July 3, 1973 M. L. WILKINS ET AL 3,743,569

ARMOR OF CERMET WITH METAL THEREIN INCREASING WITH DEPTH

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Fig. 1.

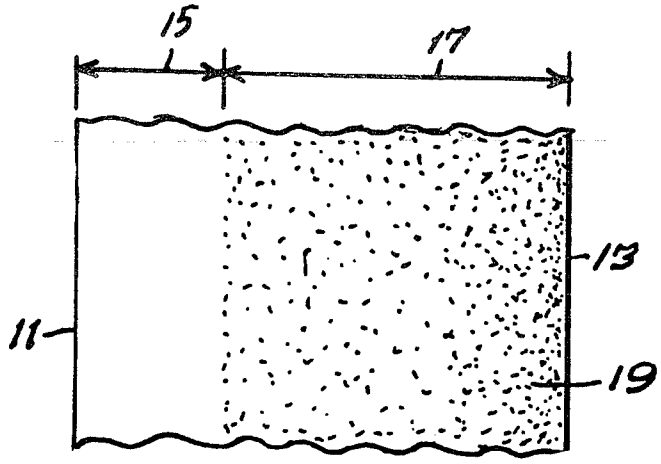
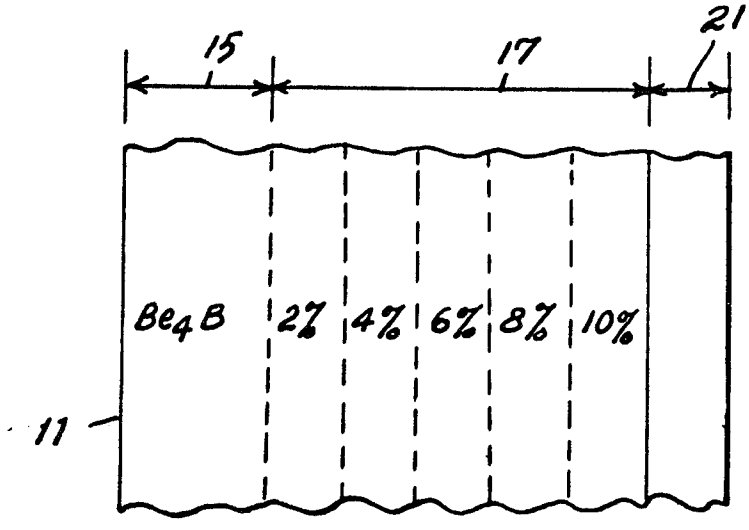


Fig. 2.



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ARMOR OF CERMET WITH METAL THEREIN INCREASING WITH DEPTH

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ABSTRACT OF THE DISCLOSURE

An armor system comprising a ceramic matrix having a gradient of fine ductile metallic particles dispersed therein in an amount of from 0.0% commencing at the front or impact surface of the armor to about 2 to 15% by volume along the interface to the back of the system.

The present invention relates to an armor system comprising a ceramic matrix having a gradient of fine metallic particles dispersed therein.

Prior lightweight armor system comprised, e.g., a monolithic ceramic material such as Al_2O_3 bonded to a ductile metal plate such as aluminum. A projectile striking the material fractures the brittle Al_2O_3 ceramic plate forming a central cone beneath the point of impact. Simultaneously, the cone distributes stress from the projectile over a circular area of the aluminum metal plate while bending moments in the metal plate initiate a fracture at the base of the cone. The actual point of fracture initiation is probably at a jagged surface feature on the interface between ceramic and the aluminum metal plate. The crack is propagated which contributes to the collapse of the ceramic cone thereby enabling the projectile to push through the armor.

The present invention relates to an armor in which the constituent materials are intimately mixed in a varying ratio along the depth dimensions of the material. At the projectile impact surface of the armor system, the armor is 100% ceramic. The metal content increases in incremental amounts toward the opposite end of the armor system. The resulting integral armor material has a continuous concentration gradient and no phase boundaries within the material. Hence, it tends to resist the formation of large cracks along or near the projectile impact axis, thereby providing stress distribution over larger portions of the body armor than has previously been possible. The resulting structural improvement is more effective in defeating armor-piercing projectiles than has been heretofore available, yet has the light weight advantage found in prior armor.

The introduction of the ductile metal into the ceramic produces essentially a trade off of gains and losses in the ballistic limit at the front-face and near the interface of the armor. More specifically, the addition of a ductile metal at the front-face of the armor decreases ballistic limit because of the decreased hardness and stiffness of the metal-ceramic mixture as compared with pure ceramic. At the backside of the armor, however, the metallic addition increase the ballistic limit because of the increased tensile strength and ductility at the interface. The reason why cermets with a gradient of 2 to 15% by volume of the metal exhibit an improved ballistic limit is because at this concentration, the losses at armor face are far exceeded by the gains due to improved properties along the interface of the system. The expression, "cermet" is used in the art to connote a ceramic-metallic composition.

It is an object of this invention to provide and disclose a lightweight armor having an improved ballistic limit.

It is a further object of this invention to provide and disclose an integral armor comprising a ceramic matrix having a gradient of fine metal particles dispersed therein.

It is an object of this invention to provide and disclose an integral armor comprising a hard exterior impact surface in combination with an energy absorbing interior medium.

