

COMPOSITE HYDROGEN STORAGE MATERIAL AND METHODS RELATED THERETO

PRIORITY OF INVENTION

5 This non-provisional application claims the benefit of priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Serial No. 60/673,859, filed Apr 22, 2005, which is herein incorporated by reference.

TECHNICAL FIELD

10 Embodiments of the present invention relate to a composite hydrogen storage material. Specifically, embodiments of the present invention relate to a composite hydrogen storage material for occluding and desorbing hydrogen.

BACKGROUND

15 Conventionally, hydrogen may be stored in the form of metal hydride powders. During the hydriding/dehydriding cycle, strain behavior causes the particle bed to become unstable, resulting in settling and compacting of the particle bed. Through repeated cycling, the three-dimensional relationship of the powder particles continues to change, causing strain to continue to increase.

20 When using metal hydride powders, inefficient heat transfer can hamper the rate and effectiveness of the hydriding/dehydriding cycle.

 When using traditional metal hydride powders, safety and handling issues arise as many materials are pyrophoric, or become pyrophoric once contacted with hydrogen. In addition, powders may be blown into the hydrogen

25 stream, which requires complicating filtering and also introduces a pressure drop into the fuel system.

 The hydriding/dehydriding process imparts strain on the storage medium causing it to expand during charging and contract during discharge. This strain, which can be quite significant, is conventionally dealt with by designing a

30 hydride storage vessel with expansion room to accommodate the strain. However, the unstable nature of the particle bed causes the packing of hydride

material, effectively filling up the expansion room and causing significant strain to be exerted on the walls of the storage vessel. Therefore, the storage vessel must be designed to deal with this internally induced mechanical strain, either by increasing wall thickness or developing a system of internal structures to cause the bed to 'unpack' itself when straining occurs. The need for these complicated designs of a storage vessel effectively reduces the volumetric hydrogen storage density of the metal hydride powders.

The hydriding/dehydriding process causes the powder particles to pack more tightly, thus increasing the compaction of the system. The three-dimensional relationship of the particles changes throughout the hydriding/dehydriding cycle, negatively affecting the hydrogen storage ability of the powder.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, which are not necessarily drawn to scale, like numerals describe substantially similar components throughout the several views. Like numerals having different letter suffixes represent different instances of substantially similar components. The drawings illustrate generally, by way of example, but not by way of limitation, various embodiments discussed in the present document.

FIG. 1 illustrates a block flow diagram of a method of making a composite hydrogen storage material, according to some embodiments of the invention.

FIG. 2 illustrates a block flow diagram of a method to occlude and desorb hydrogen using a composite hydrogen storage material, according to some embodiments of the invention.

FIG. 3 illustrates a graphical view of the pressure-composition-temperature (PCT) profile of a hydriding/dehydriding cycle of an exemplary metal hydride hydrogen storage material, that may be used in some embodiments of the invention.

FIG. 4 illustrates a perspective view of a storage vessel utilizing a composite hydrogen storage material in communication with a device, according to some embodiments of the invention.

FIG. 5 illustrates a perspective view of a storage vessel utilizing a composite hydrogen storage material, according to some embodiments of the invention.

FIG. 6 illustrates a cross-sectional view of a storage vessel utilizing a composite hydrogen storage material disposed on an interior wall, according to some embodiments of the invention.

FIG. 7 illustrates a cross-sectional view of a storage vessel utilizing a composite hydrogen storage material disposed on an interior wall, according to some embodiments of the invention.

FIG. 8 illustrates a cross-sectional view of a storage vessel a composite hydrogen storage material as a plurality of layers in a matrix within the storage vessel, according to some embodiments of the invention.

FIG. 9 illustrates a perspective view of a composite hydrogen storage material structure, according to some embodiments of the invention.

SUMMARY

Embodiments of the disclosure relate to a composite hydrogen storage material comprising active material particles and a binder, wherein the binder immobilizes the active material particles sufficient to maintain relative spatial relationships between the active material particles.

In the first aspect, there is provided a composite hydrogen storage material comprising: active material particles capable of occluding and desorbing hydrogen; and a thermoplastic binder; wherein the binder elastically immobilizes the active material particles sufficient to maintain relative spatial relationships between the active material particles before, during and after any occluding and desorbing of hydrogen; and wherein the composite hydrogen storage material is capable of withstanding a force produced by a particle strain during occlusion and desorption of hydrogen by the active material particles, sufficient to provide a load bearing member independently or within a storage vessel.

In the second aspect, there is provided a composite hydrogen storage material comprising: active material particles capable of occluding and desorbing hydrogen; a thermoplastic binder; and one or more additives; wherein the binder elastically immobilizes the active material particles and one or more additives sufficient to maintain relative spatial relationships between the active material particles and one or more additives before, during and after any occluding and desorbing of hydrogen; and wherein the composite hydrogen storage material is capable of withstanding a force produced by a particle strain during occlusion and desorption of hydrogen by the active material particles, sufficient to provide a load bearing member independently or within a storage vessel.

