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Adams et al.

(54) STRUCTURAL PANEL INSERT WITH HONEYCOMB CORE

(76) Inventors: **Richard W. Adams**, Bolton, MA (US); **Renee MacPherson**, Attleboro, MA (US); **James Sorensen**, Eagan, MN (US)

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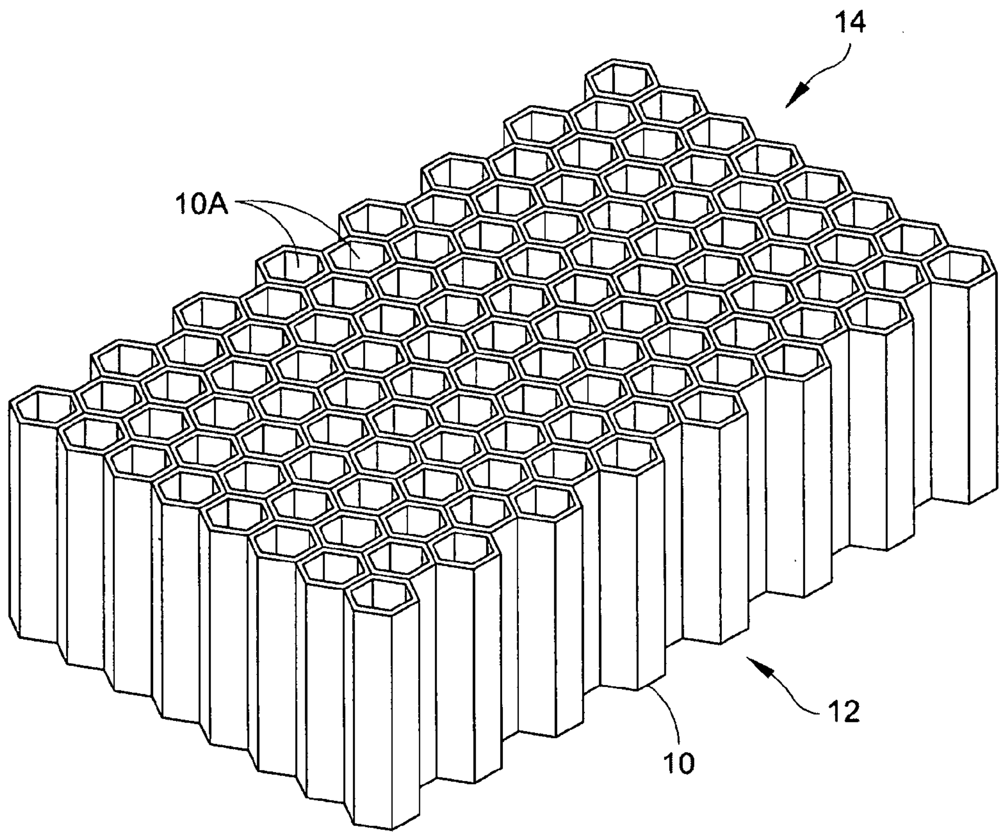
(57) **ABSTRACT**

A structural insert with a cellular core as a holder for filler materials, in combination with other dense or porous material types arranged in the structural insert, to achieve a desired shear strength and stiffness in desired locations. The insert having metal within any areas of open porosity and the insert capable of being used as a component in a composite system such as a light weight armor.