Other objects and a fuller understanding of this invention may be had by referring to the following description and claims taken in conjunction with the accompanying drawing in which:

FIG. 1 is a schematic illustration of the gradient armor system.

FIG. 2 shows a schematic of a specific example of an alternative of FIG. 1.

Referring now to FIG. 1 of the drawings, the present armor material comprises impact surface **11** and back surface **13**. The armor material is divided into two segments. Segment **15** comprises a hard ceramic having high dynamic properties. This is the hard bullet shattering medium. Segment **17** comprises a layer having gradually increasing tensile strength, i.e., static strength and energy absorbing capacity. These properties are obtained by the incorporation of metallic phase **19** into the ceramic matrix in a progressively increasing volume fraction.

FIG. 2 shows an alternative of the armor system of FIG. 1. The system includes back-up material **21** which is constructed of "woven-roving" fiberglass. Illustrative, but without limitations, the dimensions of the armor system comprise a hard ceramic surface of approximately 0.215", a cermet segment of approximately 0.215" and a back-up material segment of approximately 0.215". The dimensions of the armor are dependent upon the projectile threat to be defeated. In certain applications, the back-up material may not even be necessary. This would result in a significant weight reduction.

An exemplary gradient armor is prepared by placing tetra beryllium boride powder in a 3" standard ram and die hot press. Five successive layers of Be_4B powder, mixed with Be powder in varying proportions, are positioned over the layer of Be_4B. The first layer contained Be_4B+2% by volume Be. The successive layers each contained additional 2% increments of Be until a layer containing Be_4B+10% by volume of Be was achieved as shown in FIG. 2. The powders were pressed in an argon atmosphere for 5 minutes at 1000° C. and 5400 p.s.i. to give a pressed disk 3" in diameter and 0.43" in thickness. The disk was surface ground to a thickness of 0.41" and then bonded with an adhesive sold under the trademark of Scotchcast 221, which is manufactured by the 3M Company, to back surface **13** of the gradient material.

The Be_4B/Be disk bonded to the fiberglass backing was ballistically tested with 0.30 caliber armor-piercing ammunition. A 5% increase in ballistic limit, i.e., projectile velocity required for penetration, was obtained when compared to an ungraded pure Be_4B armor of the same areal density. The density of the original Be_4B powder for this particular test was below theoretical density. Increasing the starting density of the Be_4B powder should significantly improve on the 5% value obtained. The graded Be_4B/Be armor permitted a 15% weight reduction compared with standard B_4C/fiberglass armor.

The gradient metal utilized must be compatible with the particular ceramic that it is dispersed in. Certain metal having a low density, e.g., below 5 g./cc. have been found to give improved results when combined with specific ceramics. In addition to B_4B/Be combination, other cermets such as Be O/Ti; Al_2O_3/Al and Ti Be_1/Ti, are considered to give improved results.

In general, it is desirable to have the lowest possible metal content, since the metal decreases the overall hard-

ness of the cermet. However, a certain percentage of metal is required to act as a cementing matrix. It has been found that operable gradient metal concentrations are in the range of 2–15% by volume. In addition to hot pressing, the cermet may be made by a method of plasma spraying wherein, e.g., Be_4B and Be are fed into a high temperature filame for deposition on a substrate.

Although we have described our invention with a certain degree of particularity, we wish it to be understood that we do not desire to be limited to the exact details of formulation shown and described, for obvious modifications will occur to a person skilled in the art.

Having described our invention, we claim:

1. A cermet armor material selected from the group consisting of:
   (a) a tetra beryllium boride matrix having a gradient of beryllium metallic particles dispersed therein,
   (b) a beryllium oxide matrix having a gradient of titanium metallic particles dispersed therein, and
   (c) a titanium beryllide matrix having a gradient of titanium metallic particles dispersed therein, said metallic particles being in an amount of 0.0% commencing at the impact surface of the material to about 2 to 15% by volume along the interface to the back of the material.

2. A cermet armor material in accordance with claim 1 wherein the ceramic matrix is tetra beryllium boride and the gradient constituent metallic particles are beryllium.

3. A cermet armor material in accordance with claim 1 wherein the ceramic matrix is beryllium oxide and the gradient constituent metallic particles are titanium.

4. A cermet armor material in accordance with claim 1 wherein the ceramic matrix is titanium beryllide and the gradient constituent metallic particles are titanium.

5. A cermet armor material in accordance with claim 1 wherein the ceramic matrix is tetra beryllium boride and the gradient constituent metallic particles are beryllium.

6. A cermet armor material in accordance with claim 1 wherein the ceramic matrix is beryllium oxide and the gradient constituent metallic particles are titanium.

7. A cermet armor material in accordance with claim 1 wherein the ceramic matrix is titanium beryllide and the gradient constituent metallic particles are titanium.

8. A cermet armor material selected from the group consisting of:
   (a) a tetra beryllium boride matrix having a gradient of beryllium metallic particles dispersed therein,
   (b) a beryllium oxide matrix having a gradient of titanium metallic particles dispersed therein, and
   (c) a titanium beryllide matrix having a gradient of titanium metallic particles dispersed therein, said metallic particles being in an amount of 0.0% commercing at the impact surface of the material to about 2 to 15% by volume along the interface to the back of the material, and having a backup plate attached to the back of the material.

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2—2.5; 89—36 A, 36 B; 109—83; 161—46, 162, 168, 166, 404