In the third aspect, there is provided a composite hydrogen storage material comprising: active material particles capable of occluding and desorbing hydrogen; and a thermoplastic binder; the binder elastically immobilizing the active material particles sufficient to maintain relative spatial relationships between the active material particles; wherein the composite hydrogen storage material comprises a porosity from about 0.1% to about 50%, and wherein the active material particles comprise a packing density that is at least about 40% of the composite hydrogen storage material; and wherein the composite hydrogen storage material is capable of withstanding a force produced by a particle strain during occlusion and desorption of hydrogen by the active material particles, sufficient to provide a load bearing member independently or within a storage vessel.

Further, embodiments relate to a hydrogen storage system comprising a storage vessel, a composite hydrogen storage material disposed in the storage vessel, wherein the composite hydrogen storage material comprises active material particles and a binder, wherein the binder immobilizes the active material particles sufficient to maintain relative spatial relationships between the active material particles and at least one port for communicating with an external device.

In the fourth aspect, there is provided a hydrogen storage system comprising: (A) a storage vessel; (B) a composite hydrogen storage material disposed in the storage vessel, wherein the composite hydrogen storage material comprises: active material particles capable of occluding and desorbing hydrogen; and a thermoplastic binder;

wherein the binder elastically immobilizes the active material particles sufficient to maintain relative spatial relationships between the active material particles before, during and after any occluding and desorbing of hydrogen; and wherein the composite hydrogen storage material is capable of withstanding a force produced by a particle strain during occlusion and desorption of hydrogen by the active material particles, sufficient to provide a load bearing member independently or within a storage vessel; (C) at least one port for communicating with an external device.

Embodiments of the disclosure relates to a method for making a composite hydrogen storage material comprising forming a fine powder of active material particles, mixing a binder with the fine powder to provide a mixture and heating the

mixture sufficient to form a composite hydrogen storage material, wherein the binder immobilizes the active material particles sufficient to maintain relative spatial relationships between the active material particles.

In the fifth aspect, there is provided a method for making a composite hydrogen storage material comprising: (A) forming a fine powder of active material particles capable of occluding and desorbing hydrogen; (B) mixing a thermoplastic binder with the fine powder to provide a mixture; and (C) heating the mixture, sufficient to form a composite hydrogen storage material, wherein the binder elastically immobilizes the active material particles sufficient to maintain relative spatial relationships between the active material particles; and wherein the composite hydrogen storage material is capable of withstanding a force produced by a particle strain during occlusion and desorption of hydrogen by the active material particles, sufficient to provide a load bearing member independently or within a storage vessel.

In the sixth aspect, there is provided a method of using a composite hydrogen storage material, the method comprising: (A) occluding hydrogen onto or within a composite hydrogen storage material, wherein the composite hydrogen storage material comprises: active material particles capable of occluding and desorbing hydrogen; and a thermoplastic binder; wherein the binder elastically immobilizes the active material particles sufficient to maintain relative spatial relationships between the active material particles and the composite hydrogen storage material is capable of withstanding a force produced by a particle strain during occlusion and desorption of hydrogen by the active material particles, sufficient to provide a load bearing member independently or within a storage vessel; and (B) desorbing hydrogen from the composite hydrogen storage material.

Embodiments of the disclosure also relate to a method of using a composite hydrogen storage material, the method comprising occluding hydrogen onto or within a composite hydrogen storage material, wherein the composite hydrogen storage material comprises active material particles and a binder, wherein the binder immobilizes the active material particles sufficient to maintain relative spatial relationships between the active material particles and desorbing hydrogen from the composite hydrogen storage material.

In the seventh aspect, there is provided a composite comprising: active material particles capable of occluding and desorbing hydrogen, and a thermoplastic binder; wherein the composite is formed into a shape and wherein the binder elastically immobilizes the active material particles sufficient to maintain relative spatial relationships between the active material particles within the composite shape before, during, and after occluding and desorbing of hydrogen.

In the eighth aspect, there is provided a composite, comprising: active material particles capable of occluding and desorbing hydrogen, and a thermoplastic binder; wherein the composite is formed into an unsupported shape and wherein the binder elastically immobilizes the active material particles sufficient to maintain relative spatial relationships between the active material particles within the composite shape before, during, and after occluding and desorbing of hydrogen.

DETAILED DESCRIPTION

The following detailed description includes references to the accompanying drawings, which form a part of the detailed description. The drawings show, by way of illustration, specific embodiments in which the invention may be practiced. These embodiments, which are also referred to herein as "examples," are described in enough detail to enable those skilled in the art to practice the invention. The embodiments may be combined, other embodiments may be utilized, or structural, and logical changes may be made without departing from the scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined by the appended claims and their equivalents.

