United States Patent Office

3,729,372

Patented Apr. 24, 1973

1

3,729,372

BORON CARBIDE BALLISTIC ARMOR MODIFIED WITH CHROMIUM AND/OR BORON

Ben Matchen and David Robertson, Niagara Falls, Ontario, Canada, assignors to Norton Research Corporation (Canada) Limited, Niagara Falls, Ontario, Canada

No Drawing. Filed Nov. 22, 1971, Ser. No. 201,114
Int. Cl. B32b *1/12, 17/10;* C04b *41/04*
U.S. Cl. 161—193 7 Claims

ABSTRACT OF THE DISCLOSURE

Composite ceramic armor with improved ballistic properties. Basic boron carbide armor is improved by the addition to the boron carbide of certain quantities of chromium and/or boron. Improved ballistics also result from a multilayer ceramic face plate wherein one or more layers of the above modified boron carbide is combined with a layer of boron carbide to form an integral ceramic face plate.

BACKGROUND OF THE INVENTION

The invention relates to ceramic composites. More particularly the invention relates to ceramic composites suitable as armor plate for the protection of personnel and equipment from ballistic projectiles.

The utility of armor for the protection of personnel and equipment has long been recognized and utilized. The most successful modern armor is a composite structure consisting of a backing means or plate composed of a resin-glass fabric laminate to which has been adhered a hard ceramic face plate of e.g. boron carbide, silicon carbide, or aluminum oxide. Such a composite armor is described in detail in United States Letters Patents #3,509,833 and #3,516,989. Hard ceramic faced composite armor is also known which utilizes a metal backing in place of the aforementioned resin-glass cloth laminate backing, such as the metal backed ceramic of United States Letters Patent #3,431,818 which includes such metals as aluminum, aluminum alloys, and titanium having hard ceramic face plates adhered thereto. The mechanism by which the aforementioned types of armor successfully defeat ballistic projectiles, such as armor piercing bullets, is explained in detail in the cited patents. In summary however, it has been found that when a high velocity projectile such as a .50 caliber armor piercing bullet strikes the ceramic face plate of such an armor composite, the oncoming projectile is shattered or blunted, frequently with an accompanying local shattering of the ceramic spreading outwardly from the point of impact. The residual energy of the shattered or blunted projectile and the energy imparted to the shattered pieces of the ceramic face is absorbed by the relatively resilient metal or glass-resin laminate backing.

The primary advantage to the ceramic type of armor resides in the fact that it has about a 4 to 1 weight advantage over the prior art steel armor, i.e. a ceramic composite armor of a given weight per unit of protective area will have 4 times the resistance to penetration of high velocity projectiles as will a steel armor plate of equal weight per unit of protective area, or in other words, ceramic armor provides a degree of protection equal to that of steel armor plate at about one-fourth of the weight of the latter.

Composite ceramic armor is amenable to being fabricated into many protective articles such as the personnel body armor of United States Letters Patent #3,559,210 and the protective aircraft seat of United States Letters Patent #3,581,620 as well as protective structural components for ground vehicles and aircraft in the form of panels or the like to protect engines, fuel tanks and other vital parts of the vehicle or aircraft.

2

SUMMARY OF THE INVENTION

The ballistic property of hot-pressed boron carbide armor can be substantially improved by addition to the boron carbide molding powder of certain quantities of chromium, boron, or mixtures thereof. The result is that for a given weight per unit of protective area, the so-called areal density usually expressed in pounds per square foot, the hot-pressed chromium, and/or boron modified boron carbide ceramic plate of the present invention produces a composite armor with the backing that is up to about 12% superior in its ballistic properties, i.e. it will resist penetration of high velocity armor piercing projectiles travelling at a velocity approximately 12% greater than the velocity of projectiles which the conventional boron carbide armor is capable of protecting against. The practical manifestation of the foregoing, and the improvement over the prior art composite boron carbide armor, is that it provides a composite armor system with about 12% more protection capability.

The ceramic face plate portion of the invention composite armor may be made up entirely of hot-pressed boron carbide modified with chromium, boron, or mixtures thereof.

