A method of making a composite material. The method comprises: providing a plurality of particles, wherein each one of the particles comprises a ceramic core and a metallic outer layer surrounding the core; forming a tile from the plurality of particles by performing a bonding process on the plurality of particles; and bonding the tile to a ductile backing material. In some embodiments, the ceramic core comprises boron carbide. In some embodiments, the metallic outer layer comprises at least one of copper, tantalum, titanium, molybdenum, and aluminum.
Providing a plurality of particles, wherein each particle comprises a ceramic core and a metallic outer layer.

Forming a tile from the plurality of particles.

Bonding the tile to a ductile backing material.

Fig. 1

Fig. 2
Form a plasma.

Vaporize a metallic coater powder within the plasma to form a coater-plasma mixture.

Deliver a stream of the coater-plasma mixture into a coating chamber configured so that the mixture stream reaches a maximum enthalpy at a location within the chamber and then decreases in enthalpy as it proceeds toward a chamber outlet.

Deliver a ceramic coatee powder into the mixture stream between the location of maximum enthalpy and the chamber outlet.

Condense the vaporized metallic material onto the ceramic coatee powder, thereby coating individual particles of the ceramic coatee powder with the metallic material.

Fig. 4

Fig. 5A

Fig. 5B
IMPACT RESISTANT MATERIAL

CROSS-REFERENCE TO RELATED APPLICATIONS


FIELD OF THE INVENTION

[0002] The present invention relates to the field of composite materials. More specifically, the present invention relates to the formation of composite materials using a novel ceramic-metallic tile.

BACKGROUND OF THE INVENTION

[0003] While composite materials have a variety of different applications, all of which are within the scope of the present invention, they may be particularly useful in the production of body armor, such as bullet-proof vests.

[0004] Currently, body armor is formed by bonding two types of armor together. A meltplate is bonded to a hard plate via melting in an autoclave. However, the resulting armor is limited in both its hardness and its ductility.

[0005] What is needed in the art is a way to improve the hardness and the ductility of body armor and other composite materials.

SUMMARY OF THE INVENTION

[0006] While the present invention is particularly useful in forming body armor, it is contemplated that it may have a variety of other applications as well, all of which are within the scope of the present invention.

[0007] In one aspect of the present invention, a method of making a tile is provided. The method comprises providing a plurality of particles, wherein each one of the particles comprises a ceramic core and a metallic outer layer surrounding the core, and forming a tile from the plurality of particles by performing a bonding process on the plurality of particles.

[0008] In some embodiments, the ceramic core comprises boron carbide. In some embodiments, the metallic outer layer comprises at least one of copper, tantalum, titanium, molybdenum, and aluminum.

[0009] In some embodiments, the step of providing the plurality of particles comprises forming a plasma within a plasma production chamber and vaporizing a metallic material with the plasma, thereby forming a coater-plasma mixture comprising the vaporized metallic material. A mixture stream comprising the coater-plasma mixture flows through a coating chamber toward an outlet of the coating chamber, wherein the mixture stream reaches a maximum enthalpy at a location within the coating chamber, then decreases in enthalpy as it proceeds toward the outlet. A ceramic coating powder is delivered into the mixture stream at a location between the location of maximum enthalpy and the chamber outlet, wherein the enthalpy of the mixture stream at the location of delivery is less than the maximum enthalpy and the ceramic coating powder becomes entrained in the mixture stream. The vaporized metallic material is at least partially condensed onto the ceramic coating powder, thereby coating individual particles of the ceramic coating powder with the metallic material to form the plurality of particles entrained within the mixture stream.

[0010] In some embodiments, the bonding process is a sintering process. In some embodiments, the sintering process is a spark plasma sintering process.

[0011] In another aspect of the present invention, a method of making a composite material is provided. The method comprises providing a plurality of particles, wherein each one of the particles comprises a ceramic core and a metallic outer layer surrounding the core, and forming a tile from the plurality of particles by performing a bonding process on the plurality of particles. The tile is then bonded to a ductile backing material.

[0012] In some embodiments, the ceramic core comprises boron carbide. In some embodiments, the metallic outer layer comprises at least one of copper, tantalum, titanium, molybdenum, and aluminum.

[0013] In some embodiments, the step of providing the plurality of particles comprises forming plasma within a plasma production chamber and vaporizing a metallic material with the plasma, thereby forming a coater-plasma mixture comprising the vaporized metallic material. A mixture stream comprising the coater-plasma mixture flows through a coating chamber toward an outlet of the coating chamber, wherein the mixture stream reaches a maximum enthalpy at a location within the coating chamber, then decreases in enthalpy as it proceeds toward the outlet. A ceramic coating powder is delivered into the mixture stream at a location between the location of maximum enthalpy and the chamber outlet, wherein the enthalpy of the mixture stream at the location of delivery is less than the maximum enthalpy and the ceramic coating powder becomes entrained in the mixture stream. The vaporized metallic material is at least partially condensed onto the ceramic coating powder, thereby coating individual particles of the ceramic coating powder with the metallic material to form the plurality of particles entrained within the mixture stream.

