A production fluid control apparatus is disclosed. The apparatus includes: a gas lift assembly in fluid communication with a borehole production conduit, the gas lift assembly configured to control a flow of pressurized gas between an annular region of a borehole and the production conduit; and at least one plug disposed in operable communication with the gas lift assembly, the at least one plug configured to prevent fluid flow through the gas lift assembly and configured to be actuated to allow fluid flow through the gas lift assembly in response to exposure to a downhole fluid.
Deploy production string and gas lift assembly in borehole - 510

Produce hydrocarbons through production string - 520

Expose gas lift plug to downhole fluid and/or injected gas - 530

Actuate and/or dissolve gas lift plug via exposure to downhole fluid - 540

Perform gas lift operation - 550

FIG.12
APPARATUS AND METHOD FOR CONTROLLING GAS LIFT ASSEMBLIES

BACKGROUND

[0001] Hydrocarbon production systems typically rely on formation pressure from subterranean reservoirs to produce hydrocarbon fluids and gases. In a naturally flowing well, there is enough energy stored in the high pressure reservoir to produce liquids and gases to the surface. When this reservoir energy decreases, it is generally necessary to apply some form of artificial lift to assist in producing these liquids and gases to the surface.

[0002] Gas lift is a form of artificial lift that is used to assist in producing boreholes that do not flow or cannot flow at optimum or desired producing rates. Gas lift systems generally include a mechanism for injecting high pressure gas from an annular region of the well into a production conduit. A valve is typically used in gas lift systems to control flow of the high pressure gas into the production conduit.

[0003] Dummy valves are often loaded in side pocket mandrels when they are installed in borehole completion systems to isolate a borehole annulus from the production tubing where, for example, pressurization is required to test the tubing, test the annulus, set a hydraulic packer or activate an isolation device. If the borehole requires gas lift to unload the completion fluid or assist in producing production fluid, wireline intervention is typically required to remove the dummy valves and install a live gas lift device.

BRIEF DESCRIPTION OF THE INVENTION

[0004] A production fluid control apparatus includes: a gas lift assembly in fluid communication with a borehole production conduit, the gas lift assembly configured to control a flow of pressurized gas between an annular region of a borehole and the production conduit; and at least one plug disposed in operable communication with the gas lift assembly, the at least one plug configured to prevent fluid flow through the gas lift assembly and configured to be actuated to allow fluid flow through the gas lift assembly in response to exposure to a downhole fluid.

[0005] A method of producing hydrocarbon fluid from a borehole includes: disposing a production assembly in the borehole, the production assembly including a production conduit and a gas lift assembly in fluid communication with the production conduit, the gas lift assembly configured to control a flow of pressurized gas between an annular region of the borehole and the production conduit, the production assembly including at least one plug configured to prevent fluid flow through the gas lift assembly; exposing at least one plug to a downhole fluid; and actuating the at least one plug by dissolving or corroding at least a portion of the at least one plug in response to exposure to the downhole fluid to allow fluid to flow through the gas lift assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike.

[0007] FIG. 1 depicts an embodiment of a downhole completion and/or production system including a gas lift assembly;

[0008] FIG. 2 is a partial cross-sectional view of an exemplary embodiment of a valve configured for use with the gas lift assembly of FIG. 1;

[0009] FIG. 3 is a close-up view of a portion of an exemplary embodiment of the valve of FIG. 2;

[0010] FIG. 4 is a partial cross-sectional view of an exemplary embodiment of the gas lift assembly of FIG. 1;

[0011] FIG. 5 is a partial cross-sectional view of an exemplary embodiment of the gas lift assembly of FIG. 1;

[0012] FIG. 6 is a photomicrograph of a powder as disclosed herein that has been embedded in a potting material and sectioned;

[0013] FIG. 7 is a schematic illustration of an exemplary embodiment of a powder particle as it would appear in an exemplary section view represented by section 5-5 of FIG. 6;

[0014] FIG. 8 is a photomicrograph of an exemplary embodiment of a powder compact as disclosed herein;

[0015] FIG. 9 is a schematic illustration of an exemplary embodiment of the powder compact of FIG. 8 made using a powder having single-layer powder particles as it would appear taken along section 7-7;

[0016] FIG. 10 is a schematic illustration of another exemplary embodiment of the powder compact of FIG. 8 made using a powder having multilayer powder particles as it would appear taken along section 7-7;

[0017] FIG. 11 is a schematic illustration of a change in a property of a powder compact as disclosed herein as a function of time and a change in condition of the powder compact environment; and

[0018] FIG. 12 is a flow diagram depicting a method of controlling production fluid in a borehole.

DETAILED DESCRIPTION OF THE INVENTION

[0019] There is provided apparatuses and methods for controlling hydrocarbon production in a borehole in an earth formation. A production assembly such as a production string is configured to be disposed in a borehole and facilitate production of hydrocarbons (e.g., oil and/or gas). A gas lift assembly is disposed in the production assembly, and includes one or more ports configured to allow pressurized gas to flow through the gas lift assembly and into the production assembly, e.g., into a production conduit, to provide lift and facilitate hydrocarbon production. At least one plug that includes a material configured to react with downhole fluids is disposed in fluid communication with the gas lift assembly and prevents lift gas from flowing into the production conduit. The plug is actuation in response to exposure to downhole fluid (e.g., saltwater and/or production fluids including hydrocarbon liquids and/or gases) to allow the lift gas to flow into the production conduit. In one embodiment, the plug is a dissolvable plug configured to corrode, degrade, dissolve or go into solution upon exposure to downhole fluids.

[0020] Referring to FIG. 1, an exemplary embodiment of a downhole completion and/or production system 110 includes a borehole string 112 that is shown disposed in a borehole 114 that penetrates at least one earth formation 116. The borehole 114 may be an open hole or an at least partially cased hole, and may be generally vertical or include a horizontal component. A “borehole string”, as used herein, refers to a production assembly including a production string having a production conduit, and may also refer to any structure or carrier suitable for lowering a tool or component through a borehole and/or connecting a tool to the surface, and is not limited to the structure and configuration described herein. A “carrier”
as described herein means any device, device component, combination of devices, media and/or member that may be used to convey, house, support or otherwise facilitate the use of another device, device component, combination of devices, media and/or member. Exemplary non-limiting carriers include borehole strings of the coiled tube type, of the jointed pipe type and any combination or portion thereof. Other carrier examples include casing pipes, wirelines, wireline sondes, slickline sondes, drop shots, downhole subs, and bottom-hole assemblies.