The ceramic face plate however, may be made up of only a layer of the modified boron carbide with the remainder of the thickness of the ceramic plate being composed of conventional boron carbide. The modified boron carbide layer may be on the front or outer surface of the ceramic plate, i.e. the surface which is impacted by the high velocity projectile, or it may be on the rear or back side, i.e. the side which is adhered to the fiber glass or metal backing means or plate, or, the modified boron carbide portion may be sandwiched between two layers of conventional boron carbide. Furthermore, the modified boron carbide portion of the ceramic face plate may be in more than one layer, e.g. the face plate may be made up of two modified boron carbide layers between which is sandwiched a layer of conventional boron carbide. Whatever might be the physical location of the modified boron carbide layer or layers, it must be present in the ceramic face plate in the amount of from about 20 to 100% of the total weight of the ceramic face plate.

The hot-pressing process employed in the fabrication of the invention ceramic armor is conventional and well known as will be evident by the detailed description of the hot-press process contained in the ensuing examples. Similarly, the process used to form the multilayer ceramic plates, which preferably involves first cold-forming of each of the layers followed by hot-pressing all of the layers together to form the integral plate, is part of prior art. None of the processing involved is considered a part of the present invention.

The backing means or plate may be any of the known materials suitable for the purpose. Such materials include multiple ply resin-glass fabric laminate, metals such as aluminum, aluminum alloys, titanium and the like, or even sheet steel, although the latter is obviously undesirable because of its weight. So too, the method of unitizing the backing means and the ceramic face plate may be accomplished by any of the known techniques such as adhering the two with a polysulfide or epoxy adhesive which may or may not include a resilient energy absorbing interlayer between the backing means and the invention ceramic face plate.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the preferred mode of practicing the present invention, commercial grade boron carbide is employed which is the same type of material used to fabricate the prior art boron carbide composite armor. A typical analysis of commercial grade boron carbide is as follows:

Constituents:	Weight percent
Boron	76
Carbon	21
Boron oxide	1
Iron oxide	0.5
Aluminum oxide	0.25
Copper oxide	0.1
Cobalt oxide	0.1
Calcium oxide	0.2
Manganese oxide	0.1
Trace amounts of sodium, sulfur, silicon, titanium, chromium.	

The foregoing does not preclude the use of either more deficient boron or boron rich types of boron carbide Boron carbide with a molar ratio of 3.5 to 4.5:1 would be operable. The particle size of the boron carbide powder is not hypercritical but preferably ought to be in the range of 3 to 15 microns for the sake of attaining maximum density during the hot-pressing operation. The same is true of the particle size of the chromium and boron. The processing technology employed in the hot-pressing of the ceramic face plates and that for the assembly of the face plate and the resin-fiber glass backing were the conventional ones and for the numerous examples set forth below, were as follows:

Ceramic plate forming process

A quantity of boron carbide powder or boron carbide powder blended with the desired weight percent of the chromium, and/or boron modifier is dampened with 28 percent by weight of a 48 percent by weight aqueous emulsion of Amprol #24, an emulsifiable wax sold by Merck & Co. Inc. The dampened powder is then dried at about 82° C. to remove the water.

A predetermined amount of this molding powder, that amount sufficient to result in a hot-pressed plate approximately 6 x 6 x 0.3 inches, is placed in a mold and pressed at approximately 1 ton per square inch at room temperature resulting in a preform approximately 6 x 6 x 0.7 inches. This preformed plate is then placed in a graphite mold assembly, and the assembly placed in an induction heated press where the contents of the mold are subjected to a temperature of from 2000 to 2200° C. at a pressure of approximately 1 ton per square inch, the entire hot-pressing cycle involving 1¾ to 2½ hours. The hot-pressing operation is carried out preferably in the presence of a nonoxidizing atmosphere and even more preferably in an inert atmosphere such as argon. The hot-pressed plate is then removed from the mold, flash and/or other imperfections are removed and the plate is assembled with the backing means or plate.

When the ceramic face plate is itself a composite, then the two or more layers of the final plate are first cold-formed in the following manner: Assuming that the ceramic plate is to be trilayered and is to weigh 900 grams, then 300 grams of material A is placed in a mold, spread level and then pressed at room temperature at about 1 ton per square inch; 300 grams of material B is then spread level upon the previously cold-pressed 300 gram portion, the two layers are then cold-pressed as before; finally, a second 300 grams of material A is spread level upon the material B surface of the cold-pressed A–B composite and this composite and the final layer is then cold-pressed as before. The multilayered cold-pressed plate A–B–A is then hot pressed as described above.