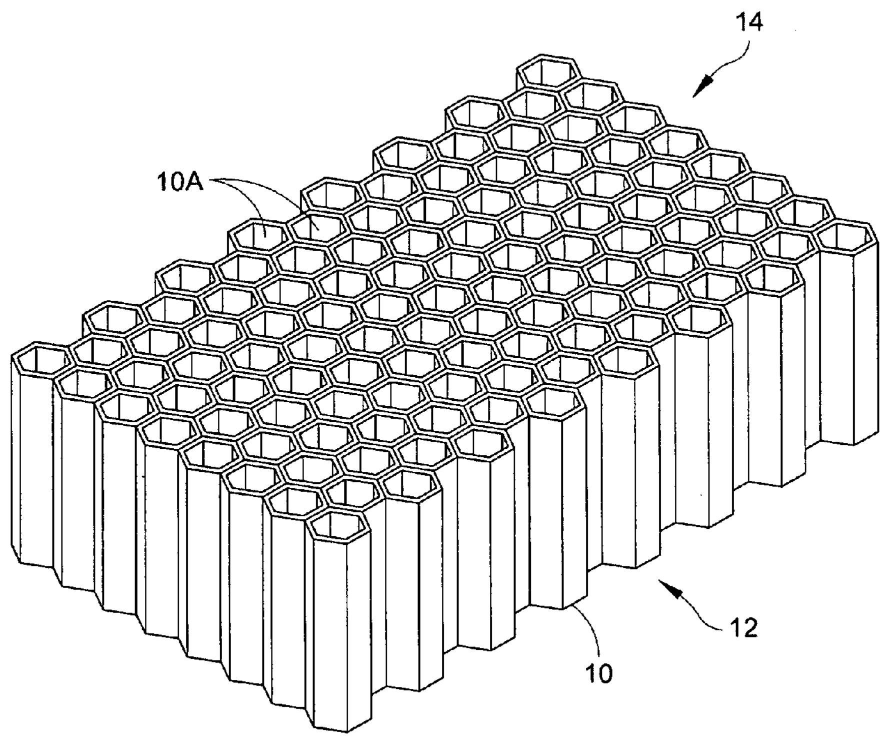


FIG. 1

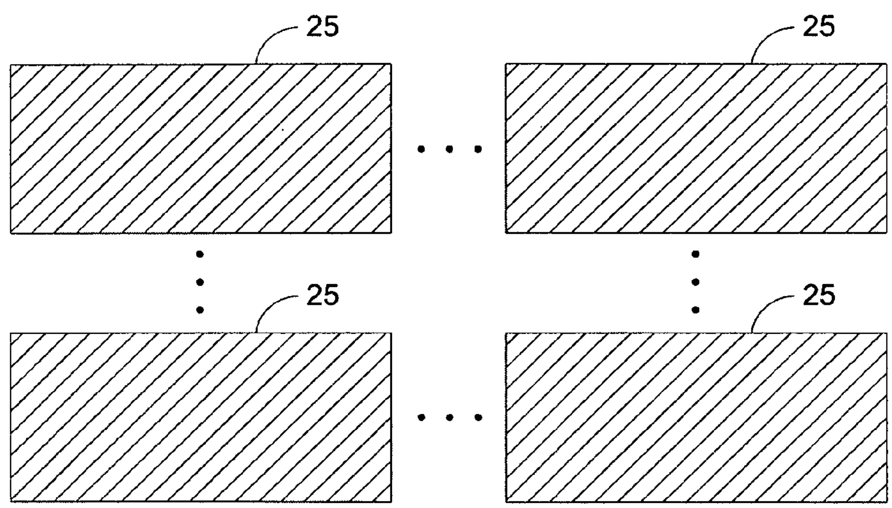


FIG. 2

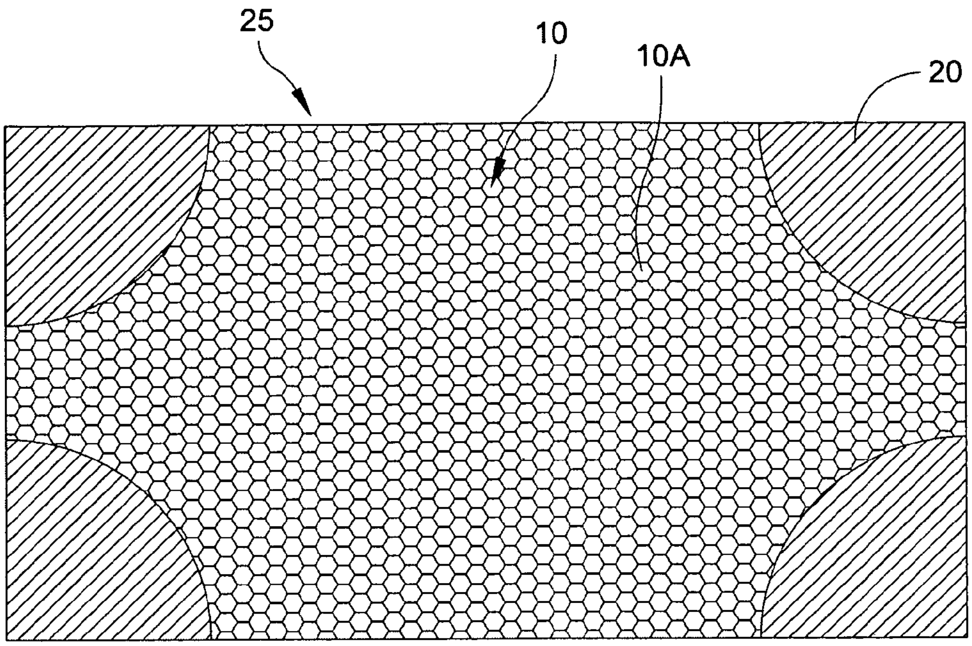


FIG. 3

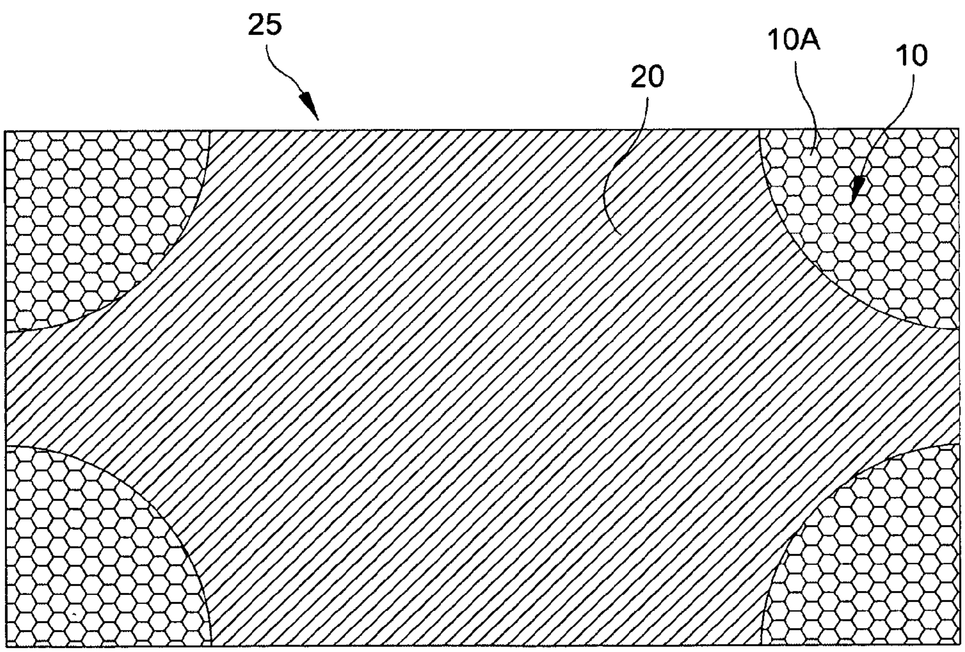


FIG. 4

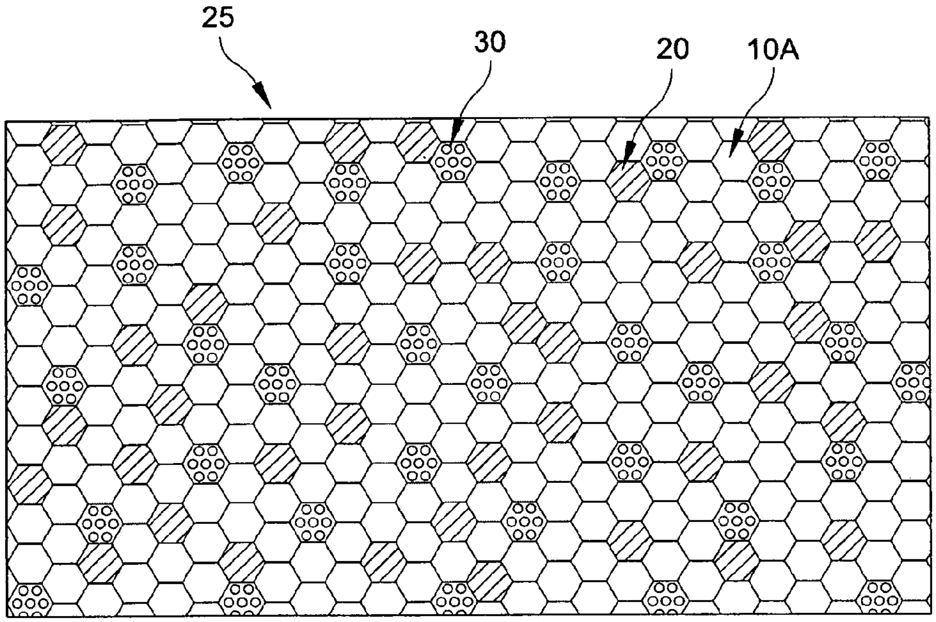


FIG. 5

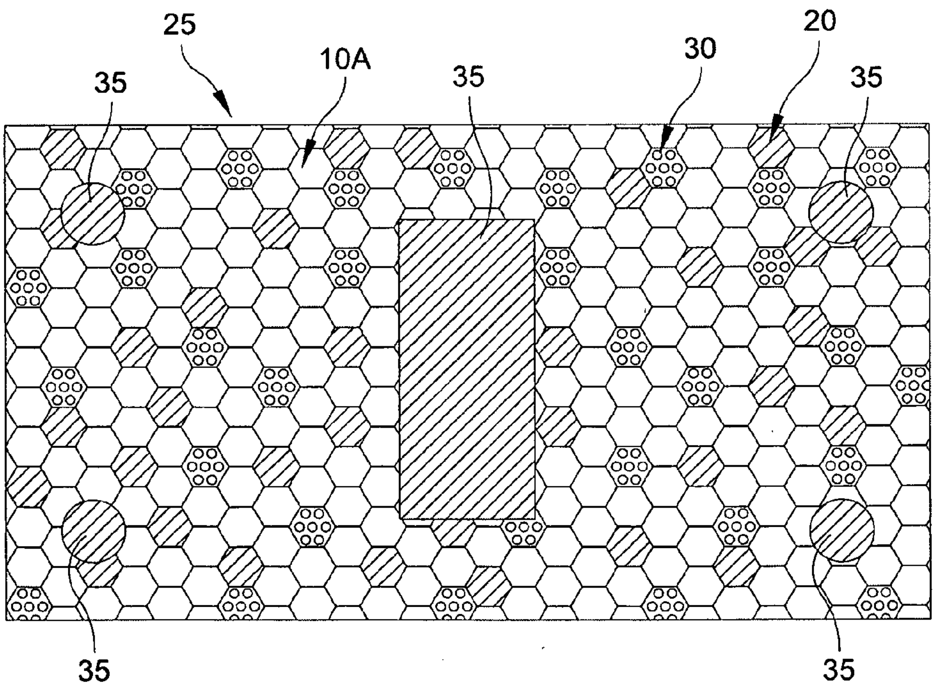


FIG. 6

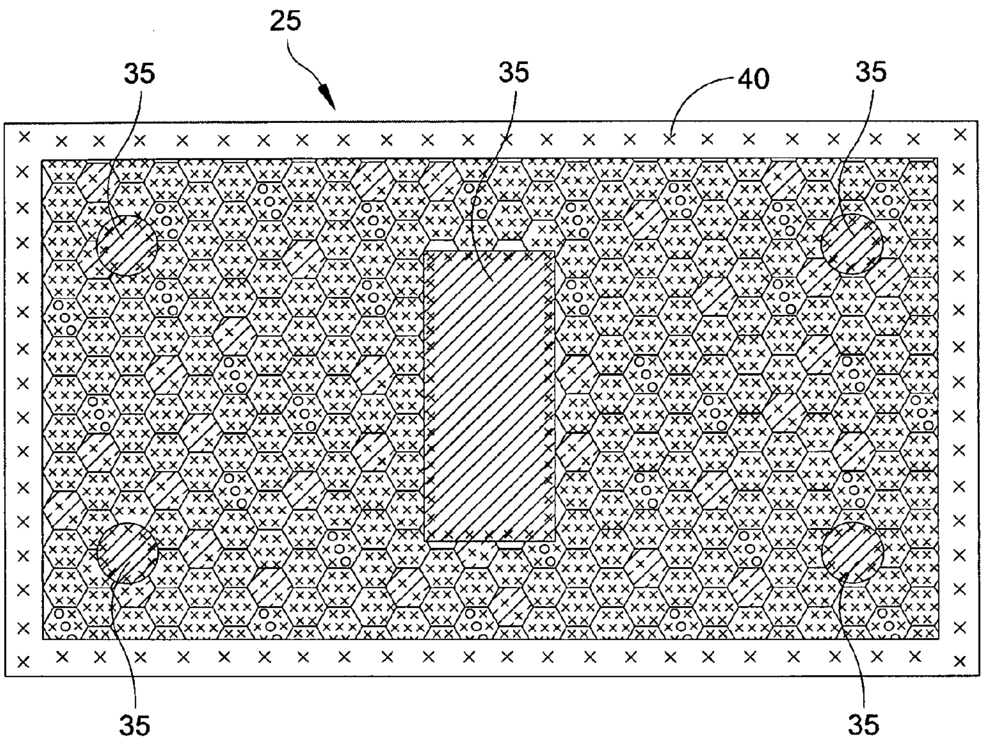


FIG. 7

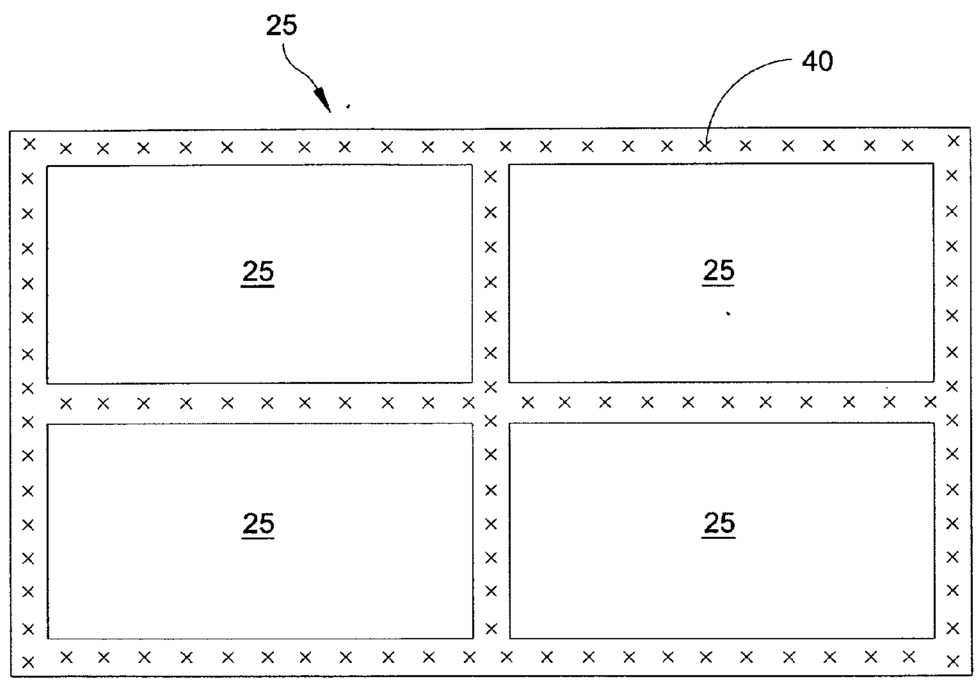


FIG. 8

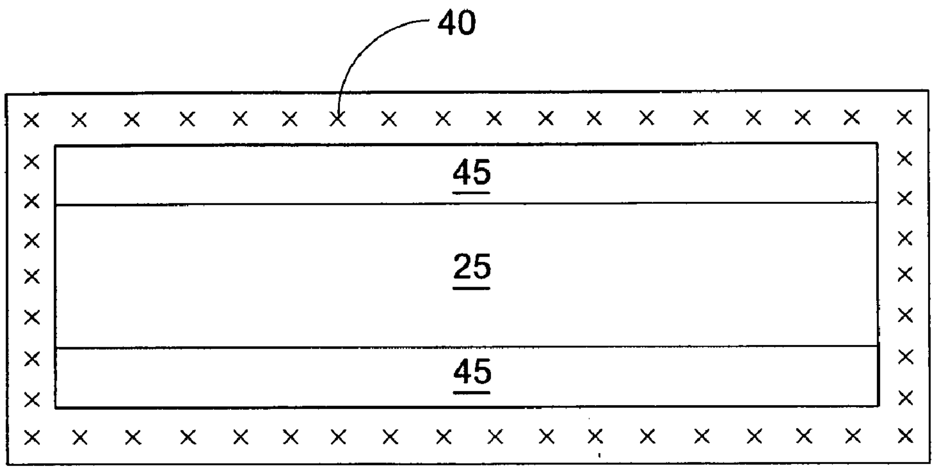


FIG. 9

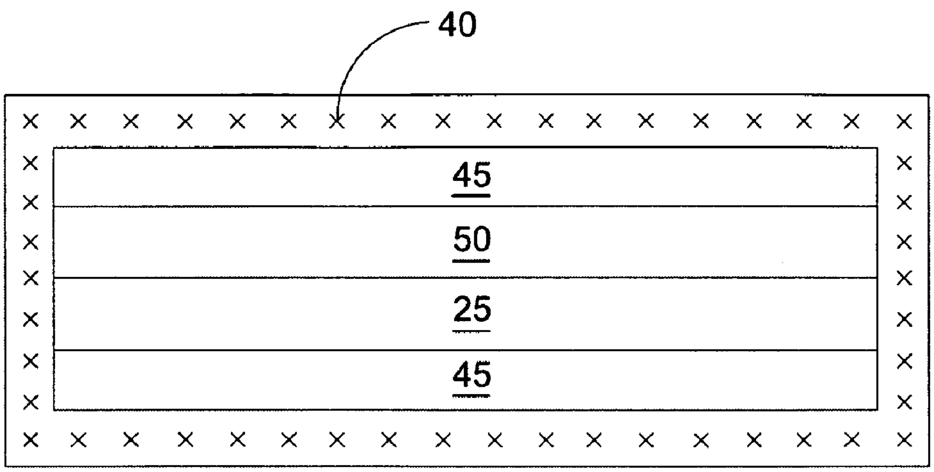


FIG. 10

STRUCTURAL PANEL INSERT WITH HONEYCOMB CORE

FIELD OF THE INVENTION

[0001] This invention relates to inserts for structural panels in general and more specifically to a structural insert for Metal Matrix Composite (MMC) Armor, the insert having a cellular structure with openings as a component part.