[0021] The system 110 may include a downhole packing tool 118 such as an inflatable or expandable packer. The packing tool 118 is configured to prevent production of formation sand or other particulates as production fluid is produced from the formation 116, and aid in directing production fluid into the borehole string 112. The packing tool 118 may be incorporated in the borehole string 112 as, for example, a packer sub or joint.

[0022] As shown in FIG. 1, the borehole string 112 includes a gas lift assembly 120 configured to pump, inject or otherwise introduce pressurized gas into a production conduit 122 in the borehole string 112 to aid in forcing production fluid toward the surface. The gas lift assembly 120 includes a support component in operable communication with the production conduit 122 and with one or more gas inlet ports 124. The gas inlet ports 124 provide fluid communication between the gas lift assembly 120 and an annular region of the borehole 112 into which pressurized gases are injected from, for example, a surface injection, processing and/or control unit 125. The support component is configured as, in one embodiment, a tubular housing extending axially (i.e., extending at least partially in a direction generally parallel to a longitudinal axis of the borehole 114) along the borehole string 112. In one embodiment, the support component includes a side pocket mandrel 126 that is held in a fixed position relative to the production conduit 122. The mandrel 126 may be held in any suitable manner, such as affixed by a mechanical connection such as a weld, screws or by a latch located in a latch profile 128, by forming a conduit in the borehole string wall. Although the support component is described herein as the mandrel 126, the support component is not so limited and may include any structures or configurations sufficient to secure the gas lift assembly 120 in or with the borehole string 112.

[0023] The mandrel 126, in one embodiment, includes one or more cavities 130 configured to hold components of the gas lift assembly 120 and/or at least partially seal the components from the production conduit 122.

[0024] Referring to FIG. 2, in one embodiment, the gas lift assembly 120 includes a gas flow control device 132 that is configured to control the flow of downhole fluid and/or the pressurized gas through the gas lift assembly 120, the mandrel 126 and/or the ports 124. The gas flow control device 132 is configured to seal in the cavities 130 and direct pressurized gas flow from an annular area in fluid communication with the flow ports 124, through flow ports 124 of the gas flow control device 132 and through the flow control device 132. In one embodiment, pressurized gas is directed from the flow ports 124 and into the production conduit 122 via one or more outlet ports 136 located in, for example, a nose section 138 of the gas flow control device 132.

[0025] In one embodiment, the gas flow control device 132 includes one or more valve assemblies configured to control fluid flow through the flow control device 132. For example, as shown in FIG. 3, a reverse flow check valve 140 is disposed in the flow control device 132 to prevent pressurized gases from flowing backward relative to the desired flow direction and/or prevent other downhole fluids from flowing into the flow control device 132.

[0026] The gas lift assembly 120 also includes at least one plug 142 disposed in operable communication with the gas lift assembly 120 and configured to block the flow of fluid (including production fluids and the pressurized gas used for the artificial lift) between the production conduit 122 and other regions in the borehole 114, such as an annular region around the production conduit 122. The plug 142 is configured to be actuated in response to exposure to downhole fluids such as water and production fluids including hydrocarbon liquids and/or gases.

[0027] The plug 142 is made at least partially from a material configured to corrode, degrade, reduce, dissolve or go into solution when in contact with a downhole fluid. In one embodiment, the plug 142 is made of a material such that the plug 142 will at least partially disappear or dissolve and allow the gas lift assembly 120 and/or flow control device 132 to function as designed. The gas lift plug 142 is manufactured from a material which will provide a temporary positive barrier to pressurized gas and downhole fluids and prevent them from flowing through the gas lift assembly 120.

[0028] In one embodiment, before the gas lift plug 142 is sufficiently dissolved to allow fluid flow therethrough, the plug 142 causes the gas lift assembly 120 to act as a temporary dummy valve. As described herein, a “dummy valve” refers to any device or mechanism that is disposed in place of a borehole component and acts to restrict fluid flow therethrough. A dummy valve is generally replaced with the borehole component when the component is needed. For example, the gas lift plug 142 isolates the annulus from the production conduit 122 where pressurization is required to perform actions such as testing the production string 112, testing the annulus, setting a packer or activating an isolation device.

[0029] FIG. 3, shows an exemplary embodiment of the gas lift plug 142. In this embodiment, the gas lift plug 142 is disposed within the flow control device 132 (e.g., by being installed or retro-fitted in the flow control device 132) to prevent fluid flow in any direction therethrough. For example, the plug 142 is disposed in a location proximate to the flow ports 136 so that the plug 142 is exposed to downhole fluid in the production conduit 122. Such a location includes, but is not limited to, a location in a nose portion 138 of the flow control device 132, between the flow ports 136 and the reverse flow check valve 140.

[0030] FIGS. 4 and 5 show additional exemplary embodiments of the gas lift plug 142. In these embodiments, the plug 142 is disposed in a fluid path between the conduit 122 and the gas lift assembly 120 and/or the mandrel 126. In the embodiment shown in FIG. 4, the plug is formed as a bar shape, a cylindrical shape and/or a tubular shape, and is disposed outside of the flow control device 132 to block the outlet ports 136 of the flow control device 132. In the embodiment shown in FIG. 5, the plug 142 is formed as a hollow cylindrical or toroidal shape having an outer diameter substantially the same or similar to the inside diameter of a length of the conduit 122. The plug 142 is held in place, for example, by a side wall of the production conduit 122 (e.g., a bottom swage 144) and the end of the fluid control device 132 and/or mandrel 126.
The configuration, size and shape of the plug 142 is not limited to that described herein. In addition to the cylindrical and annular or toroidal shapes described herein, the plug 142 may take any shape such as tubular shapes configured to conform to any conduits or cavities in or operably coupled to the gas lift assembly 120.

In one embodiment, the gas lift plug 142 is made of a material and shaped or otherwise configured to dissolve at a known rate upon exposure to a downhole fluid, and accordingly block fluid for an approximately known period of time. For example, the gas plug material is a material that does not substantially react with drilling mud or other fluids, and electrolytically decomposes in a selected time, for example, 12-24 hours in salt water dependent upon temperature and well conditions.