In this document, the terms "a" or "an" are used to include one or more than one and the term "or" is used to refer to a nonexclusive or unless otherwise indicated. In addition, it is to be understood that the phraseology or terminology employed herein, and not otherwise defined, is for the purpose of description only and not of limitation. Furthermore, all publications, patents, and patent documents referred to in this document are incorporated by reference herein in their entirety, as though individually incorporated by reference. In the event of inconsistent usages between this document and those documents so incorporated

by reference, the usage in the incorporated reference should be considered supplementary to that of this document; for irreconcilable inconsistencies, the usage in this document controls.

Embodiments of the invention provide a composite hydrogen storage material and methods related thereto. The composite hydrogen storage material allows for the occlusion and desorption of hydrogen in which the particle bed packing traditionally caused by decrepitation during the hydriding/dehydriding cycle is reduced or eliminated. The composite hydrogen storage material comprises active material particles and a binder, wherein the binder immobilizes the active material particles sufficient to maintain relative spatial relationships between the active material particles. The composite hydrogen storage material may deform under hydriding, but substantially returns to its original shape and morphology, thus the three-dimensional relationships between the active material particles are essentially unchanged throughout multiple hydriding/dehydriding cycles.

The composite hydrogen storage material also may act as a load bearing member within a storage vessel, effectively increasing the volumetric energy storage of the vessel. By utilizing the composite hydrogen storage material of the embodiments of the invention, requirements for filtration of loose metal hydride particles in the desorbed hydrogen stream is eliminated and the traditional problems of powder compaction in metal hydride storage vessels are eliminated. The composite hydrogen storage material is more thermally conductive than traditional metal hydride powders and retains similar absorption/desorption rate and capacity limits. The use of a composite hydrogen storage material for hydrogen storage is safer than traditional metal hydride powders as there is much less risk of storage vessel rupture due to powder compaction. Further, the use of a composite hydrogen storage material for hydrogen storage may allow for better compliance with national and international regulatory laws and procedures regarding the transport of hydrogen and hydrogen storage vessels.

Definitions

As used herein, "composite hydrogen storage material" refers to active material particles mixed with a binder, wherein the binder immobilizes the active material particles sufficient to maintain relative spatial relationships between the active material particles.

5 As used herein, "relative spatial relationships" refers to three-dimensional relationships between particles. Such three-dimensional relationships between particles in the context of the present invention will remain substantially unchanged. For example, the distance between particles may change during the hydriding/dehydriding cycle, but the particles return to
10 substantially the same position relative to the other particles over the course of one complete cycle. The particle structure may have, e.g., an elastic property, in that the particles may move, but maintain substantially the same three-dimensional positioning substantially relative to other particles as they move. An exemplary indicator of whether a material meets the above characteristics is
15 a qualitative measurement based upon, e.g., the volume, packing density or porosity or a dimension (e.g. length) of the composite material over repeated cycles. As such, when length of the formed composite is used as the indicator, the length of the formed composite will be at least about 80% and not more than about 120% of the parent length measured.

20 As used herein, "occlude" or "occluding" or "occlusion" refers to absorbing or adsorbing and retaining a substance. Hydrogen may be the substance occluded, for example. A substance may be occluded chemically or physically, such as by chemisorption or physisorption, for example.

 As used herein, "desorb" or "desorbing" or "desorption" refers to the
25 removal of an absorbed or adsorbed substance. Hydrogen may be removed from active material particles, for example. The hydrogen may be bound physically or chemically, for example.

 As used herein, "immobilize" refers to the holding of particles, such that relative spatial relationships are maintained. For example, active material
30 particles may be immobilized, allowing them to move, but keeping the particles substantially in the same geometric relationship to one another throughout multiple hydriding/dehydriding cycles.

As used herein, "metal hydride particles" or "metal hydrides" refer to metal or metal alloy particles that are capable of forming metal hydrides when contacted with hydrogen. Examples of such metal or metal alloys are LaNi_5 , FeTi , Mg_2Ni and ZrV_2 . Such compounds are representative examples of the more general description of metal hydride compounds: AB , AB_2 , A_2B , AB_5 and BCC, respectively. When bound with hydrogen, these compounds form metal hydride complexes, such as MgH_2 , Mg_2NiH_4 , FeTiH_2 and LaNi_5H_6 , for example. Examples of metals used to form metal hydrides include vanadium, magnesium, lithium, aluminum, calcium, transition metals, lanthanides, and intermetallic compounds and solid solutions thereof.

As used herein, "active material particles" refer to material particles capable of storing hydrogen or to material particles that may occlude and desorb hydrogen, such as metal hydrides, for example. The active material may be a metal, metal alloy or metal compound capable of forming a metal hydride when in contact with hydrogen. For example, the active material may be LaNi_5 , FeTi , a mischmetal, a mixture of metals or an ore, such as MmNi_5 , wherein Mm refers to a mixture of lanthanides. The active material particles may occlude hydrogen by chemisorption, physisorption or a combination thereof. Active material particles may also include silicas, aluminas, zeolites, graphite, activated carbons, nano-structured carbons, micro-ceramics, nano-ceramics, boron nitride nanotubes, palladium-containing materials or combinations thereof.

As used herein, "porosity" refers to the ratio of void space in a volume to the total volume (1- volume density).

