from about 45 percent titanium and about 55 percent titanium diboride and thus a composition prepared from 50 percent titanium and 50 percent titanium diboride has a slight excess of titanium over and above that required to produce a composition corresponding to TiB.

In the specific examples, two powders were employed, titanium diboride approximately −325 mesh and titanium metal approximately −100 mesh. Mixing was achieved by ball milling for a period of one hour until adjudged uniform. Two procedures have been employed: a one-step procedure and a two-step procedure. In either procedure, there is used a conventional hot pressing die including a graphite die and pistons together with appropriate tooling and appropriate heating means. Various mixtures of powdered titanium metal and powdered titanium diboride are prepared in compositions and proportions to produce layers 12, 13 and 14 of FIG. 2. These layers were then laid down in the die in order to produce the structure illustrated in FIG. 2. The die was then used in a hot pressing operation to form the shaped structure.

The two step process is carried out like the one step procedure except that no metal support or structural alloy sheet is employed. After hot pressing, the hot pressed structure is removed from the die and is then subjected to diffusion bonding. Diffusion bonding conditions are typically about 1,900°F. for 2 hours in an argon atmosphere followed by slow furnace cooling. Adhesive bonding at room temperature has been employed for bonding, but direct bonding is presently preferred.

For preparation of test structures for ballistic impact tests, in most cases, disks of 3½ inch diameter were prepared, although some larger structures have been employed. The powders were first placed in a hot press, maintaining a desired graded structure by placing successive layers of powders of graded composition. Where a one-step process was used to hot press a metal disk to the powders, such a disk was placed immediately on the top powder layer, and then hot pressed. Where a two-step process is used, first hot pressing the powders and then bonding the hot pressed refractory to the metal, the metal preferably is placed against the pressed refractory after removal from the mold and examination, cleaning and/or testing, using diffusion bonding. The hot pressed refractory or ceramic comprising the graded hot pressed structure of boron and titanium may be used as parasitic ballistic missile protection, bonded to or supported on a non-structural support such as a plastic or reinforced plastic. For structural ballistic missile protection, it is preferred that it be bonded to a structural metal base or backing.

The metal backing or structural body 11 is particularly valuable in structural ballistic impact resisting products. The metal backing acts as a structural support, and in theory any metal may be used which can be adhered to the ceramic body. In practice, there are many requirements, some of them difficult. In the first place, the metal must withstand fabricating temperatures: the hot pressing temperatures actually used in the one-step process are about 2,250°F. or even higher for certain of these ceramics, and the diffusion bonding temperatures preferred in the two-step process are about 1,900°F. For compositions containing lower percentages of titanium diboride hot pressing temperatures as low as about 2,100°F. may be employed; for compositions containing higher percentages of titanium diboride, temperatures of 2,300°F. may be required, with usual hot pressing pressures. Pressures of about 3,000 pounds per square inch for several hours are usually employed. In addition, the metal and the ceramic must adhere to each other, being not incompatible. Further, in the processing operations and in some of the uses, there is a wide temperature variation, and accordingly, thermal expansion of the metal and ceramic must be reasonably similar. Where high speed impact of a heavy object is anticipated, sonic mismatch of metal and ceramic must be minimized. In view of these several important requirements, a titanium metal or titanium alloy sheet is now preferred. A very satisfactory metal is a titanium sheet commercially available as Ti—6Al—4V, a titanium alloy containing 6 percent aluminum and 4 percent vanadium and known herein as a sheet of metallic titanium.

Generally speaking, the products of the present invention are graded structures in which the impact receiving face of the structure is relatively higher in its boron content and the rear face is relatively higher in

titanium content. Titanium boride structures are hard surfaces adapted to deflect or resist impact better than are the more ductile compositions having less boron. A presently preferred structure can be prepared with an exposed surface having a composition roughly corresponding to about 50 percent by weight titanium diboride and about 50 percent by weight titanium. This surface is extremely hard and easily deflects or defeats mild abrasion and, combined with the graded structure shown in FIG. **2** effectively defeats severe impact. When the titanium diboride proportion in the starting mix for the exposed surface is reduced to about 25 percent or less, it becomes significantly less effective. At the other end of the scale, when the percentage of titanium diboride in the starting mix is increased substantially above about 50 percent, there is a significant excess of TiB_2 in the final product, requiring higher fabricating temperatures and greater likelihood of mismatch between exposed surface and backing. This can be partially accomodated by proliferation of layers in the graded structure, but does not appear to offer sufficient advantage to justify its increased problems. Accordingly, the presently preferred proportions for the exposed surface are between about 25 percent and about 60 percent TiB_2 and between about 75 percent and about 40 percent titanium.