The gas lift plug material includes any material or combination of materials that is configured to dissolve, corrode, degrade, break up or otherwise reduce in size upon exposure to downhole fluids. Such materials include metallic materials such as magnesium and/or aluminum, which may be formed for example by depositing layers of material by techniques such as electrochemical deposition and vapor deposition such as chemical vapor deposition (CVD).

In one embodiment, the gas lift plug 142 includes or is at least partially made from a corrodible or soluble material. The materials in the gas lift plug 142 as described herein are lightweight, high-strength metallic materials that may be used in a wide variety of applications and application environments, including use in various wellbore environments to make various selectively and controllably disposable or degradable lightweight, high-strength downhole tools or other downhole components, as well as many other applications for use in both durable and disposable or degradable articles. These lightweight, high-strength and selectively and controllably degradable materials include fully-dense, sintered powder compacts formed from coated powder materials that include various lightweight particle cores and core materials having various single layer and multilayer nanoscale coatings. These powder compacts are made from coated metallic powders that include various electrochemically-active (e.g., having relatively higher standard oxidation potentials) lightweight, high-strength particle cores and core materials, such as electrochemically active metals, that are dispersed within a cellular nanomatrix formed from the various nanoscale metallic coating layers of metallic coating materials, and are particularly useful in wellbore applications. These powder compacts provide a unique and advantageous combination of mechanical strength properties, such as compression and shear strength, low density and selectable and controllable corrosion properties, particularly rapid and controlled dissolution in various wellbore fluids. For example, the particle core and coating layers of these powders may be selected to provide sintered powder compacts suitable for use as high strength engineered materials having a compressive strength and shear strength comparable to various other engineered materials, including carbon, stainless and alloy steels, but which also have low density similar to various polymers, elastomers, low-density porous ceramics and composite materials. As yet another example, these powders and powder compact materials may be configured to provide a selectable and controllable degradation or disposal in response to a change in an environmental condition, such as a transition from a very low dissolution rate to a very rapid dissolution rate in response to a change in a property or condition of a wellbore proximate an article formed from the compact, including a property change in a wellbore fluid that is in contact with the powder compact. The selectable and controllable degradation or disposal characteristics described also allow the dimensional stability and strength of articles, such as wellbore tools or other components, made from these materials to be maintained until they are no longer needed, at which time a predetermined environmental condition, such as a wellbore condition, including wellbore fluid temperature, pressure or pH value, may be configured to promote their removal by rapid dissolution. These coated powder materials and powder compacts and engineered materials formed from them, as well as methods of making them, are described further below.

Referring to FIG. 6, a metallic powder 210 includes a plurality of metallic, coated powder particles 212. Powder particles 212 may be formed to provide a powder 210, including free-flowing powder, that may be poured or otherwise disposed in all manner of forms or molds (not shown) having all manner of shapes and sizes that may be used to fashion precursor powder compacts and powder compacts 400 (FIGS. 9 and 10), as described herein, that may be used as at least a portion of the gas lift plug 142.

Each of the metallic, coated powder particles 212 of powder 210 includes a particle core 214 and a metallic coating layer 216 disposed on the particle core 214. The particle core 214 includes a core material 218. The core material 218 may include any suitable material for forming the particle core 214 that provides powder particle 212 that can be sintered to form a lightweight, high-strength powder compact 400 having selectable and controllable dissolution characteristics. Suitable core materials include electrochemically active metals having a standard oxidation potential greater than or equal to that of Zn, including as Mg, Al, Mn or Zn or a combination thereof. These electrochemically active metals are very reactive with a number of common wellbore fluids, including any number of ionic fluids or highly polar fluids, such as those that contain various chlorides. Examples include fluids comprising potassium chloride (KCl), hydrochloric acid (HCl), calcium chloride (CaCl₂), calcium bromide (CaBr₂) or zinc bromide (ZnBr₂). Core material 218 may also include other metals that are less electrochemically active than Zn or non-metallic materials, or a combination thereof. Suitable non-metallic materials include ceramics, composites, glasses or carbon, or a combination thereof. Core material 218 may be selected to provide a high dissolution rate in a predetermined wellbore fluid, but may also be selected to provide a relatively low dissolution rate, including zero dissolution, where dissolution of the nanomatrix material causes the particle core 214 to be rapidly undermined and liberated from the particle compact at the interface with the wellbore fluid, such that the effective rate of dissolution of particle compacts made using particle cores 214 of these core materials 218 is high, even though core material 218 itself may have a low dissolution rate, including core materials 220 that may be substantially insoluble in the wellbore fluid.

With regard to the electrochemically active metals as core materials 218, including Mg, Al, Mn or Zn, these metals may be used as pure metals or in any combination with one another, including various alloy combinations of these materials, including binary, tertiary, or quaternary alloys of these materials. These combinations may also include composites of these materials. Further, in addition to combinations with one another, the Mg, Al, Mn or Zn core materials
218 may also include other constituents, including various alloying additions, to alter one or more properties of the particle cores 214, such as by improving the strength, lowering the density or altering the dissolution characteristics of the core material 218.  

[0038] Among the electrochemically active metals, Mg, either as a pure metal or an alloy or a composite material, is particularly useful, because of its low density and ability to form high-strength alloys, as well as its high degree of electrochemical activity, since it has a standard oxidation potential higher than Al, Mn or Zn. Mg alloys include all alloys that have Mg as an alloy constituent. Mg alloys that combine other electrochemically active metals, as described herein, as alloy constituents are particularly useful, including binary Mg—Zn, Mg—Al and Mg—Mn alloys, as well as ternary Mg—Zn—Y and Mg—Al—X alloys, where X includes Zn, Mn, Si, Ca or Y, or a combination thereof. These Mg—Al—X alloys may include, by weight, up to about 85% Mg, up to about 15% Al and up to about 5% X. Particle core 214 and core material 218, and particularly electrochemically active metals including Mg, Al, Mn or Zn, or combinations thereof, may also include a rare earth element or combination of rare earth elements. As used herein, rare earth elements include Sc, Y, La, Ce, Pr, Nd or Er, or a combination of rare earth elements. Where present, a rare earth element or combinations of rare earth elements may be present, by weight, in an amount of about 5% or less.  

[0039] Particle core 214 and core material 218 have a melting temperature (T_m). As used herein, T_m includes the lowest temperature at which incipient melting or liquidation or other forms of partial melting occur within core material 218, regardless of whether core material 218 comprises a pure metal, an alloy with multiple phases having different melting temperatures or a composite of materials having different melting temperatures.  