As used herein, "packing density" refers to the efficiency with which the active material is packed. Packing density is the percentage of the total composite volume that is taken up by the active material. For example, a composite with a packing density of about 50% and a porosity of about 40% would consist of about 50% active material, about 10% inactive material, such as binders or additives, and about 40% void space by volume.

As used herein, "fine powder" refers to a powder comprising particles with a small size. For example, the fine powder may substantially be comprised of particles sized below about 100 microns. The fine powder may be

substantially comprised of particles sized below about 50 microns, about 10 microns, about 1 micron or about 10 nanometers, for example.

Referring to FIG. 1, a block flow diagram of a method 100 of making a composite hydrogen storage material is shown, according to some embodiments of the invention. Active material particles may be formed 102 into a fine powder. A binder may be mixed 104 with the fine powder sufficient to create a mixture. The mixture may be heated 106 sufficient to form a composite hydrogen storage material, wherein the binder immobilizes the active material particles sufficient to maintain relative spatial relationships between the active material particles.

Active material particles may be comprised of material particles that are capable of storing hydrogen or of material particles that occlude and desorb hydrogen. Metal hydrides are examples. Examples may be LaNi_5 , FeTi , Mg_2Ni and ZrV_2 . The active material particles may form 102 a fine powder. The fine powder may be formed 102 by milling, for example chemical milling, ball milling, high energy ball milling, or jet milling, or grinding, or by atomizing liquid metals to form small particles, or combinations thereof, for example.

The fine powder may be mixed 104 with a binder, such as a thermoplastic binder. Examples of suitable binders include polypropylene, polyethylene, polyvinylidene fluoride (PVDF), hexafluoropropylene vinylidene fluoride copolymer, cross-linked copolymers, polytetrafluoroethylene (PTFE), perfluoro alkoxy (PFA), thermoplastic polyesters (for example, NylonTM). If a thermoplastic binder is used, the binder may be readily melt-processable and may have an elongation to break of at least about 20%, for example. The amount of binder may be about 50% by weight or less of the mixture. The binder may be flexible enough to withstand the charging/discharging (hydriding/dehydriding) strain, while not melting or softening during the elevated temperatures of the charging phase.

The mixture may be heated 106 to form a composite hydrogen storage material. The composite hydrogen storage material produced may have a porosity from about 0.1% to about 50%, for example. The composite hydrogen storage material may have a porosity of about 5% to about 40% or from about

15% to about 25%, for example. The packing density of the active material into the metal hydride composite may be no less than about 40%, for example. The packing density may be from about 45% to about 90%, from about 60% to about 80% or greater than about 70%, for example. Optionally, the composite

5 hydrogen storage material may undergo pressure treatment. The compression pressure may be from about 0.2 MPa to about 1000 MPa, or from about 100 MPa to about 400MPa. In addition, the mixture may be vibrated as well. A further step may include molding of the composite hydrogen storage material. Examples of molding include compression molding, injection molding, extrusion

10 or combinations thereof. The composite hydrogen storage material may be molded into a specific shape, such as a prismatic shape, a pellet, a wafer, a disc, a film, a sheet, a perforated sheet, a rod or combinations thereof.

The composite hydrogen storage material can have sufficient structural strength with a proper binder to withstand the strain induced by charging and

15 discharging the active material particles without causing the composite to fracture. Structural strength of the composite hydrogen storage material allows it to be used as a load bearing member that can resist the force exerted by the hydrogen absorbing into the metal hydride particles. Due to this ability to resist the force produced by particle strain, the composite hydrogen storage material is

20 able to retain its structural integrity and remain as a solid during multiple occlusion and desorption cycles. The composite hydrogen storage material may be shaped as pellets, discs, spheres, wafers, rectangular wafers or any porous or geometric shape.

Optionally, the composite hydrogen storage material may be comprised

25 of additional ingredients, additives or structures that improve the thermal or mechanical properties of the composite. Examples include graphite flakes, carbon fibers, carbon nanofibers, carbon nanotubes, polymer fibers, thermal conductive materials, a metal honeycomb/lattice, metal fibers, wire, metal particles, glass fibers, and combinations thereof. Examples of thermally

30 conductive materials are aluminum foil, aluminum honeycomb, aluminum powder, carbon fibers, carbon flakes and similar materials. Examples of structural additives include carbon flakes, carbon nanotubes, fibers of fiberglass,

carbon fibers, carbon nanofibers and combinations thereof. A lubricant may be an example of an additive. A portion of the composite hydrogen storage material may optionally be removed during manufacture in order to expose such additional materials as thermally conductive materials and structural additives for example.

Additionally, an adsorbent or absorbent material can be added to the composite hydrogen storage material. The adsorbent or absorbent material may adsorb or absorb materials toxic to the active ingredient or that may interfere with the hydriding/dehydriding process. Some examples may include activated carbon, calcium oxide, other metals that readily oxidize, or 'oxygen getters'.