Assembly of ceramic face plate and backing

A standard 12 ply unsaturated polyester resin bonded fiber glass laminate of appropriate size, i.e. 6 x 6 inches, is mildly sandblasted to provide an optimum surface for adhesion. The ceramic face plates and the backing pieces are warmed to a range of about 32° C. to 38° C. A thermosetting polysulfide adhesive is spread over the sandblasted surface of the backing with a serrated spreader. The ceramic face plate is then placed on the cement or adhesive coated surface and forced into the adhesive by pressing and moving slightly by hand. Each composite is then clamped tightly in the center for 2 or 3 minutes to force out excess adhesive and air. The excess adhesive is removed and the composites, while still clamped, are heated at about 65° C. for 2 to 2½ hours in order to thermoset the polysulfide adhesive. The resin-fiber glass with ceramic face plate composite is now a finished piece of ballistic armor.

Following the procedures outlined above, composite ceramic armor with 12 ply fiber glass backing, was fabricated of various ceramic face plate compositions and having a variety of layer arrangements within the face plates made of the various compositions described above. These were tested ballistically against standard boron carbide armor. The ballistic properties of this type of armor are, amongst other things, highly dependent on the areal density (weight per unit area) of the composite and the specific gravity of the materials making up the armor. Herein the same 12 ply backing was employed in all samples and the ceramic face plate in all cases was about 0.3 inch thick. Thus the face plates composed of chromium or boron modified boron carbide had a different specific gravity than the control composite made with standard boron carbide. In the table to follow two columns of relative ballistic data appear. The relative ballistic data identified as "Actual" are based on the actual ballistic data measured, relative to the reference standard boron carbide armor, ignoring the differences in areal density of the composite armor of the present invention as compared to the reference standard boron carbide armor; the actual areal density is also shown beside the "Actual" relative ballistic results. The ballistic results of the invention composites corrected or adjusted to an areal density of 6.55 pounds per square foot, the areal density of the boron carbide reference standard, are shown in the column identified as "Corrected." The "Corrected" ballistic data for the invention composite armor thus shows the degree of superiority of said invention armor as compared to the standard boron carbide armor for the same areal density. The superiority of the invention armor may be taken advantage of by direct substitution of invention armor of the same areal density (weight) as the standard boron carbide armor for the latter thus providing armor that will defeat ballistic projectiles travelling at a greater velocity than the standard boron carbide armor is capable of stopping, or, substitute invention armor of a reduced areal density (weight) for the standard boron carbide armor thus reducing the weight of the armor employed while providing an equal degree of protection as is afforded by the heavier standard boron carbide armor.

In the following table of examples, the data under "Resistance to Penetration" shows the capability of the invention ballistic armor to resist penetration by armor piercing projectiles in terms of percent related to the capability of standard prior art composite boron carbide armor as 100%. The amounts of chromium listed under "Composition Wt. Percent" are the amounts of chromium added to the boron carbide powder and not the amounts of chromium remaining in the ceramic plate after hot-pressing. The latter amount is always substantially less than the former, however it is the former that governs the properties of the final product and not the latter. Unless otherwise indicated, the layers are each of equal weight, e.g. in a bilayer plate the weight of the B_4C layer is equal to the weight of the modified layer.

Example	Layers in face plate		Resistance to penetration [1]			
	Location	Composition, wt. percent	Actual, percent	A.D.[2]	Corrected, percent	A.D.[2]
Control	Single	100% B_2C	100	6.55	100	6.55
I	do	4%+96% B_4C	114	6.70	111	6.55
II	do	8% B+92% B_4C	121	7.11	111	6.55
III	do	2% Cr+98% B_4C	111	6.77	108	6.55
IV	do	16% B+84% B_4C	108	6.57	108	6.55
V	do	5% Cr+95% B_4C				
VI	Double—Front	100% B_4C	100	6.12	108	6.55
	Rear	10% Cr+90% B_4C				
VII	do—Front	25% B+75% B_4C	114	6.79	109	6.55
	Rear	10% Cr+90% B_4C				
VIII	Triple—Front	8% B+92% B_4C	112	6.78	109	6.55
	Middle	5% Cr+95% B_4C				
	Rear	8% B+92% B_4C				

Percentages rounded off to the nearest whole percent.
A.D. is areal density in pounds per square foot.