Supporting this face is a graded structure, either continuously gradient in composition or having been prepared from several layers of powder of different titanium and boron proportions, the higher proportions of boron being nearer the impact receiving surface and the higher proportions of titanium being away from the impact receiving surface. Continuous gradation is more easily approximated, if desired, in an engineered-production operation; a layered structure generally is produced in low quantity production. When a titanium metal sheet or structure is at the back of the product, it is believed that this higher proportion of titanium promotes bonding between the hot pressed powders and the metal. Bonding is important among other reasons because one form of failure under high velocity impact can be separation at this bond. In addition, however, the refractory which is higher in titanium is more ductile and structurally stronger. What is important is that graded vs. non-graded structure gives a major difference in performance with same thickness of sample.

The preferred graded structures and the presence or absence of a metal backing plate or structure depend on the intended use and application. For structural impact resistance uses where both armor piercing ammunition and fragmentation impact are to be expected, as with many military uses, a higher boron content in the impact receiving face and a support metal structure are both desired. For resistance to small arms fire, as with non-military security operations, a lower boron content is satisfactory. For certain primarily fragmentation impact situations, as with many industrial and construction uses, thinner structures with or without structural metal backing are generally satisfactory and may be preferred because of cost, weight, or both. For many industrial uses the metal structural support is very important.

The front, or impact receiving surface is of relatively high boron content, generally corresponding to about 25 percent to about 60 percent, preferably around 50 percent by weight titanium diboride. A substantial excess of TiB_2, that is more than about 55 percent TiB_2 and 45 percent Ti metal requires increasingly high fabrication temperatures, and it has not yet been found that more than 60 percent TiB_2 improves the product sufficiently to justify its added problems. Graded structures in which its impact receiving or abrasion receiving surface is pressed from as little as 25 percent TiB_2 mixed with 75 percent Ti metal has moderate resistive properties but is not as effective as a product whose exposed face is pressed from 50 percent TiB_2 and 50 percent Ti metal powder.

The rear face of the refractory, or the hot pressed powder product is substantially lower in boron content than the front face. In any event, the rear face is lower in boron content than the proportions equivalent to 25 weight percent TiB_2, preferably less than about 10 weight percent. If the rear face is bonded to a metal support sheet or structure, the boron content at the rear face of the refractory, or the face is bonded to the metal, is less than that corresponding to 10 percent TiB_2 and is preferably close to or essentially 0 percent TiB_2.

For non-severe uses and applications employing a lower proportion of TiB_2, a two layer structure may suffice. For uses and applications employing a higher proportion of TiB_2, several layers may be required. For the most severe uses as illustrated in the examples, a metal backing supporting or supplying structure for layers **12, 13** and **14,** have, to date been found satisfactory, far out-performing the best known products previously available. The intermediate layer **13** (or plurality of layers **13**) is of significantly lower proportion of equivalent TiB_2 than is the exposed surface (layer **14**), generally between about 10 percent and about 25 percent TiB_2 in the original powder mixture.

For industrial uses, such as tools, dies, etc., the metal backed products of the present invention offer the prospect that for the first time a product may exist which can resist the thermal stresses, wear and erosion, and other conditions of use, and at the same time can be accidentally attacked, as by being knocked from bench to floor without being ruined.

EXAMPLE I

A layered product was prepared by hot pressing as follows: a first layer in amount which, when fully compacted, will compact to a layer approximately 0.1 inch thick was placed in a graphite hot pressing mold and was prepared by ball milling to produce an essentially uniform mixture of titanium diboride powder and titanium powder in proportions corresponding to 50 percent by weight titanium diboride and 50 percent titanium metal. On top of this layer was placed a second layer also compacting to approximately 0.1 inch thick of a ball milled mixture corresponding to the composition of about 25 percent by weight titanium diboride and about 75 percent titanium metal powders. A next layer was formed by adding thereto a layer of titanium metal powder essentially without any added titanium diboride. This layer also being such as to be compacted to a layer about 0.05 inch thick. Finally, a 0.125 inch thick plate of Ti—6Al—4V titanium alloy was placed on top of the powders. The layered product was then hot pressed at about 2,250°F. and about 3,000 pounds per square inch pressure for about 3 hours, after which it was cooled and removed from the mold. The pressing has been carried out in air, but the preferred ambient atmosphere is an inert gas. Argon was employed here.

Three types of tests have been used in evaluation of the structures and products of the present invention. 30 caliber armor piercing ammunition is fired at point blank range, perpendicular to the surface at a muzzle velocity of 2,400 ft./sec. or higher. This is considered to be a very severe test. Next, a 30 caliber ball is fired, again perpendicular to the surface at muzzle velocities of 1,400 to 2,500 ft./sec. This test, employing softer ammunition is considered to be a fair test representing resistance to small arms fire. Third, 17 grain fragmentation simulators at 2,500 to 4,000 ft./sec. represent resistance to fragmentation uses.