[0014] In some embodiments, the bonding process is a sintering process. In some embodiments, the sintering process is a spark plasma sintering process.

[0015] In some embodiments, the ductile backing material comprises a plurality of fibers. In some embodiments, the ductile backing material comprises a plurality of polyethylene fibers.

[0016] In some embodiments, the tile is bonded to the ductile backing material using an autoclave process. In some embodiments, the tile is bonded to the ductile backing material using heat-curable adhering material and catalyzed foambale exothermic material between the tile and the ductile backing material, wherein heat generated from the use of the catalyzed foambale exothermic material cures the heat-curable adhering material. In some embodiments, the adhering material is resin.

[0017] In yet another aspect of the present invention, a tile is provided comprising a plurality of particles bonded together, wherein each one of the particles comprises a ceramic core and a metallic outer layer surrounding the core.

[0018] In some embodiments, the ceramic core comprises boron carbide. In some embodiments, the metallic outer layer comprises at least one of copper, tantalum, titanium, molybdenum, and aluminum.

[0019] In yet another aspect of the present invention, a composite material is provided comprising a tile comprising
a plurality of particles bonded together, wherein each one of
the particles comprises a ceramic core and a metallic outer
layer surrounding the core, and a ductile backing material
bonded to the tile.

[0020] In some embodiments, the ceramic core comprises
boron carbide. In some embodiments, the metallic outer layer
comprises at least one of copper, tantalum, titanium, molyb-
denum, and aluminum.

[0021] In some embodiments, the ductile backing material
comprises a plurality of fibers. In some embodiments, the
ductile backing material comprises a plurality of polyethy-
lene fibers.

[0022] In some embodiments, the composite material fur-
ther comprises an adhering material disposed between the tile
and the ductile backing material, wherein the adhering mate-
rial bonds the tile and the ductile backing material together.
In some embodiments, the composite material further com-
prises a cured adhering material and a foam material disposed
between the tile and the ductile backing material, wherein
the cured adhering material and the foam material bond the tile
and the ductile backing material together.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] FIG. 1 is a flowchart illustrating one embodiment of
a method of making a composite material in accordance with
the principles of the present invention.

[0024] FIG. 2 illustrates one embodiment of a plurality of
particles having a ceramic core and a metallic outer layer in
accordance with the principles of the present invention.

[0025] FIG. 3 illustrates one embodiment of a particle pro-
duction system that synthesizes coated powders in accor-
dance with the principles of the present invention.

[0026] FIG. 4 is a flowchart illustrating one embodiment of
a method of providing a plurality of particles having a
 ceramic core and a metallic outer layer in accordance with
 the principles of the present invention.

[0027] FIG. 5A illustrates one embodiment of a tile and a
ductile backing material before insertion of catalyzed foamy
exothermic material within the interior volume between
them.

[0028] FIG. 5B illustrates one embodiment of a tile and a
ductile backing material after insertion of catalyzed foamy
exothermic material within the interior volume between them
in accordance with the principles of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0029] The following description is presented to enable one
of ordinary skill in the art to make and use the invention and
is provided in the context of a patent application and its
requirements. Various modifications to the described embod-
iments will be readily apparent to those skilled in the art and
the generic principles herein may be applied to other embod-
iments. Thus, the present invention is not intended to be lim-
ited to the embodiment shown but is to be accorded the widest
scope consistent with the principles and features described
herein.

[0030] This disclosure refers to both particles and powders.
These two terms are equivalent, except for the caveat that a
singular “powder” refers to a collection of particles. The
present invention may apply to a wide variety of powders and
particles. Powders that fall within the scope of the present
invention may include, but are not limited to, any of the follow-
ing: (a) nano-structured powders(nano-powders), hav-
ing an average grain size less than 250 nanometers and an
aspect ratio between one and one million; (b) submicron
powders, having an average grain size less than 1 micron
and an aspect ratio between one and one million; (c) ultra-fine
powders, having an average grain size less than 100 microns
and an aspect ratio between one and one million; and (d) fine
powders, having an average grain size less than 500 microns
and an aspect ratio between one and one million.

[0031] FIG. 1 is a flowchart illustrating one embodiment of
a method 100 of making a composite material in accordance
with the principles of the present invention. As mentioned
above, in some embodiments, the method of the present
invention is used in forming body armor. However, it is con-
templated that it has a variety of other applications as well, all
of which are within the scope of the present invention.

[0032] At step 110, a plurality of particles are provided.
Each particle comprises a ceramic core and a metallic outer
layer. FIG. 2 illustrates one embodiment of a plurality of
particles 200, with each particle having a ceramic core 210
and a metallic outer layer 220. While FIG. 2 shows the par-
ticles being uniformly sized and shaped, it is contemplated
that the particles can also vary in size and shape. In some
embodiments, the ceramic cores 210 in the plurality of par-
ticles are each micron-sized, having an average grain size
greater than or equal to 1 micron. In some embodiments, the
thickness of the metallic outer layer 220 is substantially uni-
form around the entire ceramic core 210, while in other
embodiments, the thickness of the metallic outer layer 220 is
not uniform around the entire ceramic core 210.