Optionally, a fire retardant may be added to the composite hydrogen storage material. Suitable specific fire retardants include, e.g., phosphonium ammonium borate (i.e., phospho-ammonium boron); 3,4,5,6-dibenzo-1,2-oxaphosphane-2-oxide or 9,10-dihydro-9-oxa-10-phosphaphenanthrene-10-oxide (OPC) [CAS Registry Number 35948-25-5]; sulfamic acid monoammonium salt (ammonium sulfamate) [CAS Registry Number 7773-06-0]; di-n-butyltin oxide (DBTO) [CAS Registry Number 818-08-6]; di-n-octyltin oxide (DOTO) [CAS Registry Number 780-08-6]; dibutyltin diacetate di-n-butyltin diacetate (NS-8) [CAS Registry Number 1067-33-0]; dibutyltin dilaurate di-n-butyltin dilaurate (Stann BL) [CAS Registry Number 77-58-7]; ferrocene; iron pentacarbonyl; ammonium sulfate; ammonium phosphate; zinc chloride; and combinations thereof, for example.

The following are examples of composite hydrogen storage materials and methods related thereto, according to some embodiments of the invention

Example 1:

5 grams LaNi_5 powder with a particle size of about 1 micron or less is mixed with 0.2 grams of Atofina's 2851 kynarflex (Polyvinylidene fluoride derivative) grade thermoplastic powder with a particle size of about 0.1 micron or less. The mixture is compression molded at about 100 MPa and 165°C in a mold of the desired shape. The mold is then cooled to room temperature while maintaining the 100 MPa of compression pressure. The resulting part released from the mold is a porous solid composite with about 28% porosity, a mass of

5.2 grams, a specific gravity of about 5.2, and a LaNi_5 packing factor of about 60%.

Example 2:

5 5 grams LaNi_5 powder with a particle size of about 1 micron or less is mixed with 0.2 grams of graphitic flakes with a particle size of about 1 – 10 microns and with 0.2 grams of Atofina's 2851 kynarflex (Polyvinylidene fluoride derivative) grade thermoplastic powder with a particle size of about 0.1 micron or less. The mixture is compression molded at 100 MPa and 165°C in a
10 mold of the desired shape. The mold is then cooled to room temperature while maintaining the about 100 MPa of compression pressure. The resulting part released from the mold is a porous solid composite with about 28% porosity, a mass of 5.4 grams, a specific gravity of about 5.0, and a LaNi_5 packing factor of about 56%. The addition of the graphitic flakes increases the strength and
15 thermal conductivity of the composite solid. These improved properties are beneficial to improve the rate of hydrogen charging and the structural integrity of the part.

Example 3:

20 5 grams LaNi_5 powder with a particle size of about 1 micron or less is mixed with 0.2 grams of Polyparaphenylene terephthalamide (Kevlar) fibers about 10 – 20 microns in diameter/ about 1-2 mm long and with 0.2 grams of Atofina's 2851 kynarflex (Polyvinylidene fluoride derivative) grade thermoplastic powder with a particle size of about 0.1 micron or less. The
25 mixture is compression molded at about 100 MPa and 165°C in a mold of the desired shape. The mold is then cooled to room temperature while maintaining the 100 MPa of compression pressure. The resulting part released from the mold is a porous solid composite with about 28% porosity, a mass of 5.4 grams, a specific gravity of about 4.9, and a LaNi_5 packing factor of about 53%. The
30 addition of the Polyparaphenylene terephthalamide fibers increases the strength of the composite material

Example 4:

5 grams LaNi₅ powder with a particle size of about 1 micron or less is mixed with 0.2 grams of activated carbon with a particle size of about 1 – 10 microns and with 0.2 grams of Atofina's 2851 kynarfex (Polyvinylidene fluoride derivative) grade thermoplastic powder with a particle size of about 0.1 micron or less. The mixture is compression molded at 100 MPa and 165°C in a mold of the desired shape. The mold is then cooled to room temperature while maintaining the about 100 MPa of compression pressure. The resulting part released from the mold is a porous solid composite with about 28% porosity, a mass of 5.4 grams, a specific gravity of about 4.8, and a LaNi₅ packing factor of about 52%. The activated carbon serves to adsorb harmful compounds that may otherwise contaminate the metal hydride during charging.

Referring to FIG. 2, a block flow diagram of a method 200 to occlude and desorb hydrogen using a composite hydrogen storage material is shown, according to some embodiments of the invention. A composite hydrogen storage material 202 may be placed in a storage vessel 204 to create a composite hydrogen storage material-vessel structure 206. Hydrogen may be occluded onto or within a composite hydrogen storage material-vessel structure 206 sufficient to produce a composite hydrogen storage material-vessel structure storing hydrogen 210. The hydrogen may be desorbed 212, which readies the composite hydrogen storage material-vessel structure 206 for another cycle of hydrogen absorption/desorption. The absorption/desorption of hydrogen may be repeated numerous times, up to about 10,000, or up to about 100,000 for example, depending on the hydride material used.