BACKGROUND OF THE INVENTION

[0002] Many different kinds of lightweight armor systems are known and are currently being used in a wide range of applications, including, for example, aircraft, light armored vehicles, and body armor systems, wherein it is desirable to provide protection against bullets and other projectiles.

[0003] While early armor systems tended to rely on a single layer of material, it was soon realized that the effectiveness of the armor system could be improved considerably by using more than one material layer; each layer optimized for a specific purpose. For example, utilizing a hard monolithic ceramic face to initiate destruction of hardened projectiles and a backing layer of energy absorbing material such as high strength Ceramic fibers.

[0004] However, Ceramic and other polymer composites have poor strength in the through-the-thickness direction and they are not as rigid or stiff as metal backings. But metal backings have the problem of increased weight due to their higher density.

[0005] It has been discovered by the present inventors that a metal or metal matrix composite backing, with lower density than an equivalent metal backing can be made by including a lightweight metal insert with cellular openings. Further, the openings can be filled with low density ceramic micro-spheres prior to infiltrating with aluminum.

[0006] It has been discovered that the use of an insert having a cellular structure filled with energy absorbing materials, such as high volume hollow micro-spheres functions to attenuate a blast from a projectile hit by deforming in response to the blast shock. The bubbles give some additional ability to absorb and deflect the blast force thus breaking up the attendant stress waves. Furthermore, the cellular structure can be placed in a variety of locations throughout the structural insert to achieve desired shear strength or density variations where needed.

[0007] Although honeycomb structures are prevalent in the prior art, a structural insert integrally cast in a Metal Matrix Composite (MMC) and utilizing a percentage of cellular structure placed in combination with other materials in a single insert is neither taught nor suggested in the prior art.