[0033] In some embodiments, the ceramic core 210 com-
prises boron carbide. However, it is contemplated that other
ceramic materials can be used in addition to or as an alterna-
tive to boron carbide. In some embodiments, the ceramic core
210 consists of only one ceramic material. For example, in
some embodiments, the ceramic core 210 consists only of
boron carbide. In other embodiments, the ceramic core 210
consists of a combination of ceramic materials. It is com-
templated that any metallic material can be used for the metallic
outer layer 220. However, certain metals have been found to
be particularly advantageous. Such metals include copper,
tantalum, titanium, molybdenum, and aluminum. In some
embodiments, the metallic outer layer 220 consists of only
one type of metal. For example, in some embodiments, the
metallic outer layer 220 consists only of copper. In other
embodiments, the metallic outer layer 220 comprises a com-
bination of different metals.

[0034] It is contemplated that the plurality of particles hav-
ing a ceramic core and a metallic outer layer can be produced
and provided in a variety of different ways, using a variety of
different systems. The present invention considers a wide
variety of gas phase particle production systems including
combustion based systems, plasma based systems, laser abla-
tion systems and vapor deposition systems. The preferred
systems take material inputs in a broad range of forms,
including solid phase inputs, and provide product in high
surface area forms, including powders ranging in grain size
from nano-structured to fine. In addition, the process controls
preferably provide a fine degree over a plurality of reaction
parameters, permitting fine gradients of product composition
ratios to be produced.

[0035] An exemplary particle production system that can
be used for the present invention is a plasma powder produc-
tion reactor. Generally, the plasma powder production reactor
produces an output comprising particles entrained within a
gas stream. Particle production preferably includes the steps of combination, reaction, and conditioning. The present invention can employ concepts similar to those used in the nano-powder production systems disclosed in related U.S. patent application Ser. No. 11/110,541, filed on Apr. 19, 2005 and entitled, "HIGH THROUGHPUT DISCOVERY OF MATERIALS THROUGH VAPOR PHASE SYNTHESIS", which is currently published as U.S. Publication No. 2005-0233380-A. In such nano-powder production systems, working gas is supplied from a gas source to a plasma reactor. Within the plasma reactor, energy is delivered to the working gas, thereby creating a plasma. A variety of different means can be employed to deliver this energy, including, but not limited to, DC coupling, capacitive coupling, inductive coupling, and resonant coupling. One or more material dispensing devices introduce at least one material, preferably in powder form, into the plasma reactor. The combination within the plasma reactor of the plasma and the material(s) introduced by the material dispensing device(s) forms a highly reactive and energetic mixture, wherein the powder can be vaporized. This mixture of vaporized powder moves through the plasma reactor in the flow direction of the working gas. As it moves, tire mixture cools and particles are formed therein. The still-energetic output mixture, comprising hot gas and energetic particles, is emitted from the plasma reactor.

[0036] A wide variety of material types and forms can be processed in preferable particle production reactors used in the present invention. Without prejudice, the present invention specifically considers the provision of materials in the following forms: solid, liquid and gas.

[0037] FIG. 3 illustrates one embodiment of a particle production system 300 that synthesizes coated powders in accordance with the principles of the present invention. System 300 is disclosed in U.S. patent application Ser. No. 12/152,111, filed on May 9, 2008 and entitled, "POWDER COATING SYSTEM AND METHOD INCLUDING GUN EXTENSION", the entirety of which is hereby incorporated by reference as if set forth herein. The system 300 comprises a plasma production chamber 320, a coating chamber 330, a cooling conduit 370, a sampling system 380, and a motive pump 390. The plasma production chamber 320 and coating chamber 330 are preferably enclosed in a motive gas supply chamber 310.

[0038] The motive gas supply chamber 310 is fluidly coupled to a motive gas supply system 315, which is configured to supply a motive gas. Preferably, the motive gas is an inert gas, such as argon. Furthermore, the chamber 310 preferably include airtight inlets and outlets configured to permit conduits to pass through to supply the plasma production chamber 320 and coating chamber 330. The motive gas supply chamber 310 can include airtight couplings that permit these conduits to pass through while preventing leakage either into or out of the chambers.

[0039] Furthermore, output from the coating chamber 330 can flow into the cooling conduit 370, which can also pass through a wall of the motive gas supply chamber 310. Preferably, the cooling conduit 370 also exits the motive gas supply chamber through an airtight coupling.

[0040] The plasma production chamber 320 preferably includes several types of inputs for receiving power, gas, and target materials. Inputs are provided to the chamber 320 by a variety of supply systems through means described below. Functional aspects of these supply systems are also described below.

[0041] Various input conduits fluidly couple the plasma gas supply mixer 340 with a first gas supply vessel 342 and a second gas supply vessel 344. The plasma gas supply system 340 includes an outlet fluidly coupled with an inlet of the plasma production chamber 320. The gas supply system 340 and the production chamber 320 are coupled by a conduit that passes through the motive gas supply chamber 310. Preferably, but not shown in the figure, an overall system controller provides control signals to the plasma gas supply system 340.