A composite hydrogen storage material 202 may be placed in a storage vessel 204, such as a tank or container. As an example, the composite hydrogen storage material 202 may be utilized in a cellular fuel tank such as discussed in Zimmermann, U.S. Provisional Patent Application Serial No. 60/757,782 (Attorney Docket No. 2269.004PRV), entitled "CELLULAR RESERVOIR AND METHODS RELATED THERETO," filed January 9, 2006, the disclosure of which is incorporated herein by reference in its entirety.

Because of its structural strength in solid form, the composite hydrogen storage material 202 serves the dual function of storing hydrogen and also of holding the hydrogen storage particles in a fixed relative spatial relationship. Therefore, the function of resisting the strain induced by the charging of hydrogen onto the material is fulfilled entirely by the composite hydrogen storage material. As a result, the vessel for storing the hydrogen 210 need be designed to resist only the gas pressure of the system.

Referring to FIG. 3, a graphical display of the absorbing/desorbing characteristics of an exemplary hydrogen storage material within a storage vessel is shown. FIG. 3 shows a graphical view of the pressure-composition-temperature (PCT) profile of a hydriding/dehydriding cycle of a metal hydride hydrogen storage material, such as one which may be used in some embodiments of the invention.

Referring to FIG. 4, a perspective view of a storage vessel utilizing a composite hydrogen storage material in communication with a device 400 is shown, according to some embodiments of the invention. The storage vessel 410 comprises an external wall 408, an optional pressure relief functionality 406, and port 404 in which to communicate with an external device 402. The optional pressure relief functionality 406 may be a pressure relief mechanism, such as a valve, a spring loaded-valve, a fusible trigger, a rupture disk, a diaphragm, or a vent feature, which may be integral to a tank. The port 404 may be a sealable port, for example. The external device may be a fuel cell system, a hydrogen source, a heat pump, a hydrogen compressor, or air conditioning system, for example. External device 402 may also be a gas management device, such as a regulator, check valve, on/off valve or other interconnection, for example. Alternatively, a portion of one of the exterior walls 408 may comprise a fuel cell layer, fuel cell system, a hydrogen source, a heat pump or a hydrogen compressor, for example.

When used in conjunction with a fuel cell, it is possible to create a compact system for powering portable electronic devices. Some examples of portable electronics for use with the fuel cell include, but are not limited to, cellular phones, satellite phones, laptop computers, computer accessories,

displays, personal audio or video players, medical devices, televisions, transmitters, receivers, lighting devices including outdoor lighting or flashlights, electronic toys, or any device conventionally used with batteries.

The storage vessel 410 may be of a small size and the optional pressure relief functionality 406 may be integrated into the design of the storage vessel 410. For larger storage vessels 410, a pressure activated relief device or temperature activated relief device may be usable. The activation temperature range may be from about 150°C to about 400°C for a temperature activated relief device. For a pressure activated relief device, the activation pressure may be from about 200 to about 1000psi, but will depend on the thickness and strength of the storage vessel 410 walls.

Referring to FIG. 5, a perspective view of a storage vessel 500 utilizing a composite hydrogen storage material is shown, according to some embodiments of the invention. The storage vessel 500 comprises an optional pressure relief functionality 504 and port 506. Pressure relief functionality 504 is optional and may be eliminated from the design of the storage vessel, particularly when the vessel is very small, or has been designed with an integral feature to fail while allowing reasonably safe relief of internal pressure. The port 506 may be used to communicate with any number of external devices (not shown in figure).

Referring to FIG. 6, a cross-sectional view of a storage vessel 600 utilizing a composite hydrogen storage material disposed on an interior wall is shown, according to some embodiments of the invention. The storage vessel 600 comprises an interior wall 606 and exterior wall 602. A composite hydrogen storage material 604 may be disposed within the interior wall 606, creating a space 608 between the composite hydrogen storage material 604 and interior wall 606. The composite hydrogen storage material 604 may be in the form of matrix which may utilize a melt processible polymer, for example polyvinylidene fluoride, polyethylene or polypropylene, as the binder. The matrix may partially or entirely fill the interior space of the storage vessel 600.

The composite hydrogen storage material 604 may be optionally adhered to at least a portion of at least one of the interior walls 606 of the storage vessel 600. The composite hydrogen storage material 604 may be adhered using a melt

processable polymer, for example. Alternatively, adhering may be performed by gluing the composite hydrogen storage material 604 to at least a portion of at least one of the interior walls 606. An example of glue that may be utilized is an epoxy adhesive or a silicone adhesive, for example.

5 Referring to FIG. 7, a cross-sectional view of a storage vessel 700 utilizing a composite hydrogen storage material as a matrix substantially filling the storage vessel is shown, according to some embodiments of the invention. The storage vessel 700 comprises an interior wall 706 and exterior wall 702. A composite hydrogen storage material 704 may be disposed as a matrix within the
10 interior wall 702, substantially filling the storage vessel 700.