SUMMARY OF THE INVENTION

[0008] A structural insert according to the present invention can be utilized in a Metal Matrix Composite (MMC) structure such as an armor structure having one or more material layers with each material layer having at least one structural insert arranged along a common surface.

[0009] A portion of at least one structural insert up to and including the entire insert may contain a cellular structure. The cellular structure can be placed in a variety of locations throughout the insert in combination with other material types to achieve desired shear strength, bend strength, stiffness, and energy absorption where needed. The cellular structure may also contain filler materials inserted in the cells. The cellular structure enables locating the filler material in specific locations and acts as a "holder" for the filler materials. The insert may comprise in combination with the cellular structure dense or porous material types arranged in the insert .

[0010] The insert is infiltrated with a liquid metal which solidifies within the inserts open porosity. A reinforcement material containing a fraction of high volume hollow micro-spheres with interior voids can be utilized and placed within the inserts cellular structure to decrease the weight of the armor system. The inserts may include an infinite combination of dense material and porous material types and geometries. These dense materials may comprise inorganic material systems such as ceramics, metals or composites with dense microstructures.

[0011] The structural inserts of the present invention can be used as a component in the material layers of a Metal Matrix Composite Armor System and may be included in one or more material layers. A typical armor system may include multiple material components arranged in a common plane and stacked upon each other. The material components can include, in addition to the structural inserts of the present invention, inserts made of dense and porous material types, such as dense ceramic tiles or porous ceramic fillers.

[0012] The material layers are infiltrated with liquid metal which solidifies within the materials open porosity thereby binding the layers together to create a coherent integral structure. The selection of different dense and porous material types allows the designer to vary physical and mechanical properties throughout the structure for optimization and increased effectiveness of the armor system. The selection of different material types may be based on strength, toughness, thermal expansion and weight attributes of the individual material types desirable for projectile impact protection.

[0013] The liquid metal is introduced under pressure into the casting mold encapsulating and infiltrating the material layers. The mold chamber is fabricated to create the final shape or closely approximate that desired of the final product.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The invention is best understood from the following detailed description when read in connection with the accompanying drawings, which illustrate various embodiments of the present invention:

[0015] FIG. **1** is a perspective view of a Honeycomb material utilized in the structural insert of the present invention.

[0016] FIG. **2** illustrates that structural insert **25** can be configured as part of a multi-layer metal matrix composite armor system having multiple inserts **25** placed side by side and stacked upon each other.

[0017] FIG. **3** and FIG. **4** illustrate a structural insert **25** with alternative placement of honeycomb material **10** and filler material **20** prior to metal infiltration.

[0018] FIG. **5** illustrates a structural insert **25** utilizing a honeycomb material **10** with a portion of openings **10**A filled with a filler material **20** and with hollow micro-spheres **30**.

[0019] FIG. **6** illustrates the structural insert **25** of FIG. **5** further including metal inserts **35** placed within honeycomb material **10** prior to metal infiltration.

[0020] FIG. **7** illustrates the structural insert **25** of FIG. **6** subsequent to metal infiltration casting.

[0021] FIG. **8** illustrates a top view of the structural insert **25** of FIG. **6** arranged in a Metal Matrix Composite Armor subsequent to metal infiltration casting.

[0022] FIG. **9** illustrates a cross-section of the structural insert **25** of FIG. **6** having top and bottom facesheets **45** subsequent to metal infiltration casting.

[0023] FIG. **10** illustrates a cross-section of the structural insert **25** having facesheets **45** of FIG. **9**, and further including a dense ceramic layer **50**.

DETAILED DESCRIPTION OF THE INVENTION

[0024] A structural insert for a Metal Matrix Composite Armor having a polygonal or HoneyComb Core, according to the present invention, is best seen in the embodiments illustrated in FIGS. **3-10**. Referring to FIG. **1**, a honeycomb core or cellular structure **10** is disclosed with openings **10**A and oppositely facing sides **12** and **14** between which the openings **10**A extend. In the disclosed embodiment the openings **10**A are of hexagonal form, but may take on any cellular structure.

[0025] The honeycomb core **10** may be made from either ceramic or metal and is placed in a sealed mold cavity prior to metal infiltration casting. Suitable metal infiltrants include but are not limited to aluminum alloys, copper, titanium and magnesium, and other metal alloys cast from the molten liquid phase. The liquid metal infiltration process is described in U.S. Pat. No. 3,547,180 and incorporated herein by reference for all that it discloses.

[0026] FIG. **3** illustrates honeycomb core **10** as part of a structural insert **25** prior to metal infiltration. Insert **25** includes filler material **20** replacing a portion of honeycomb core **10** at the edges of the insert **25**. FIG. **4** illustrates an alternative embodiment where honeycomb core **10** replaces a portion of filler material **20** at the edges of insert **25**. It is contemplated that any combination of filler material **20** and honeycomb core **10** may be utilized in an insert **25** to provide different characteristics such as increased shear strength at the edges of insert **25** or blast force absorbtion and deflection of an attendant stress wave.