[0042] The power supply system 325 is also coupled to the plasma production chamber 320 through conduits that pass through the motive gas supply chamber 310. Preferably, but not shown in the figure, an overall system controller provides control signals to the power supply system 325.

[0043] The coater supply system 352 houses precursor material (e.g., metallic powder) and includes an externally controllable delivery system fluidly coupled to a materials inlet of the plasma production chamber 320. The supply system 352 is coupled with the production chamber 320 by a conduit that passes through the motive gas supply chamber 310. Preferably, but not shown in the figure, an overall system controller provides control signals to the supply system 352.

[0044] Preferably, the conduits that run between the plasma gas supply system 340 and the production chamber 320, the coater supply system 352 and the plasma production chamber 320, and the power supply system 325 and the plasma production chamber 320, all enter the motive gas supply chamber 310 through air-tight seals. In some embodiments, the conduits of the various supply systems all have dedicated airtight entrances to the motive gas supply chamber 310. In some embodiments, a single airtight entrance accommodates multiple conduits.

[0045] The coating chamber 330 preferably includes inlets for motive gas, coater material plasma mixture, and coater material, as well as an outlet to provide an output to the cooling conduit 370. The inlets for motive gas couple the motive gas supply chamber 310 to the interior of the coating chamber 330. Preferably, these inlets are channels of adjustable size that directly coupled the two chambers, yet permit for controlled flow from the supply chamber 310 into the coating chamber 330.

[0046] Coater material (e.g., ceramic powder) is stored within the coater material supply system 354, which preferably sits outside the motive gas supply chamber 310. A conduit passes from the supply system 354 through the motive gas supply chamber 310 and also through a wall of the coating chamber 330. The coater material supply system 354 includes a controllable delivery system that provides coater material to the coater. Preferably, the conduit enters both chambers through airtight seals. The conduit terminates within the coating chamber at a selected location. Preferably, the location of the terminus is selected based on parameters of operation. Also preferably, but not shown, an overall system controller is configured to supply control signals to the supply system 354.

[0047] The cooling conduit 370 connects the coating chamber 330 with the sampling system 380. The conduit 370 exiting the motive gas supply chamber 310 through airtight means. The cooling conduit 370 includes a first section 372, a second section 374, third section 376, and fourth section 378. The sections are joined by gas input couplings that contain gas
input features. The first section 372 is joined to the second section 374 by the gas input coupling 362. In turn, the second section 374 is joined to the third section 376 by the gas input coupling 364. The gas input coupling 366 joins the third section 376 to the fourth section 378.

[0048] In the illustrated embodiment, no gas is shown being supplied to the gas input couplings 362, 364, 366 for input into the cooling conduit 370. However, gas can be supplied through one or more of the gas input couplings.

[0049] The sampling system 380 is fluidly coupled between the cooling conduit 370 and the motive pump 390. The sampling system 380 is configured to receive output from the cooling conduit 370, sample material having appropriate characteristics from the output, and permit remains of the output to flow to the motive pump 390, which is fluidly coupled through a conduit to the sampling system 380.

[0050] During operation, the supply systems 340, 352, and 325 provide plasma gas, coater material, and power, respectively, to the plasma production chamber 320. Power from the deliver system 352 is used to energize gas from the supply system 340 to produce a plasma within the production chamber 320. The coater material supply system 352 provides coater material (e.g., metallic powder) in metered amounts into the plasma production chamber 320, exposing the coater material to plasma formed therein.

[0051] The overall control system (not shown) sends signals to the plasma gas supply system 340, coater material supply system 352, and power supply system 325 to set operational parameters. The plasma gas supply system 340 determines the ratio of mixing for the first and second gases to produce plasma gas, as well as the rate at which the plasma gas feeds into the plasma production chamber 320. In a preferred embodiment, the first gas is hydrogen and the second gas is an inert gas, such as argon. The coater material supply system 352 determines the rate at which the coater material is supplied into the plasma production chamber 320. The power supply system 325 determines the voltage and amperage at which power is supplied to the plasma production chamber. In combination, these parameters determine the characteristics of the plasma produced within the plasma production chamber 320, as well as the characteristics of the plasma-coatee material mixture also produced within the chamber 320. Furthermore, although the coater supply system is described as providing only a single coater material into the plasma production chamber 320 at a single location, in some embodiments of the present invention, the coater supply system 352 supplies a plurality of materials into the plasma production chamber 320 at one or more locations.

[0052] The motive gas supply chamber 310 receives motive gas, typically an inert gas such as argon, from a preferably dedicated motive gas supply system 315. The motive gas supply chamber 310 provides an airtight enclosure around the plasma production chamber 320 and coating chamber 330. The motive gas supply system 315 preferably maintains a pressure within the motive gas supply chamber 310 that slightly exceeds the ambient pressure of the environment in which the system 300 is housed, regardless of any variation in suction force generated by the motive pump 390.