[0040] Particle cores 214 may have any suitable particle size or range of particle sizes or distribution of particle sizes. For example, the particle cores 214 may be selected to provide an average particle size that is represented by a normal or Gaussian type unimodal distribution around an average or mean. In another example, particle cores 214 may be selected or mixed to provide a multimodal distribution of particle sizes, including a plurality of average particle core sizes, such as, for example, a unimodal distribution of core particle sizes. The selection of the distribution of particle core size may be used to determine, for example, the particle size and interparticle spacing 215 of the particles 212 of powder 210. In an exemplary embodiment, the particle cores 214 may have a unimodal distribution and an average particle diameter of about 5 μm to about 300 μm, more particularly about 80 μm to about 120 μm, and even more particularly about 100 μm.  

[0041] Particle cores 214 may have any suitable particle shape, including any regular or irregular geometric shape, or combination thereof. In an exemplary embodiment, particle cores 214 are substantially spheroidal electrochemically active metal particles. In another exemplary embodiment, particle cores 214 are substantially irregularly shaped ceramic particles. In yet another exemplary embodiment, particle cores 214 are carbon or other nanotube structures or hollow glass microspheres.  

[0042] Each of the metallic coated powder particles 212 of powder 210 also includes a metallic coating layer 216 that is disposed on particle core 214. Metallic coating layer 216 includes a metallic coating material 220. Metallic coating material 220 gives the powder particles 212 and powder 210 its metallic nature. Metallic coating layer 216 is a nanoscale coating layer. In an exemplary embodiment, metallic coating layer 216 may have a thickness of about 25 nm to about 2500 nm. The thickness of metallic coating layer 216 may vary over the surface of particle core 214, but will preferably have a substantially uniform thickness over the surface of particle core 214. Metallic coating layer 216 may include a single layer, as illustrated in FIG. 7, or a plurality of layers as a multilayer coating structure. In a single layer coating, or in each of the layers of a multilayer coating, the metallic coating layer 216 may include a single constituent chemical element or compound, or may include a plurality of chemical elements or compounds. Where a layer includes a plurality of chemical constituents or compounds, they may have all manner of homogeneous or heterogeneous distributions, including a homogeneous or heterogeneous distribution of metallurgical phases. This may include a graded distribution where the relative amounts of the chemical constituents or compounds vary according to respective constituent profiles across the thickness of the layer. In both single layer and multilayer coatings 216, each of the respective layers, or combinations of them, may be used to provide a predetermined property to the powder particle 212 or a sintered powder compact formed therefrom. For example, the predetermined property may include the bond strength of the metallurgical bond between the particle core 214 and the coating material 220; the interdiffusion characteristics between the particle core 214 and metallic coating layer 216, including any interdiffusion between the layers of a multilayer coating layer 216; the interdiffusion characteristics between the various layers of a multilayer coating layer 216; the interdiffusion characteristics between the metallic coating layer 216 of one powder particle and that of an adjacent powder particle 212; the bond strength of the metallurgical bond between the metallic coating layers of adjacent sintered powder particles 212, including the outermost layers of multilayer coating layers; and the electrochemical activity of the coating layer 216.  

[0043] Metallic coating layer 216 and coating material 220 have a melting temperature (T_m). As used herein, T_m includes the lowest temperature at which incipient melting or liquidation or other forms of partial melting occur within coating material 220, regardless of whether coating material 220 comprises a pure metal, an alloy with multiple phases each having different melting temperatures or a composite, including a composite comprising a plurality of coating material layers having different melting temperatures.  

[0044] Metallic coating material 220 may include any suitable metallic coating material 220 that provides a sinterable outer surface 221 that is configured to be sintered to an adjacent powder particle 212 that also has a metallic coating layer 216 and sinterable outer surface 221. In powders 210 that also include second or additional (coated or uncoated) particles 232, as described herein, the sinterable outer surface 221 of metallic coating layer 216 is also configured to be sintered to a sinterable outer surface 221 of second particles 232. In an exemplary embodiment, the powder particles 212 are sinterable at a predetermined sintering temperature (T_s) that is a function of the core material 218 and coating material 220, such that sintering of powder compact 400 is accomplished entirely in the solid state and where T_s is less than T_m and T_c. Sintering in the solid state limits particle core 214/metallic coating layer 216 interactions to solid state diffusio-
cesses and metallurgical transport phenomena and limits growth of and provides control over the resultant interface between them. In contrast, for example, the introduction of liquid phase sintering would provide for rapid interdiffusion of the particle core 214/metallic coating layer 216 materials and make it difficult to limit the growth of and provide control over the resultant interface between them, and thus interfere with the formation of the desirable microstructure of particle compact 400 as described herein.

[0045] In an exemplary embodiment, core material 218 will be selected to provide a core chemical composition and the coating material 220 will be selected to provide a coating chemical composition and these chemical compositions will also be selected to differ from one another. In another exemplary embodiment, the core material 218 will be selected to provide a core chemical composition and the coating material 220 will be selected to provide a coating chemical composition and these chemical compositions will also be selected to differ from one another at their interface. Differences in the chemical compositions of coating material 220 and core material 218 may be selected to provide different dissolution rates and selectable and controllable dissolution of powder compacts 400 that incorporate them making them selectively and controllably dissolvable. This includes dissolution rates that differ in response to a changed condition in the wellbore, including an indirect or direct change in a wellbore fluid. In an exemplary embodiment, a powder compact 400 formed from powder 210 having chemical compositions of core material 218 and coating material 220 that make compact 400 is selectively dissolvable in a wellbore fluid in response to a changed wellbore condition that includes a change in temperature, change in pressure, change in flow rate, change in pH or change in chemical composition of the wellbore fluid, or a combination thereof. The selectable dissolution response to the changed condition may result from actual chemical reactions or processes that promote different rates of dissolution, but also encompass changes in the dissolution response that are associated with physical reactions or processes, such as changes in wellbore fluid pressure or flow rate.

[0046] As illustrated in FIGS. 7 and 8, particle core 214 and core material 218 and metallic coating layer 216 and coating material 220 may be selected to provide powder particles 212 and a powder 210 that is configured for compaction and sintering to provide a powder compact 400 that is lightweight (i.e., having a relatively low density), high-strength and is selectively and controllably removable from a wellbore in response to a change in a wellbore property, including being selectively and controllably dissolvable in or in contact with an appropriate wellbore fluid, including various wellbore fluids as disclosed herein. In one embodiment, the gas lift plug 142 is at least partially formed from the powder compact 400.