[0027] It is further contemplated that the inserts may be utilized in an armor structure having one or more stacked material layers and each material layer having at least one reinforcement insert arranged along a common surface, as illustrated in FIG. **2**.

[0028] An insert **25** having a honeycomb core **10** is illustrated in FIG. **5** and FIG. **6** prior to metal infiltration. In FIG. **5** a portion of openings **10**A are filled with a filler material **20** and with hollow micro-spheres **30** and the remaining openings **10**A are open. In FIG. **6**, an additional filler material comprising a metal insert **35** replaces a portion of honeycomb core **10** prior to metal infiltration. The metal insert can be machined to provide an attachment means for the insert **25**. FIG. **7** illustrates the insert **25** of FIG. **6** subsequent to metal infiltration casting.

[0029] FIG. **8** illustrates the arrangement of four inserts **25** after placement in a mold cavity and subsequent to metal infiltration casting. As illustrated in FIG. **7**, the metal "XX" infiltrates all areas of open porosity including any open areas between hollow micro-spheres **30** and the openings **10**A. Since metal inserts **35** contain no open porosity the metal "XX" infiltrates only at the surface.

[0030] As illustrated in FIGS. **7-9**, subsequent to metal infiltration casting, a metal enveloping layer **40** is formed around the metal infiltrated insert(s) **25**. FIG. **8** illustrates a top view of the side by side placement of inserts **25**, with spacing there-between, and metal infiltrated around and in between the inserts **25**. As illustrated in the FIG. **9** cross-section, top and bottom face sheets **45** comprising a filler material **20** of metal composite or metal matrix material, being dense or porous, may be placed around insert **25** to create a structural sandwich panel having facesheets **45** to provide strength and stiffness in bending.

[0031] The facesheets **45** range in thickness from 1/10 to 1/4 the thickness of honeycomb cellular structure **10**, as measured by the distance between oppositely facing sides **12** and **14**. FIG. **10** illustrates the insert of FIG. **9**, further including a dense ceramic layer **50** and face sheets **45**. The filler material **20** can be of a variety of dense or porous material types.

[0032] Dense material types may include surface voids that are filled with aluminum during the Al infiltration process such as metal inserts **35** as illustrated in FIG. **6**. Mechanical and chemical reactive surface bonding allows the dense material metal infiltrated surface to bond to adjacent material types during metal infiltration casting.

[0033] The compression and containment provided in a Metal Matrix Composite Armor comprised of inserts **25** having a honeycomb core **10** functions to attenuate a blast from a projectile by deforming in response to the blast shock. These differing material properties tend to absorb or attenuate the shock wave more effectively than is generally possible with a material that has uniform material properties throughout. Utilizing materials of different CTE values and which are strongly bound both mechanically and chemically produces compressive and tensioned layers throughout the composite armor after metal infiltration and solidification.

[0034] Porous material types include reinforcement of ceramic or metal in the form of particulates or fibers. The ceramic and/or metal particulate or fiber reinforcement include materials such as aluminum oxide, carbon, graphite, silicon carbide, boron carbide, titanium, tungsten, molybdenum, copper, aluminum and other anticipated ceramics or metal materials. The porous material types have an interior open porosity between about 30% and about 98% prior to metal infiltration and have a predetermined fraction of void volume or open structure throughout the material structure, or can be open spaces in a closed mold, such as honeycomb core **10** openings **10**A, that are filled with molten metal subsequent to metal infiltration casting.

[0035] A process of forming a porous material or preform constituent, which may be utilized in subject invention, is disclosed in U.S. Pat. No. 5,047,182, incorporated herein by reference for all it discloses. A filler material type **20** of porous material can be utilized as described herein as part of insert **25** (FIG. **3**, **4**) and can also be used to fill openings **10**A of honeycomb core **10** (FIG. **5**, **6**). Furthermore a porous material can be utilized as a facesheet **45** as illustrated in FIG. **9**.

[0036] Filler material **20** of dense material types includes aluminum oxide, silicon carbide, boron carbide, silicon nitride, and chemical vapor deposit diamond. Dense materials may be a dense metal such as titanium, tungsten, molybdenum, and depleted uranium. Other suitable dense materials include but are not limited to glass-ceramics, and other inorganic material systems which are compatible with molten metal processing and which can contribute to ballistic resistance of the integrated system.

[0037] Dense materials such as high strength steels, metal alloys, and ceramic alloys may be used in subject invention. A filler material type **20** of dense material can be utilized as described herein as part of insert **25** (FIG. **3**, **4**) and can also be used to fill openings **10**A of honeycomb core **10** (FIG. **5**, **6**).

Furthermore a dense material can be utilized as a facesheet **45** or layer **50** as illustrated in FIG. **9** and FIG. **10** or as inserts **35** as illustrated in FIG. **6** and FIG. **7**.

[0038] In one embodiment, and to reduce the density of the armor layer, high volume fractions of hollow micro-spheres **30** with interior voids, are used to fill openings **10**A. The bubble material **30** comprises a lightweight, inert hollow spheres filled with air and/or gas with a density about 0.4 to 1.6 grams/cubic-centimeter. The hollow spheres **20** are denoted by "000" and the metal infiltrant denoted by "XXX" in FIGS. **7-9** after metal infiltration. Bubble material **20** is dispersed randomly throughout openings **10**A as illustrated in FIG. **5**.