[0053] The coating chamber 330 receives a coater material and plasma mixture from the plasma production chamber 320. The coating chamber 330 also receives motive gas through input features. Preferably, these input features provide for an adjustable flow rate of motive gas into the coating chamber 330. Motive gas flow is preferably motivated by the motive pump 390 by pulling a negative pressure on the conduit 370, motivating mass flow through the outlet of the coating chamber 370. However, the flow rate of the motive gas into the coating chamber 330 is preferably controlled by the overall control system.

[0054] Furthermore, the coatee material supply system 354 provides a metered stream of coatee material through the coatee material conduit to the conduit’s terminus location within the coating chamber 330. The rate at which coatee material is provided into the chamber 330 preferably is determined by the overall control system. Furthermore, although the terminus of the coatee material supply conduit is shown to deposit material only at one location within the coating chamber 330, in some embodiments of the present invention, the terminus deposits coatee material at a plurality of locations within the conduit (e.g., in an annular configuration surrounding the output of the plasma production chamber 320).

[0055] Preferably, coating chamber 330 is shaped and the operational parameters of the apparatus 300 are controlled so that the coatee material and plasma mixture enters the coating chamber and reaches a maximum enthalpy shortly thereafter. Most preferably, this maximum of enthalpy occurs within a defined region of the coating chamber 330, with the average enthalpy of the mixture falling as it moves away from that region with its minimum (within the coating chamber 330) coming at the outlet to the cooling conduit 370. For example, as illustrated in FIG. 3, the maximum enthalpy occurs in region 301. In these embodiments, the location of the terminus for delivery of the coatee material is chosen to be outside the maximum region and between the maximum region and the outlet.

[0056] Furthermore, in certain embodiments of the present invention, the coating chamber 330 is shaped and the operational parameters of the apparatus 300 are chosen so that the coatee material begins to condense from the coatee material and gas mixture within a defined region of the coating chamber 330. For example, in FIG. 3, the region 302 is such an initial condensation region. Typically, the initial condensation region lies between the maximum enthalpy region and the outer of the coating chamber 330. In some embodiments, the coatee material is delivered into the initial condensation region. Preferably in these embodiments, sufficient enthalpy remains in the condensing mixture to vaporize the coatee material. Thus, as the coatee material is condensing to form particles, the coatee material is vaporized mixed with the condensing particles. As the coatee material gas particle mixture mixes with the vaporized coatee material and moves towards the outlet, the coatee condenses on the coatee particles, forming a plurality of coated particles.

[0057] The cooling conduit 370 receives the coated particle and gas mixture from the coating chamber 330. Preferably, the mixture is pulled into the cooling conduit by the motive pump 390.

[0058] However, in some embodiments, a motive pump or other system within the sampling system 380 provides some motive force to pull the mixture. Of course, to some extent, pressure provided by the plasma production chamber 320 and the motive as supply 315 motivate the movement of the mixture into the cooling conduit 370.

[0059] In some embodiments, the cooling conduit 370 is equipped with an active cooling system. In some embodiments, gas is supplied into the gas input couplings 362, 364, or 366. In some of these embodiments, the gas is a cooling and entraining gas. In some of these embodiments, the gas is a
passivating gas configured to reduce the reactivity of the condensed particles within the mixture.

[0060] As mentioned above, the sampling system 380 preferably permits the motive pump 390 to provide a motive force therethrough. However, in some embodiments the sampling system 380 provides additional motive force. In some embodiments the sampling system 380 supplies the motive force provided by the motive pump 390 and provides a substitute motive force to the cooling conduit 370.

[0061] It is contemplated that the sampling system 380 can be configured in a variety of ways. In one embodiment, the sampling system 380 comprises a sampling structure, at least one filled aperture formed in the sampling structure, and at least one unfilled aperture formed in the sampling structure. Each filled aperture is configured to collect particles from the mixture stream, such as by using a filter. The sampling structure is configured to be adjusted between a pass-through configuration and a collection configuration. The pass-through configuration comprises an unfilled aperture being fluidly aligned with a conduit, such as conduit 140, thereby allowing the unfilled aperture to receive the mixture stream from the conduit and the mixture stream to flow through the sampling structure without substantially altering the particle content of the mixture stream. The collection configuration comprises a filled aperture being fluidly aligned with the conduit, thereby allowing the filled aperture to receive the mixture stream and collect particles while the mixture stream is being flown through the filled aperture. It is contemplated that the sampling structure can be adjusted between the pass-through configuration and the collection configuration in a variety of ways. In one embodiment, the sampling structure is a disk-shaped structure including an annular array of apertures, wherein the annular array comprises a plurality of the filled apertures and a plurality of the unfilled apertures. The sampling structure is rotatably mounted to a base, wherein rotational movement of the sampling structure results in the adjustment of the sampling structure between the pass-through configuration and the collection configuration. In another embodiment, the sampling structure is a rectangular-shaped structure including a linear array of apertures, wherein the linear array comprises a plurality of the filled apertures and a plurality of the unfilled apertures. The sampling structure is slidably mounted to a base, wherein sliding of the sampling structure results in the adjustment of the sampling structure between the pass-through configuration and the collection configuration.