The mechanism by which the addition of boron and/or chromium enhances the ballistic properties of composite ceramic faced armor made from boron carbide is not completely understood. It is believed with a reasonable degree of confidence however, that the mechanism involving boron modified boron carbide is different than that when chromium modified boron carbide is involved.

When 4 to 35% by weight of boron is added to boron carbide and ceramic plates hot-pressed therefrom, the resulting ceramic plate when wedded with a resin-fiber glass backing, is a superior armor to the standard boron carbide armor. Analysis of the modified boron carbide plate shows no substantial weight loss, i.e. loss of boron, yet the chemical analysis shows no significant amount of free boron. For example when a standard boron carbide powder was modified with 8% by weight of boron and hot-pressed, the chemical analysis of this product was as follows, compared to the standard unmodified boron carbide powder:

	Weight percent composition	
	Standard B_4C	B modified B_4C
Carbon	20.5	20.6
Boron	76.5	77.4
Other	3.0	2.0

Chemical analysis of the two ceramic plates failed to show any significant difference in composition yet the ballistic properties of the two were substantially different, the boron modified boron carbide being 11% more effective in resisting penetration by armor piercing projectiles. At least some of the boron reacts with free carbon in the boron carbide.

The addition to the standard boron carbide molding powder of 2 to 10% by weight of chromium, in the form of the powdered metal or as a solution of for example chromium acetate, on the other hand appears to improve the ballistic properties of standard boron carbide by a different mechanism. It is believed that the chromium does not react to any significant degree with boron carbide or free carbon. A substantial portion of the chromium added melts and is squeezed out of the ceramic plate during the hot-pressing of said plate. For example when two chromium modified boron carbide cold-formed plates containing 5 and 2% by weight of chromium were hot-pressed, the resulting finished plates contained only 1.04 and 0.73% by weight respectively, of chromium. That quantity of chromium which was lost, in both cases, was squeezed out of the ceramic composition during the hot-pressing operation. Some minor amounts of chromium boride were identified in the finished plates. The addition of an amount of chromium less than 2% by weight, for example 1%, with essentially all of the 1% remaining in the finished plate after hot-pressing, does not produce a superior product, ballistically, to the standard unmodified boron carbide plate. This strongly suggests that the mechanism by which the chromium modification manifests itself in an improved final product, is a process phenomenon.

Although the foregoing description of the preferred mode of practicing the present invention involves hot-pressing of the ceramic preforms, cold-pressing to form the preforms followed by sintering is also operable. The preference for hot-pressing arises from the capability of this method of consistently producing plates of maximum and uniform density.

What is claimed is:

1. A composite ballistic armor including a backing means and integral ceramic face plate, said face plate comprising 20 to 100% by weight of one or more of a first type of layer, said first type of layer consisting essentially of the product resulting from hot-pressing a mixture of boron carbide and a material selected from the group consisting of chromium, boron and mixtures thereof, the remainder of said face plate being a second type of layer consisting essentially of boron carbide.

2. The ballistic armor of claim **1** wherein said backing means is a metal.

3. The ballistic armor of claim **1** wherein said backing means is a fiber glass-organic polymer laminate.

4. The ballistic armor of claim **1** wherein said face plate consists of one of said first type of layer and one of said second type of layer.

5. The ballistic armor of claim **1** wherein said face plate consists of two of said first type of layer separated by one of said second type of layer.

6. The ballistic armor of claim **1** wherein said first type of layer is the product resulting from the hot-pressing of a mixture consisting essentially of 4 to 35% by weight of boron and 65 to 96% by weight of boron carbide.

7. The ballistic armor of claim **1** wherein said first type of layer is the product resulting from the hot-pressing of a mixture consisting essentially of 2 to 10% by weight of chromium and 90 to 98% by weight of boron carbide.

References Cited

UNITED STATES PATENTS

3,516,989	6/1970	Cook	161—93
3,649,342	3/1972	Bartlett	161—404 X
3,671,374	6/1972	Kolarik	161—404 X

ROBERT F. BURNETT, Primary Examiner

M. E. McCAMISH, Assistant Examiner

U.S. Cl. X.R.

75—204; 89—36; 106—43; 161—196, 225, 404