[0047] Powder compact 400 includes a substantially continuous, cellular nanomatrix 416 of a nanomatrix material 420 having a plurality of dispersed particles 414 dispersed throughout the cellular nanomatrix 416. The substantially continuous cellular nanomatrix 416 and nanomatrix material 420 formed of sintered metallic coating layers 216 is formed by the compaction and sintering of the plurality of metallic coating layers 216 of the plurality of powder particles 212. The chemical composition of nanomatrix material 420 may be different than that of coating material 220 due to diffusion effects associated with the sintering as described herein. Powder metal compact 400 also includes a plurality of dispersed particles 414 that comprise particle core material 418. Dispersed particle cores 414 and core material 418 correspond to and are formed from the plurality of particle cores 214 and core material 218 of the plurality of powder particles 212 as the metallic coating layers 216 are sintered together to form nanomatrix 416. The chemical composition of core material 418 may be different than that of core material 218 due to diffusion effects associated with sintering as described herein.

[0048] As used herein, the use of the term substantially-continuous cellular nanomatrix 416 does not connote the major constituent of the powder compact, but rather refers to the minority constituent or constituents, whether by weight or by volume. This is distinguished from most matrix composite materials where the matrix comprises the majority constituent by weight or volume. The use of the term substantially-continuous, cellular nanomatrix is intended to describe the extensive, regular, continuous and interconnected nature of the distribution of nanomatrix material 420 within powder compact 400. As used herein, “substantially-continuous” describes the extension of the nanomatrix material throughout powder compact 400 such that it extends between and envelopes substantially all of the dispersed particles 414. Substantially-continuous is used to indicate that complete continuity and regular order of the nanomatrix around each dispersed particle 414 is not required. For example, defects in the coating layer 216 over particle core 214 on some powder particles 212 may cause bridging of the particle cores 214 during sintering of the powder compact 400, thereby causing localized discontinuities to result within the cellular nanomatrix 416, even though in the other portions of the powder compact the nanomatrix is substantially continuous and exhibits the structure described herein. As used herein, “cellular” is used to indicate that the nanomatrix defines a network of generally repeating, interconnected, compartments or cells of nanomatrix material 420 that encompass and also interconnect the dispersed particles 414. As used herein, “nanomatrix” is used to describe the size or scale of the matrix, particularly the thickness of the matrix between adjacent dispersed particles 414. The metallic coating layers that are sintered together to form the nanomatrix are themselves nanoscale thickness coating layers. Since the nanomatrix at most locations, other than the intersection of more than two dispersed particles 414, generally comprises the interdiffusion and bonding of two coating layers 216 from adjacent powder particles 212 having nanoscale thicknesses, the matrix formed also has a nanoscale thickness (e.g., approximately two times the coating layer thickness as described herein) and is thus described as a nanomatrix. Further, the use of the term dispersed particles 414 does not connote the minor constituent of powder compact 400, but rather refers to the majority constituent or constituents, whether by weight or by volume. The use of the term dispersed particle is intended to convey the discontinuous and discrete distribution of particle core material 418 within powder compact 400.

[0049] Powder compact 400 may have any desired shape or size, including that of a cylindrical billet or bar that may be machined or otherwise used to form any desired plug shape or size. The pressing used to form precursor powder compact and sintering and pressing processes used to form powder compact 400 and deform the powder particles 212, including particle cores 214 and coating layers 216, to provide the full density and desired macroscopic shape and size of powder compact 400 as well as its microstructure. The microstructure of powder compact 400 includes an equiaxed configuration of
dispersed particles 414 that are dispersed throughout and embedded within the substantially-continuous, cellular nanomatrix 416 of sintered coating layers. This microstructure is somewhat analogous to an equixed grain microstructure with a continuous grain boundary phase, except that it does not require the use of alloy constituents having thermodynamic phase equilibria properties that are capable of producing such a structure. Rather, this equixed dispersed particle structure and cellular nanomatrix 416 of sintered metallic coating layers 216 may be produced using constituents where thermodynamic phase equilibrium conditions would not produce an equixed structure. The equixed morphology of the dispersed particles 414 and cellular network 416 of particle layers results from sintering and deformation of the powder particles 212 as they are compacted and inter-diffuse and deform to fill the interparticle spaces 215. The sintering temperatures and pressures may be selected to ensure that the density of powder compact 400 achieves substantially full theoretical density.

In an exemplary embodiment as illustrated in FIGS. 9 and 10, dispersed particles 414 are formed from particle cores 214 dispersed in the cellular nanomatrix 416 of sintered metallic coating layers 216, and the nanomatrix 416 includes a solid-state metallurgical bond 417 or bond layer 419, as illustrated schematically in FIG. 9, extending between the dispersed particles 414 throughout the cellular nanomatrix 416 that is formed at a sintering temperature (T_s), where T_s is less than T_x, T_y, and T_z. As indicated, solid-state metallurgical bond 417 is formed in the solid state by solid-state interdiffusion between the coating layers 216 of adjacent powder particles 212 that are compressed into touching contact during the compaction and sintering processes used to form powder compact 400, as described herein. As such, sintered coating layers 216 of cellular nanomatrix 416 include a solid-state bond layer 419 that has a thickness (t) defined by the extent of the interdiffusion of the coating materials 220 of the coating layers 216, which will in turn be defined by the nature of the coating layers 216, including whether they are single or multilayer coating layers, whether they have been selected to promote or inhibit such interdiffusion, and other factors, as described herein, as well as the sintering and compaction conditions, including the sintering time, temperature and pressure used to form powder compact 400.

As nanomatrix 416 is formed, including bond 417 and bond layer 419, the chemical composition or phase distribution, or both, of metallic coating layers 216 may change. Nanomatrix 416 also has a melting temperature (T_{m,M}). When used herein, T_{m,M} includes the lowest temperature at which incipient melting or liquidation or other forms of partial melting will occur within nanomatrix 416, regardless of whether nanomatrix material 420 comprises a pure metal, an alloy with multiple phases each having different melting temperatures or a composite, or a combination thereof, or otherwise. As dispersed particles 414 and particle core materials 418 are formed in conjunction with nanomatrix 416, diffusion of constituents of metallic coating layers 216 into the particle cores 214 is also possible, which may result in changes in the chemical composition or phase distribution, or both, of particle cores 214. As a result, dispersed particles 414 and particle core materials 418 may have a melting temperature (T_{DP}) that is different than T. As used herein, T_{DP} includes the lowest temperature at which incipient melting or liquidation or other forms of partial melting will occur within dispersed particles 414, regardless of whether particle core material 418 comprise a pure metal, an alloy with multiple phases each having different melting temperatures or a composite, or otherwise. Powder compact 400 is formed at a sintering temperature (T_s), where T_s is less than T_{DP}.