[0062] FIG. 4 is a flowchart illustrating one embodiment of a method of providing a plurality of particles having a ceramic core and a metallic outer layer in accordance with the principles of the present invention.

[0063] At step 410, a plasma is formed. It is contemplated that the plasma can be formed in a variety of ways. However, in a preferred embodiment, a working gas is supplied to a plasma production chamber, where the working gas is energized to form the plasma. Preferably, a plasma is formed from hydrogen and an inert gas, such as argon. Hydrogen is used to provide high heat conductivity within the plasma. By having a highly heat conductive plasma, higher vapor point coater materials can be used.

[0064] At step 420, a metallic coater powder (e.g., copper, tantalum, titanium, molybdenum, aluminum, etc.) is vaporized within the plasma to form a coater-plasma mixture. Preferably, as the gas used to form a plasma flows through a plasma production chamber in an ‘upstream’ area of the plasma production chamber, energy is delivered to the gas stream to form the plasma, then later in a ‘downstream’ area of the plasma production chamber, a water material is introduced into the resulting stream of plasma. However, it is contemplated that other configuration can be used as well. The material is vaporized and results in a stream of coater-plasma mixture.

[0065] At step 430, a stream of the coater-plasma mixture is delivered into a coating chamber. Preferably, the coating chamber is configured so that the mixture stream reaches a maximum enthalpy at a location within the chamber and then decreases in enthalpy as it proceeds toward a chamber outlet.

[0066] At step 440, a ceramic coatee powder (e.g., boron carbide) is delivered into the mixture stream between the location of maximum enthalpy and the chamber outlet. It is possible for such delivery to take place at a location where the stream has sufficient enthalpy to vaporize the coatee material. Furthermore, the method optionally includes additional steps, such as maintaining the mixture at a selected enthalpy below the maximum enthalpy to vaporize the ceramic coatee material.

[0067] At step 450, the vaporized metallic material is partially or completely condensed onto the ceramic coatee powder, thereby coating the individual ceramic particles with the metallic material and forming a plurality of particles, each having a ceramic core with a metallic outer layer.

[0068] Referring back to the method in FIG. 1, at step 120, a tile is formed from the plurality of particles. It is noted that these particular particles, each having a ceramic core surrounded by a metallic outer layer, help form a novel tile that provides significant advantages over the prior art. The ceramic core maintains the toughness of the resulting tile, while the metallic outer layer makes the tile more ductile, thereby reducing the likelihood of fracture.

[0069] It is contemplated that this formation can be achieved in a variety of ways. In some embodiments, the tile is formed by performing a sintering process on the plurality of particles. When using nano-particles to form the tile, maintaining the nano-scale properties of the particles during formation may be difficult. For example, performing a standard sintering process on a plurality of nano-particles will typically result in an undesirable amount of melting of the nano-particles due to the high-temperature of the standard sintering process, thereby leading to nano-particles unifying with nearby nano-particles to a degree that they form particles that are larger than nano-particles. Therefore, in order to maintain the nano-scale properties of the particles within the formed tile, some embodiments employ spark plasma sintering (also known as field assisted sintering technique) on the plurality of particles to form the tile. Spark plasma sintering uses axial pressure and elevated temperature that are generated by a current flow. The energy released by the current raises the temperature in the graphite dies enclosing the powder and within powders that have some electrical conductivity. The heat is generated internally, in contrast to conventional hot pressing, where the heat is provided by external heating elements. The spark plasma sintering process is very fast, thereby ensuring it has the potential of densifying powders with nanosize or nanostructure, while avoiding coarsening which accompanies standard densification routes. Spark plasma sintering provides significant advantages by lowering the required sintering temperature and shortening its duration. It is contemplated that the spark plasma sintering can
also be advantageously used when forming a tile from particles other than nano-particles, such as micron-sized particles.

[0070] At step 130, the tile is bonded to a ductile backing material using heat-curable adhering material and catalyzed foamable exothermic material between the tile and the ductile backing material. Such a bonding process is described in U.S. Pat. No. 6,117,376 to Merkel, entitled “Method of Making Foam-Filled Composite Products,” the entirety of which is hereby incorporated by reference as if set forth herein. Merkel discloses a method for making foam-filled parts having fiber-reinforced skins or surfaces. Mold halves of pressure-resisting thermally insulative material are covered with a release material, which is then covered with the fiber skins. The fiber skins are coated with heat-curable resin, and the mold halves are then clamped together to form a cavity. A catalyzed foam-forming mixture is poured into the cavity. The mixture foams and expands to the full volume of the cavity. While the mixture hardens, it generates heat sufficient to cure the resin.