In addition to observing actual ballistic missile stopping power, it is useful to correlate stopping power with weight, as the products of the invention are often intended to be carried by people or to be carried by or to form portions of the structures of airborne vehicles. Areal density conversions or the density of a unit area required to defeat test impact, indicate that the products of this invention have defeated the most severe of the tests described at areal densities of 8.6 pounds per square foot, and areal densities of about 4 pounds per square foot successfully defeat the less severe tests described herein.

In the Table are shown results of ballistic tests on three products. Product A has an upper layer or volume approximately 0.1 inch thick of a composition hot pressed from 50 weight percent TiB_2 and 50 percent Ti metal powder, a middle layer or volume of about 0.1 inch thick pressed from 25 percent TiB_2 and 75 percent Ti metal powder, a lower layer about 0.05 inch thick pressed from Ti metal without TiB_2, and an alloy plate about 0.125 inch thick of Ti—6Al—4V alloy. Product B has an upper layer about 0.03 inch thick of similarly hot pressed 50 percent TiB_2 and 50 percent Ti, a middle layer about 0.1 inch thick of 25 percent TiB_2 and 75 percent Ti, a lower layer of about 0.05 inch thick of 100 percent Ti, and an alloy plate of Ti—6Al—4V about 0.125 inch thick. Product C has a top layer about 0.03 inch thick pressed from 50 percent TiB_2 and 50 percent Ti, a lower layer about 0.02 inch thick of 100 percent Ti and an alloy plate about 0.125 inch thick of Ti—6Al—4V alloy.

EXAMPLE II

The procedure of Example I has been repeated with various thickness of layers and compositions some of which were tested as shown in the Table. In one of these procedures a continuous gradient was approximated by producing a twelve layer structure comprising a metal base of Ti—6Al—4V approximately 0.125 inch thick bearing eleven graded layers thereon. As in Example I, a first layer in an amount which, when fully compressed will compact to a layer approximately 0.022 inch thick was placed in a hot pressing mold, this layer being a uniform mixture of 50 percent by weight titanium diboride and 50 percent by weight powdered titanium metal. Thereafter, 10 successive layers, each adapted to compress to a layer 0.022 inch thick, were placed thereover, each layer containing about 5 percent less titanium diboride than the previous layer, until the last or top layer was a layer of titanium powder. The Ti—6Al—4V metal was then placed in contact with the titanium metal powder, and the structure hot pressed as in Example I. After hot pressing, the product was tested against 30 caliber armor piercing ammunition at 2,400 ft./sec. velocity, with similar but better result as with a four zone structure: the ceramic was punctured and lifted from the alloy, but there was no penetration of the alloy. The product also resisted successfully impact of 30 caliber armor piercing ammunition at 2,500 ft./sec. velocity.

PRODUCT	TEST CONDITIONS	TEST RESULTS
A Area density 8.6 lbs./ft.	Threat 30 caliber AP; Velocity 2500 ft./sec. Obliquity angle 0°.	Ceramic fragmented; projectile stopped;. no penetration of alloy
A	Threat 30 caliber AP; Velocity 2400 ft./sec. Obliquity angle 0°.	Ceramic punctured and lifted from alloy; no penetration of alloy.
A	Threat 30 caliber ball; Velocity 2500 ft./sec. Obliquity angle 0°.	Ceramic punctured and lifted from alloy; no penetration of alloy.
A	Threat 30 caliber ball; Velocity 1400 ft./sec.; Obliquity angle 0°.	Small surface chip on ceramic; no damage to alloy.
A	Threat 17 grain fragment; Velocity 3000 ft./sec.	Same ceramic surface damage; no damage to alloy.
B Area density 7.1 lbs./ft.	Threat 17 grain fragment; Velocity 3500 ft./sec.	Ceramic punctured and lifted from alloy; no penetration of alloy.
B	Threat 17 grain fragment; Velocity 4000 ft./sec.	Ceramic punctured but not lifted; partial penetration of alloy.
C Area density 4.2 lbs./ft.	Threat 30 caliber ball; Velocity 1500 ft./sec. Obliquity angle 0°.	Partial fragmentation of ceramic; ceramic not lifted; no penetration of alloy.

The test conditions regarding 30 caliber AP at 2,400 ft./sec. velocity has been repeatedly used in the laboratory as a standard test procedure with consistently informative results. When a single test is performed for comparative purposes, this is the test now selected. Thus, this test procedure in the Table represents many repeated experiments.