[0052] Dispersed particles 414 may comprise any of the materials described herein for particle cores 214, even though the chemical composition of dispersed particles 414 may be different due to diffusion effects as described herein. In an exemplary embodiment, dispersed particles 414 are formed from particle cores 214 comprising materials having a standard oxidation potential greater than or equal to Zn, including Mg, Al, Zn or Mn, or a combination thereof, may include various binary, tertiary and quaternary alloys or other combinations of these constituents as disclosed herein in conjunction with particle cores 214. Of these materials, those having dispersed particles 414 comprising Mg and the nanomatrix 416 formed from the metallic coating materials 216 described herein are particularly useful. Dispersed particles 414 and particle core material 418 of Mg, Al, Zn or Mn, or a combination thereof, may also include a rare earth element, or a combination of rare earth elements as disclosed herein in conjunction with particle cores 214.

[0053] In another exemplary embodiment, dispersed particles 414 are formed from particle cores 214 comprising metals that are less electrochemically active than Zn or non-metallic materials. Suitable non-metallic materials include ceramics, glasses (e.g., hollow glass microspheres) or carbon, or a combination thereof, as described herein.

[0054] Dispersed particles 414 of powder compact 400 may have any suitable particle size, including the average particle sizes described herein for particle cores 214.

[0055] Dispersed particles 214 may have any suitable shape depending on the shape selected for particle cores 214 and powder particles 212, as well as the method used to sinter and compact powder 210. In an exemplary embodiment, powder particles 212 may be spheroidal or substantially spheroidal and dispersed particles 414 may include an equixed particle configuration as described herein.

[0056] The nature of the dispersion of dispersed particles 414 may be affected by the selection of the powder 210 or powders 210 used to make particle compact 400. In one exemplary embodiment, a powder 210 having a unimodal distribution of powder particle 212 sizes may be selected to form powder compact 400 and will produce a substantially homogeneous unimodal dispersion of particle sizes of dispersed particles 414 within cellular nanomatrix 416, as illustrated generally in FIG. 8. In another exemplary embodiment, a plurality of powders 210 having a plurality of powder particles with particle cores 214 that have the same core materials 218 and different core sizes and the same coating material 220 may be selected and uniformly mixed as described herein to provide a powder 210 having a homogenous, multimodal distribution of powder particle 212 sizes, and may be used to form powder compact 400 having a homogeneous, multimodal dispersion of particle sizes of dispersed particles 414 within cellular nanomatrix 416. Similarly, in yet another exemplary embodiment, a plurality of powders 210 having a plurality of particle cores 214 that may have the same core materials 218 and different core sizes and the same coating material 220 may be selected and distributed in a non-uniform manner to provide a non-homogenous, multimodal distribution of powder particle sizes, and may be used to form powder
compact 400 having a non-homogeneous, multimodal dispersion of particle sizes of dispersed particles 414 within cellular nanomatrix 416. The selection of the distribution of particle core size may be used to determine, for example, the particle size and interparticle spacing of the dispersed particles 414 within the cellular nanomatrix 416 of powder compacts 400 made from powder 210.

Nanomatrix 416 is a substantially-continuous, cellular network of metallic coating layers 216 that are sintered to one another. The thickness of nanomatrix 416 will depend on the nature of the powder 210 or powders 210 used to form powder compact 400, as well as the incorporation of any second powder 230, particularly the thicknesses of the coating layers associated with these particles. In an exemplary embodiment, the thickness of nanomatrix 416 is substantially uniform throughout the microstructure of powder compact 400 and comprises about two times the thickness of the coating layers 216 of powder particles 212. In another exemplary embodiment, the cellular network 416 has a substantially uniform average thickness between dispersed particles 414 of about 50 nm to about 500 nm.

Nanomatrix 416 is formed by sintering metallic coating layers 216 of adjacent particles to one another by interdiffusion and creation of bond layer 419 as described herein. Metallic coating layers 216 may be single layer or multilayer structures, and they may be selected to promote or inhibit diffusion, or both, within the layer or between the layers of metallic coating layer 216, or between the metallic coating layer 216 and particle core 214, or between the metallic coating layer 216 and the metallic coating layer 216 of an adjacent powder particle, the extent of interdiffusion of metallic coating layers 216 during sintering may be limited or extensive depending on the coating thicknesses, coating material or materials selected, the sintering conditions and other factors. Given the potential complexity of the interdiffusion and interaction of the constituents, description of the resulting chemical composition of nanomatrix 416 and nanomatrix material 420 may be simply understood to be a combination of the constituents of coating layers 216 that may also include one or more constituents of dispersed particles 414, depending on the extent of interdiffusion, if any, that occurs between the dispersed particles 414 and the nanomatrix 416. Similarly, the chemical composition of dispersed particles 414 and particle core material 418 may be simply understood to be a combination of the constituents of particle core 214 that may also include one or more constituents of nanomatrix 416 and nanomatrix material 420, depending on the extent of interdiffusion, if any, that occurs between the dispersed particles 414 and the nanomatrix 416.

In an exemplary embodiment, the nanomatrix material 420 has a chemical composition and the particle core material 418 has a chemical composition that is different from that of nanomatrix material 420, and the differences in the chemical compositions may be configured to provide a selectable and controllable dissolution rate, including a selectable transition from a very low dissolution rate to a very rapid dissolution rate, in response to a controlled change in a property or condition of the wellbore proximate the compact 400, including a property change in a wellbore fluid that is in contact with the powder compact 400, as described herein.

Nanomatrix 416 may be formed from powder particles 212 having single layer and multilayer coating layers 216. This design flexibility provides a large number of material combinations, particularly in the case of multilayer coating layers 216, that can be utilized to tailor the cellular nanomatrix 416 and composition of nanomatrix material 420 by controlling the interaction of the coating layer constituents, both within a given layer, as well as between a coating layer 216 and the particle core 214 with which it is associated or a coating layer 216 of an adjacent powder particle 212. Several exemplary embodiments that demonstrate this flexibility are provided below.