[0071] In some embodiments, the concave inner surfaces of the mold halves are covered with a commercial Teflon™ sheet having an adhesive backing. This material adheres to the mold face through numerous replications of parts and freely releases from polymers that are cured in direct contact with its surface. This approach also has the advantage of avoiding contamination of the resin surface with the release agent, such as wax-based materials. Dry (i.e., unimpregnated) fiber-reinforced skin material is laid in to cover the inner surfaces of the mold halves. The fiber skins can be in loosely woven sheet or strip form, having sufficient cross weave fibers to permit easy handling without separating. The fibers are then thoroughly wetted or impregnated in place with an uncured resin, such as an epoxy resin from West, sold as system resin with 205 or 206 harder. The hardener is a thermally activated catalyst that requires a long term curing at ambient temperature, although it acts quickly above a threshold, so that it remains wet until the proper time in the ensuing process. The resin system causes the fiber reinforcement to adhere tightly to the inner surfaces of the mold halves, despite the Teflon™ covering. With the two mold halves prepared in this manner, they can be placed together. With side flanges being in intimate contact, an interior cavity is defined between the concave inner surfaces of the mold halves, and C-clamps are then placed about the periphery of the flanges and tightened. The clamped mold halves thus form what may be regarded as a pressure vessel. In addition, a malleable seal is placed across one end of the mold cavity.

[0072] When the two mold halves are clamped together in opposition, the C-clamps are tightened sufficiently on the flanges to prevent leakage of foam material out the sides. The mold cavity is thus sealed on three sides, and can be placed in a substantially vertical position so that a premixed foamable liquid can be poured in immediately after preparation. This mix may be of the type such as Polytech 200/8-, and will include the proper amount of catalyst for the volume of resin and the cavity. This material expands to about 40 times its original volume. The foamable liquid mix rapidly begins to expand and build up interior pressure within the mold cavity after being poured. The reaction is strongly exothermic, and heats the foam to in excess of 300 degrees F, as it expands under significant local pressure everywhere in the mold cavity. The heat is conducted into the skin layers throughout. A property of this mixture, however, is that the expansion is self-limiting, in that while significant pressure is generated during expansion, total expansion is limited by the rapid hardening characteristic of the material. Consequently, while the predetermined volume of mix is such that material foams out of the top of the mold cavity, and may even leak through the malleable seal to a limited extent, the interior of the mold cavity is uniformly pressurized and there are no voids. The heat generated by the exotherm raises the temperature of the wet resin matrix at the skin above the curing level. A high temperature level is also maintained for many more minutes by the insulative characteristic of the mold halves. The close physical, pressurized contact between the foam and the skin resin system not only cures the skins into true fiber-reinforced composites, but assures chemical adherence at the interface between the foam and the skin on all surfaces. Typically, after one to two hours, the C-clamps are released and the mold halves are readily separated from the formed composite.

[0073] While any of the features of U.S. Pat. No. 6,117,376 to Merkel can be used in the bonding process of the present invention, it is contemplated that certain modifications can be made in order to bond an inorganic tile to a ductile backing material, which is not disclosed in Merkel. For example, in some embodiments, fiber skins may be required on only one of the mold halves or on one side of the composite (e.g., acting as the ductile backing material). Additionally, in some embodiments, the resin (or other heat curable adhering material) may be required on only one of the mold halves or on one side of the composite. Furthermore, in some embodiments, separable mold halves may not be required. In some embodiments, all that is required is that an interior volume between the tile and the ductile backing material be sealed to a degree sufficient to allow the catalyzed foamable exothermic material to expand and build up interior pressure within the interior volume, thereby creating physical pressurized contact between the catalyzed foamable exothermic material and the heat-curable adhering material of each of the tile and the ductile backing material. Other modifications are within the scope of the present invention as well.

[0074] FIG. 5A illustrates one embodiment 500 of a tile 510 and a ductile backing material 520 before insertion of catalyzed foamable exothermic material within the interior volume 530 between them. The tile 510 is formed from the plurality of particles previously discussed. In some embodiments, the ductile backing material 520 is formed from organic material. In some embodiments, the ductile backing material 520 is formed from a plurality of fibers. In some embodiments, the ductile backing material 520 is formed from a plurality of polyethylene fibers. In some embodiments, the ductile backing material 520 is Dyneema® or Kevlar®.

[0075] The interior surface of the tile 510 is wetted with a heat-curable adhering material 515. The interior surface of the ductile backing material 520 is also wetted with a heat-curable adhering material 525. In some embodiments, heat-curable adhering material 515 and heat-curable adhering material 525 are the same material. In some embodiments, the adhering material is resin.

[0076] An interior volume 530 is formed between the tile 510 and the ductile backing material 520, with the interior surface of the tile 510 and the interior surface of the ductile backing material 520 facing one another. The interior surface of the tile 510 and the interior surface of the ductile backing material 520 each form a boundary of the interior volume 530. The tile 510 and the ductile backing material 520 can be secured in this position using mold halves and/or clamps,
and/or other securing and sealing means. For the purposes of this disclosure, the interior volume 530 does not extend into any area that is not disposed between the tile 510 and the ductile backing material 520.