Referring to FIG. 8, a cross-sectional view of a storage vessel 800 utilizing a composite hydrogen storage material as a plurality of layers in a matrix within the storage vessel is shown, according to some embodiments of the invention. The storage vessel 800 comprises an interior wall 810 and exterior
15 wall 802. A composite hydrogen storage material 804 can be disposed as a plurality of layers within the interior wall 802, creating spaces 806. Between each layer of the composite hydrogen storage material 804, may be placed an optional conductive member 808. During the manufacture of the composite hydrogen storage material 804, portions of the structure may be removed in
20 order to expose a conductive member 808.

For example, a storage vessel 800 may be filled with composite hydrogen storage material 804 so that storage vessels 800 of differing sizes may be built up from the same basic element. This would allow for the placement of composite hydrogen storage material 804 with other materials inside the storage
25 vessel 800, i.e. placing heat conducting members around the composite hydrogen storage material 804, as shown. Some of the material may then be removed to expose parts of the composite 804 that have particular characteristics, such as exposing heat conducting members 808 embedded within the material.

Referring to FIG. 9, a perspective view of a composite hydrogen storage
30 material structure 900 is shown, according to some embodiments of the invention. A composite hydrogen storage material structure 900 can be formed in such shapes as a rectangular wafer 902, for example. The cross-sectional cut

out illustrates the interaction of active material 904, such as a metal hydride, and binder 908, which may create one or more interstitial spaces or voids 906. The spaces 906 allow for hydrogen diffusion and flow through the active material, such as metal hydride particles so that hydrogen is able to reach the interior of the formed composite hydrogen storage material.

While the present invention has been particularly shown and described with reference to preferred embodiments, it will be readily appreciated by those of ordinary skill in the art that various changes and modifications may be made without departing from the spirit and scope of the invention. It is intended that the claims be interpreted to cover the disclosed embodiment, those alternatives which have been discussed above and all equivalents thereto.

The Abstract is provided to comply with 37 C.F.R. §1.72(b) to allow the reader to quickly ascertain the nature and gist of the technical disclosure. The Abstract is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims.

CLAIMS

What is claimed is:

1. A composite hydrogen storage material comprising:
active material particles capable of occluding and desorbing hydrogen; and a thermoplastic binder;
wherein the binder elastically immobilizes the active material particles sufficient to maintain relative spatial relationships between the active material particles before, during and after any occluding and desorbing of hydrogen; and wherein the composite hydrogen storage material is capable of withstanding a force produced by a particle strain during occlusion and desorption of hydrogen by the active material particles, sufficient to provide a load bearing member independently or within a storage vessel.
2. The composite hydrogen storage material of claim 1, wherein the active material particles occlude hydrogen by physisorption, chemisorption or a combination thereof.
3. The composite hydrogen storage material of claim 1, wherein the active material particles comprises a metal hydride.
4. The composite hydrogen storage material of claim 1 wherein the active material particles comprise type AB, AB₂, A₂B, AB₅, BCC metal hydrides or combinations thereof.
5. The composite hydrogen storage material of claim 1, wherein the active material particles comprises LaNi₅, FeTi, or MmNi₅, wherein Mm refers to a mixture of lanthanides.

6. The composite hydrogen storage material of claim 1, wherein the active material particles comprise silicas, aluminas, zeolites, graphite, activate carbons, nano-structured carbons, micro-ceramics, nano-ceramics, boron nitride nanotubes, palladium-containing materials or combinations thereof.
7. The composite hydrogen storage material of claim 1, wherein the thermoplastic binder is selected from the group of polypropylene, polyethylene, polyvinylidene fluoride, hexafluoropropylene vinylidene fluoride copolymer, cross-linked copolymers and combinations thereof.
8. The composite hydrogen storage material of claim 1, further comprising one or more additives.
9. The composite hydrogen storage material of claim 1, further comprising a thermally conductive additive.
10. The composite hydrogen storage material of claim 9, wherein the thermally conductive additive comprises aluminum, graphite flakes, graphite fibers, or a combination thereof.
11. The composite hydrogen storage material of claim 1, further comprising an adsorbent additive.
12. The composite hydrogen storage material of claim 11, wherein the adsorbent additive is capable of adsorbing materials that can interfere with the hydrogen storing function of the active material particles.
13. The composite hydrogen storage material of claim 12, wherein the adsorbent comprises activated carbon.

14. The composite hydrogen storage material of claim 1, further comprising a structural additive.
15. The composite hydrogen storage material of claim 14, wherein the structural additive is selected from the group of carbon flakes, carbon nanotubes, fibers of fiberglass, carbon fibers, carbon nanofibers and combinations thereof.
16. The composite hydrogen storage material of claim 1, further comprising a fire retardant.
17. The composite hydrogen storage material of claim 1, further comprising a lubricant.
18. A composite hydrogen storage material comprising:
 - active material particles capable of occluding and desorbing hydrogen;
 - a thermoplastic binder; and one or more additives; wherein the binder elastically immobilizes the active material particles and one or more additives sufficient to maintain relative spatial relationships between the active material particles and one or more additives before, during and after any occluding and desorbing of hydrogen; and wherein the composite hydrogen storage material is capable of withstanding a force produced by a particle strain during occlusion and desorption of hydrogen by the active material particles, sufficient to provide a load bearing member independently or within a storage vessel.
19. A composite hydrogen storage material comprising:
 - active material particles capable of occluding and desorbing hydrogen; and a thermoplastic binder; the binder elastically immobilizing the active material particles sufficient to maintain relative spatial relationships between the active material particles;