As illustrated in FIG. 9, in an exemplary embodiment, powder compact 400 is formed from powder particles 212 where the coating layer 216 comprises a single layer, and the resulting nanomatrix 416 between adjacent ones of the plurality of dispersed particles 414 comprises the single metallic coating layer 216 of one powder particle 212, a bond layer 419 and the single coating layer 216 of another one of the adjacent powder particles 212. The thickness (t) of bond layer 419 is determined by the extent of the interdiffusion between the single metallic coating layers 216, and may encompass the entire thickness of nanomatrix 416 or only a portion thereof. In one exemplary embodiment of powder compact 400 formed using a single layer powder 210, powder compact 400 may include dispersed particles 414 comprising Mg, Al, Zn or Mn, or a combination thereof, as described herein, and nanomatrix 216 may include Al, Zn, Mn, Mg, Mo, W, Cu, Fe, Si, Ca, Co, Ta, Re or Ni, or an oxide, carbide or nitride thereof, or a combination of any of the aforementioned materials, including combinations where the nanomatrix material 420 of cellular nanomatrix 416, including bond layer 419, has a chemical composition and the core material 418 of dispersed particles 414 has a chemical composition that is different from the chemical composition of nanomatrix material 416. The difference in the chemical composition of the nanomatrix material 420 and the core material 418 may be used to provide selectable and controllable dissolution in response to a change in a property of a wellbore, including a wellbore fluid, as described herein. In a further exemplary embodiment of a powder compact 400 formed from a powder 210 having a single coating layer configuration, dispersed particles 414 include Mg, Al, Zn or Mn, or a combination thereof, and the cellular nanomatrix 416 includes Al or Ni, or a combination thereof.

As illustrated in FIG. 10, in another exemplary embodiment, powder compact 400 is formed from powder particles 212 where the coating layer 216 comprises a multilayer coating layer 216 having a plurality of coating layers, and the resulting nanomatrix 416 between adjacent ones of the plurality of dispersed particles 414 comprises the plurality of layers (t) comprising the coating layer 216 of one particle 212, a bond layer 419, and the plurality of layers comprising the coating layer 216 of another one of powder particles 212. In FIG. 10, this is illustrated with a two-layer metallic coating layer 216, but it will be understood that the plurality of layers of multi-layer metallic coating layer 216 may include any desired number of layers. The thickness (t) of the bond layer 419 is again determined by the extent of the interdiffusion between the plurality of layers of the respective coating layers 216, and may encompass the entire thickness of nanomatrix 416 or only a portion thereof. In this embodiment, the plurality of layers comprising each coating layer 216 may be used to control interdiffusion and formation of bond layer 419 and thickness (t).

Sintered and forged powder compacts 400 that include dispersed particles 414 comprising Mg and nanomatrix 416 comprising various nanomatrix materials as
described herein have demonstrated an excellent combination of mechanical strength and low density that exemplify the lightweight, high-strength materials disclosed herein. Examples of powder compacts 400 that have pure Mg dispersed particles 414 and various nanomatrixes 416 formed from powders 210 having pure Mg particle cores 214 and various single and multilayer metallic coating layers 216 that include Al, Ni, W or Al₂O₃, or a combination thereof. These powders compacts 400 have been subjected to various mechanical and other testing, including density testing, and their dissolution and mechanical property degradation behavior have also been characterized as disclosed herein. The results indicate that these materials may be configured to provide a wide range of selectable and controllable corrosion or dissolution behavior from very low corrosion rates to extremely high corrosion rates, particularly corrosion rates that are both lower and higher than those of powder compacts that do not incorporate the cellular nanomatrix, such as a compact formed from pure Mg powder through the same compaction and sintering processes in comparison to those that include pure Mg dispersed particles in the various cellular nanomatrixes described herein. These powder compacts 400 may also be configured to provide substantially enhanced properties as compared to powder compacts formed from pure Mg particles that do not include the nanoscale coatings described herein. Powder compacts 400 that include dispersed particles 414 comprising Mg and nanomatrix 416 comprising various nanomatrix materials 420 described herein have demonstrated room temperature compressive strengths of at least about 37 ksi, and have further demonstrated room temperature compressive strengths in excess of about 50 ksi, both dry and immersed in a solution of 3% KCl at 200°F. In contrast, powder compacts formed from pure Mg powders have a compressive strength of about 20 ksi or less. Strength of the nanomatrix powder metal compact 400 can be further improved by optimizing powder 210, particularly the weight percentage of the nanoscale metallic coating layers 216 that are used to form cellular nanomatrix 416. Strength of the nanomatrix powder metal compact 400 can be further improved by optimizing powder 210, particularly the weight percentage of the nanoscale metallic coating layers 216 that are used to form cellular nanomatrix 416. For example, varying the weight percentage (wt. %), i.e., thickness, of an alumina coating within a cellular nanomatrix 16 formed from coated powder particles 212 that include a multilayer (Al/Al₂O₃/Al) metallic coating layer 16 on pure Mg particle cores 214 provides an increase of 21% as compared to that of 0 wt % alumina.

[0063] Powder compacts 400 comprising dispersed particles 414 that include Mg and nanomatrix 416 that includes various nanomatrix materials as described herein have also demonstrated a room temperature shear strength of at least about 20 ksi. This is in contrast with powder compacts formed from pure Mg powders, which have room temperature shear strengths of about 8 ksi.

[0064] Powder compacts 400 of the types disclosed herein are able to achieve an actual density that is substantially equal to the predetermined theoretical density of a compact material based on the composition of powder 210, including relative amounts of constituents of particle cores 214 and metallic coating layer 216, and are also described herein as being fully-dense powder compacts. Powder compacts 400 comprising dispersed particles that include Mg and nanomatrix 416 that includes various nanomatrix materials as described herein have demonstrated actual densities of about 1.738 g/cm³ to about 2.50 g/cm³, which are substantially equal to the predetermined theoretical densities, differing by at most 4% from the predetermined theoretical densities.