[0077] A catalyzed foambable exothermic material, such as that used in U.S. Pat. No. 6,117,376 to Merkel, is inserted into the interior volume after wetting the interior surfaces of the tile 510 and the ductile backing material 520 with the heat-curable adhering material. An amount of catalyzed foambale exothermic material is used that is sufficient to fill (in some cases, overfill) the entire interior volume when foamed and form a solid foam body between the tile 510 and the ductile backing material 520. The exotherm from the foaming is allowed to activate and cure the heat-curable adhering material 515, 525 for a time sufficient to unite the solid foam body to the heat-curable adhering material 515, 525 of the tile 510 and the ductile backing material 520.

[0078] FIG. 51B illustrates one embodiment 500 of the tile 510 and the ductile backing material 520 after insertion of catalyzed foambable exothermic material within the interior volume between them in accordance with the principles of the present invention. The catalyzed foambable exothermic material has expanded to form a solid foam body 535 that fills the entire interior volume 530. The heat-curable adhering material 515 and 525 has been cured by the exotherm from the foaming to form cured adhering material 515 and 525.

[0079] The use of the catalyzed foambable exothermic material and heat-curable adhering material provides a significant advantage over the use of an autoclave, which is the standard way of bonding a meltplate to a hard plate. An autoclave process is too hot, resulting in the loss of certain advantageous properties (e.g., nano-scale properties) of the tile 510. Typically, the maximum temperature of the bonding process is half the melting point temperature of the particles of the tile 510. However, when the tile 510 is formed from nano-particles, the maximum temperature of the bonding process is preferably one-quarter of the melting point temperature of the particles of the tile 510. Using the exotherm from the foambable material instead of the heat from an autoclave allows the temperature of the bonding process to be sufficiently minimized and the tile 510 to retain its advantageous structural properties.

[0080] It is noted that while FIG. 5A-B show certain shapes and sizes of the components, other shapes and sizes, as well as other configurations, are also within the scope of the present invention. For example, the tile 510, ductile backing material 520, and the interior volume 530 are shown as having substantially rectangular features. However, it is contemplated that these components can be shaped in other ways, such as with curves. Additionally, although the tile 510 and the ductile backing material 520 are shown having substantially the same thickness, it is contemplated that one can be substantially thicker than the other. Furthermore, the heat-curable adhering material 525 may extend into the ductile backing material 520. For example, in an embodiment where the ductile backing material 520 comprises fibers, the fibers may be held together and/or in position by the heat-curable adhering material.

[0081] The present invention has been described in terms of specific embodiments incorporating details to facilitate the understanding of principles of construction and operation of the invention. Such reference herein to specific embodiments and details thereof is not intended to limit the scope of the claims appended hereto, it will be readily apparent to one skilled in the art that other various modifications may be made in the embodiment chosen for illustration without departing from the spirit and scope of the invention as defined by the claims.

1-31. (canceled)
32. A method of making a tile, comprising:
vaporizing a coater material;
condensing the vaporized coater material onto coatee particles to form coated particles comprising a layer of the coater material on the coatee particles; and
sintering the coated particles to form the tile.
33. The method of claim 32, wherein vaporizing the coater material comprises:
vaporizing the coater material within a plasma stream.
34. The method of claim 32, wherein the sintering comprises spark plasma sintering.
35. The method of claim 32, wherein the coatee particles comprise ceramic coatee particles.
36. The method of claim 35, wherein the ceramic coatee particles comprise boron carbide.
37. The method of claim 32, wherein the coated particles comprise an average grain size of less than 250 nanometers.
38. The method of claim 37, wherein the coated particles are sintered so that the nano-particle size and structure of the coated particles is maintained in the tile.
39. The method of claim 32, wherein the coater material comprises metallic coater material.
40. The method of claim 32, wherein the metallic coater material comprises at least one of copper, tantalum, titanium, molybdenum, and aluminum.
41. A method of making a composite material, comprising:
vaporizing a coater material;
condensing the vaporized coater material onto coatee particles to form coated particles comprising a layer of the coater material on the coatee particles;
sintering the coated particles to form the tile; and
bonding the tile to a ductile backing material.
42. The method of claim 41, wherein vaporizing the coater material comprises:
vaporizing the coater material within a plasma stream.
43. The method of claim 41, wherein the sintering comprises spark plasma sintering.
44. The method of claim 41, wherein the coatee particles comprise ceramic coatee particles.
45. The method of claim 41, wherein the coated particles comprise an average grain size of less than 250 nanometers.
46. The method of claim 45, wherein the coated particles are sintered so that the nano-particle size and structure of the coated particles is maintained in the tile.
47. The method of claim 41, wherein the coater material comprises metallic coater material.
48. The method of claim 41, wherein the tile is bonded to the ductile backing material by an autoclave process.
49. The method of claim 41, wherein the tile is bonded to the ductile backing material using heat-curable adhering material and catalyzed foambale exothermic material between the tile and the ductile backing material, wherein heat generated from the use of the catalyzed foambale exothermic material cures the heat-curable adhering material.
50. The method of claim 41, wherein the ductile backing material comprises a plurality of fibers.
51. The method of claim 50, wherein the plurality of fibers comprises polyethylene fibers.