wherein the composite hydrogen storage material comprises a porosity from about 0.1 % to about 50%, and wherein the active material particles comprise a packing density that is at least about 40% of the composite hydrogen storage material; and wherein the composite hydrogen storage material is capable of withstanding a force produced by a particle strain during occlusion and desorption of hydrogen by the active material particles, sufficient to provide a load bearing member independently or within a storage vessel.

20. A hydrogen storage system comprising:

(A) a storage vessel;

(B) a composite hydrogen storage material disposed in the storage vessel, wherein the composite hydrogen storage material comprises:

active material particles capable of occluding and desorbing hydrogen; and
a thermoplastic binder;

wherein the binder elastically immobilizes the active material particles
sufficient to maintain relative spatial

relationships between the active material particles before, during and after
any occluding and desorbing of hydrogen; and wherein the composite
hydrogen storage material is capable of withstanding a force produced by a
particle strain during occlusion and desorption of hydrogen by the active
material particles, sufficient to provide a load bearing member independently
or within a storage vessel;

(C) at least one port for communicating with an external device.

21. The hydrogen storage system of claim20, wherein the external device is a device comprising one or more of fuel cell system, a hydrogen source, a heat pump, a hydrogen compressor, a valve or a pressure regulator.
22. A method for making a composite hydrogen storage material comprising:
 - (A) forming a fine powder of active material particles capable of occluding and desorbing hydrogen;
 - (B) mixing a thermoplastic binder with the fine powder to provide a mixture; and
 - (C) heating the mixture, sufficient to form a composite hydrogen storage material, wherein the binder elastically immobilizes the active material particles sufficient to maintain relative spatial relationships between the active material particles; and wherein the composite hydrogen storage material is capable of withstanding a force produced by a particle strain during occlusion and desorption of hydrogen by the active material particles, sufficient to provide a load bearing member independently or within a storage vessel.
23. The method of claim22, further comprising after heating the mixture, applying pressure to the composite hydrogen storage material.
24. The method of claim22, further comprising after heating the mixture, applying vibration to the composite hydrogen storage material.
25. The method of claim22, further comprising after the grinding, mixing an additive with the binder and the fine powder.
26. A method of using a composite hydrogen storage material, the method comprising:
 - (A) occluding hydrogen onto or within a composite hydrogen storage material, wherein the composite hydrogen storage

material comprises:

active material particles capable of
occluding and desorbing hydrogen; and
a thermoplastic binder;

wherein the binder elastically immobilizes the active
material particles sufficient to maintain relative spatial
relationships between the active material particles and the
composite hydrogen storage material is capable of
withstanding a force produced by a particle strain during
occlusion and desorption of hydrogen by the active
material particles, sufficient to provide a load bearing
member independently or within a storage vessel; and

(B) desorbing hydrogen from the composite hydrogen storage
material.

27. The method of claim 26, further comprising after desorbing hydrogen,
occluding hydrogen onto or within a composite hydrogen storage
material a second time.

28. The method of claim 27, further comprising after occluding hydrogen
onto or within a composite hydrogen storage material a second time, desorbing
hydrogen from the composite hydrogen storage material a second time.

29. The method of claim 28, further comprising after desorbing hydrogen
from the composite hydrogen storage material a second time,
occluding hydrogen and desorbing hydrogen three or more times, up to
about 100,000 times.

30. The method of claim 29, wherein the active material particles
substantially
maintain spatial relationships between the active material particles
during the
occluding hydrogen and desorbing hydrogen up to about 100,000 times.

31. A composite comprising:
active material particles capable of occluding and desorbing hydrogen,
and a thermoplastic binder;
wherein the composite is formed into a shape and wherein the binder
elastically immobilizes the active material particles sufficient to
maintain relative spatial relationships between the active material
particles within the composite shape before, during, and after occluding
and desorbing of hydrogen.
32. The composite of claim 31, wherein the shape comprises a prismatic
shape, a pellet, a wafer, a disc, a rod or combinations thereof.
33. A composite, comprising:
active material particles capable of occluding and desorbing hydrogen,
and a thermoplastic binder;
wherein the composite is formed into an unsupported shape and wherein the
binder elastically immobilizes the active material particles sufficient to maintain
relative spatial relationships between the active material particles within the
composite shape before, during, and after occluding and desorbing of hydrogen.
34. The composite of claim 33, wherein the unsupported shape comprises a
prismatic shape, a pellet, a wafer, a disc, a rod or combinations thereof.
35. The composite of claim 33, wherein the composite is formed by heating
the mixture sufficient to sinter the binder.