[0039] The hollow spheres are hermetic, and do not collapse or fill with metal during the metal infiltration process. The hollow spheres have been demonstrated by the inventor to be strong enough to withstand the pressure of metal infiltration casting and will not soften or crush under extreme metal infiltration temperatures greater than 600 degrees celsius. Furthermore, the hollow spheres do not degrade or dissolve due to chemical reactions with the metal infiltrant.

[0040] In the disclosed embodiment, hollow spheres of the Cenosphere variety are utilized as the hollow micro-sphere material **30**. However, any ceramic or metallic bubble which is hermetic with the metal infiltrant, has sufficient crush strength, and acceptable reactivity with the infiltrant is acceptable. Cenospheres, a component of aluminum fly-ash, have shown to exhibit light weight, and when used in Metal Matrix Composite (MMC) structures can reduce density to less than 2 g/cc.

[0041] Cenospheres are produced as a natural by-product of coal combustion during the generation of electric power. As a portion of the fly-ash generated in coal production, cenospheres are recycled from the waste stream. They are made up of inert silica, iron and alumina, and have a size ranging from 1 to 300 microns with an average compressive strength of 3000 PSI. Cenospheres of low bulk density are produced by Sphere Services, Inc, of Oakridge, Tenn.

[0042] Following infiltration casting the insert(s) **25** becomes metal rich in its open porosity at its surface (in the case of a dense material type) and throughout its open porosity in the case of porous material type.

[0043] The insert(s) **25** as illustrated in FIGS. **3-6** are initially placed into a mold cavity suitable for molten metal infiltration casting. The mold cavity is typically prepared from a die suitable for molten metal infiltration casting with the dimensions defined to produce a multi-structure metal matrix composite. The final products, as illustrated in alternative embodiments 7-10, are infiltrated with molten aluminum to form a metal matrix bonded composite in the desired product shape geometry. At this point the insert **25** (and additional facesheets for FIG. **9** embodiment, and additional dense layer for FIG. **10** embodiment) now becomes metal rich and can alternatively be referred to as a "Metal Matrix Composite".

[0044] It should be understood that the preceding is merely a detailed description of one embodiment of this invention and that numerous changes to the disclosed embodiment can be made in accordance with the disclosure herein without departing from the spirit or scope of the invention. Rather, the scope of the invention is to be determined only by the appended claims and their equivalents.

We claim:

1. A structural insert for a composite armor, comprising:

an encapsulating barrier formed around a cellular structure, said cellular structure having a plurality of openings , said plurality of openings having oppositely faced sides between which said plurality of openings extend; and

a filler material disposed within at least one of said plurality of openings, said plurality of openings further comprising said encapsulating metal.

2. A structural insert for a composite armor as in claim **1**, further comprising a second filler material disposed in at least one of said plurality of openings, said first filler material and said second filler material in different openings.

3. A structural insert for a composite armor as in claim **1**, further comprising a second filler material disposed in at least one of said plurality of openings, said first filler material and said second filler material in the same openings.

4. A structural insert for a composite armor as in claim **1**, wherein a portion of said cellular structure is replaced by a second filler material , wherein said second filler material is porous, said porous material further comprising a metal infiltrated therein.

5. A structural insert as in claim **1**, wherein one or more of said structural inserts are arranged in a common plane, said common plane inserts further arranged in one or more stacked layers.

6. A structural insert as in claim **1** wherein said encapsulating metal barrier is continuous from the interior of said cellular structure to the periphery of said cellular structure.

7. A structural insert as in claim **1** further comprising first and second face sheets disposed on opposite sides of said cellular structure, said encapsulating metal barrier formed around said cellular structure and said face sheets.

8. A structural insert for a composite armor as in claim **1**, wherein a portion of said cellular structure is replaced by a second filler material, wherein said second filler material is a dense material.

9. A structural insert for a composite armor as in claim **5**, wherein said structural inserts arranged in a common plane have spacing therebetween.

10. A structural insert for a composite armor as in claim **5**, wherein said one or more stacked layers further comprise one or more dense materials disposed between said one or more stacked layers.

11. A structural insert as in claim **7**, further comprising a dense material layer, said dense material layer disposed between said first and second face sheets.

12. A structural insert as in claim **5**, further comprising one or more face sheets disposed on the top and bottom of said one or more stacked layers.

13. A structural insert as in claim **1**, wherein said filler material is a plurality of high volume hollow microspheres.

14. A structural insert as in claim **7**, wherein said first and second face sheet thickness precludes said cellular structure from bending.

15. A structural insert as in claim **14**, wherein said first and second face sheet thickness is from about $1/10$ to $1/4$ the thickness of said cellular structure.

16. A structural insert as in claim **1**, wherein said encapsulating metal bonds said cellular structure and said filler material.

* * * * *