The thickness of the shaped articles will depend on use and application, as well as on shape and structure. The purpose of the investigation illustrated by the examples has been to develop products having the lightest possible weight capable of defeating the severe threats to which they were subjected. Body thicknesses considerably greater can be employed. In such cases, it is expected that a more nearly continuous gradation will be advantageous. Layer **12**, the interface layer, need not be very thick. The second layer **13** may comprise a substantial thickness or depth of the article. The exposed layer **14** must be thick enough to receive and withstand the initial impact. For the purposes of the very severe threats of the tests shown in the table, layer **12** was satisfactory at a thickness of about 0.05 inch and thinner layers appear to be excellent. Layer **13** was preferred at a thickness of about 0.1 inch in a four layer structure and layer **14** preferred at a thickness of about 0.1 inch. The thinnest structure tested to date for ballistic impact had a total thickness of 0.075 inch, of which the metal support was 0.032 inch, layer **12** was 0.01 inch, layer **13** was 0.013 inch and layer **14** was 0.02 inch. This exhibited moderate ballistic impact resistance.

It is to be expected that elements related to titanium, such as for example, hafnium or zirconium may partly

or completely replace titanium in the products. In particular, hafnium may be used to replace part or all of the titanium content of the titanium diboride, and zirconium may replace a significant portion of the titanium of the titanium diboride.

It also is realistic now to contemplate use of these new structural ceramics for many of the purposes where the combination of properties of ceramics and of metallic structural backing support are important.

I claim:

1. A graded structure comprising a hot pressed body having a structure of graded composition, the exposed face of the body having a boron and titanium concentration corresponding to the boron and titanium concentrations of a mixture of between about 25 and about 60 percent by weight of TiB_2 and about 75 and about 40 percent by weight of titanium, and the back face of the body having a substantially lower boron concentration, the boron and titanium concentrations at the back face corresponding to the boron and titanium concentrations of a mixture of between about zero and about 35 percent TiB_2 and between about 100 percent and 75 percent titanium.

2. A graded structure according to claim 1, wherein the back face of the hot pressed body is bonded to a metal support surface.

3. The graded structure of claim 1, wherein the back face of the body is bonded to a titanium metal support structure by means of a metallic titanium interface.

4. The graded structure of claim 1, wherein the back face of the hot pressed body is bonded to a metal titanium alloy having a composition of approximately 90 percent titanium, 6 percent aluminum and 4 percent vanadium.

5. A graded structure comprising a hot pressed body having a structure of graded composition, the impact receiving face of the body having a boron and titanium concentration corresponding to the boron and titanium concentrations of a mixture of between about 25 and about 60 percent by weight of TiB_2 and about 75 and about 40 percent by weight of titanium, and the back face of the body having a substantially lower boron concentration corresponding to the boron and titanium concentrations of a mixture of between about zero and about 35 percent TiB_2 and between about 100 and 75 percent titanium and a metallic titanium support bonded to the back face of the hot pressed body.

6. The structure of claim 5, wherein the metallic titanium support is bonded to the hot pressed body by a layer of hot pressed powdered titanium metal.

7. A method of forming a graded structure comprising

forming a first mixture of finely divided powders containing titanium and boron consisting essentially of proportions corresponding to between about 25 and about 60 percent by weight titanium diboride and the remainder essentially titanium;

separately forming at least one second mixture of finely divided powders containing titanium and boron consisting essentially of proportions corresponding to between about 10 and about 25 percent by weight titanium diboride and the remainder essentially titanium;

disposing said first mixture and at least one of said second mixtures in graded layers, said layers being so disposed and arranged that said first mixture having higher boron content is positioned to become an exposed surface in a formed structure and said second layer having less boron content to become a back surface facing away from said exposed surface;

forming said powders into a shaped graded structure hot pressing said graded layers at a temperature between about 2,100°F. and about 2,500°F.; and

bonding said back surface of said pressed layers to a metal structure by means of a metallic titanium interface.

8. The method of claim 7, wherein the first mixture of powders is a mixture of titanium diboride powder and titanium metal powder.

9. The method of claim 7, wherein said metal structure is bonded to said shaped pressed powder structure in the hot pressing step.

10. The method of claim 7, wherein said metal structure is bonded to said shaped pressed powder structure subsequent to the hot pressing step.

11. In the method according to claim 7, wherein said metal structure is metallic titanium bonded to said shaped pressed powder, the step comprising hot pressing graded layers of said first and second mixtures, an intermediate layer of titanium powder and a metallic titanium structure.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,802,850 Dated Apr. 9, 1974

Inventor(s) Edward V. Clougherty

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In The Abstract,

line 14, delete "geometry"

line 15, delete "grometry" and insert --geometry--

Column 9, line 45, after "100" insert --percent--

Signed and Sealed this

fifth **Day of** *August 1975*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks

UNITED STATES PATENT OFFICE

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