[0065] Powder compacts 400 as disclosed herein may be configured to be selectively and controllably dissolvable in a wellbore fluid in response to a changed condition in a wellbore. Examples of the changed condition that may be exploited to provide selectable and controllable dissolvability include a change in temperature, change in pressure, change in flow rate, change in pH or change in chemical composition of the wellbore fluid, or a combination thereof. An example of a changed condition comprising a change in temperature includes a change in wellbore fluid temperature. For example, powder compacts 400 comprising dispersed particles 414 that include Mg and cellular nanomatrix 416 that includes various nanomatrix materials as described herein have relatively low rates of corrosion in a 5% KCl solution at room temperature that range from about 0 to about 11 mg/cm²/hr as compared to relatively high rates of corrosion at 200°F, that range from about 1 to about 246 mg/cm²/hr depending on different nanoscale coating layers 216. An example of a changed condition comprising a change in chemical composition includes a change in a chloride ion concentration or pH value, or both, of the wellbore fluid. For example, powder compacts 400 comprising dispersed particles 414 that include Mg and nanomatrix 416 that includes various nanoscale coatings described herein demonstrate corrosion rates in 15% HCl that range from about 4750 mg/cm²/hr to about 7432 mg/cm²/hr. Thus, selectable and controllable dissolvability in response to a changed condition in the wellbore, namely the change in the wellbore fluid chemical composition from KCl to HCl, may be used to achieve a characteristic response as illustrated graphically in FIG. 11, which illustrates that at a selected predetermined critical service time (CST) a changed condition may be imposed upon powder compact 400 as it is applied in a given application, such as a wellbore environment, that causes a controllable change in a property of powder compact 400 in response to a changed condition in the environment in which it is applied. For example, at a predetermined CST changing a wellbore fluid that is in contact with powder contact 400 from a first fluid (e.g., KCl) that provides a first corrosion rate and an associated weight loss or strength as a function of time to a second wellbore fluid (e.g., HCl) that provides a second corrosion rate and associated weight loss and strength as a function of time, wherein the corrosion rate associated with the first fluid is much less than the corrosion rate associated with the second fluid. This characteristic response to a change in wellbore fluid conditions may be used, for example, to associate the critical service time with a dimension loss limit or a minimum strength needed for a particular application, such that when a wellbore tool or component formed from powder compact 400 as disclosed herein is no longer needed in service in the wellbore (e.g., the CST) the condition in the wellbore (e.g., the chloride ion concentration of the wellbore fluid) may be changed to cause the rapid dissolution of powder compact 400 and its removal from the wellbore. In the example described above, powder compact 400 is selectively dissolvable at a rate that ranges from about 0 to about 7000 mg/cm²/hr. This range of response provides, for example the ability to remove a 3 inch diameter ball formed from this material from a wellbore by altering the wellbore fluid in less than one hour. The selectable and controllable dissolvability behavior
described above, coupled with the excellent strength and low density properties described herein, define a new engineered dispersed particle-nanomatrix material that is configured for contact with a fluid and configured to provide a selectable and controllable transition from one of a first strength condition to a second strength condition that is lower than a functional strength threshold, or a first weight loss amount to a second weight loss amount that is greater than a weight loss limit, as a function of time in contact with the fluid. The dispersed particle-nanomatrix composite is characteristic of the powder compacts 400 described herein and includes a cellular nanomatrix 416 of nanomaterial material 420, a plurality of dispersed particles 414 including particle core material 418 that is dispersed within the matrix. Nanomatrix 416 is characterized by a solid-state bond 419, which extends throughout the nanomatrix. The time in contact with the fluid described above may include the CST as described above. The CST may include a predetermined time that is desired or required to dissolve a predetermined portion of the powder compact 200 that is in contact with the fluid. The CST may also include a time corresponding to a change in the property of the engineered material or the fluid, or a combination thereof. In the case of a change of property of the engineered material, the change may include a change of a temperature of the engineered material. In the case where there is a change in the property of the fluid, the change may include the change in fluid temperature, pressure, flow rate, chemical composition or pH or a combination thereof. Both the engineered material and the change in the property of the engineered material or the fluid, or a combination thereof, may be tailored to provide the desired CST response characteristic, including the rate of change of the particular property (e.g., weight loss, loss of strength) both prior to the CST (e.g., Stage 1) and after the CST (e.g., Stage 2), as illustrated in FIG. 11.

[0066] Without being limited by theory, powder compacts 400 are formed from coated powder particles 212 that include a particle core 214 and associated core material 218 as well as a metallic coating layer 216 and an associated metallic coating material 220 to form a substantially-continuous, three-dimensional, cellular nanomatrix 416 that includes a nanomatrix material 420 formed by sintering and the associated diffusion bonding of the respective coating layers 216 that includes a plurality of dispersed particles 414 of the particle core materials 418. This unique structure may include metastable combinations of materials that would be very difficult or impossible to form by solidification from a melt having the same relative amounts of the constituent materials. The coating layers and associated coating materials may be selected to provide selectable and controllable dissolution in a predetermined fluid environment, such as a wellbore environment, where the predetermined fluid may be a commonly used wellbore fluid that is either injected into the wellbore or extracted from the wellbore. As will be further understood from the description herein, controlled dissolution of the nanomatrix exposes the dispersed particles of the core materials. The particle core materials may also be selected to also provide selectable and controllable dissolution in the wellbore fluid. Alternately, they may also be selected to provide a particular mechanical property, such as compressive strength or sheer strength, to the powder compact 400, without necessarily providing selectable and controlled dissolution of the core materials themselves, since selectable and controlled dissolution of the nanomatrix material surrounding these particles will necessarily release them so that they are carried away by the wellbore fluid. The microstructural morphology of the substantially-continuous, cellular nanomatrix 416, which may be selected to provide a strengthening phase material, with dispersed particles 414, which may be selected to provide equiaxed dispersed particles 414, provides these powder compacts with enhanced mechanical properties, including compressive strength and sheer strength, since the resulting morphology of the nanomatrix/dispersed particles can be manipulated to provide strengthening through the processes that are akin to traditional strengthening mechanisms, such as grain size reduction, solution hardening through the use of impurity atoms, precipitation or age hardening and strength/work hardening mechanisms. The nanomatrix/dispersed particle structure tends to limit dislocation movement by virtue of the numerous particle nanomatrix interfaces, as well as interfaces between discrete layers within the nanomatrix material as described herein. This is exemplified in the fracture behavior of these materials. A powder compact 400 made using uncoated pure Mg powder and subjected to a shear stress sufficient to induce failure demonstrated intergranular fracture. In contrast, a powder compact 400 made using powder particles 212 having pure Mg powder particle cores 214 to form dispersed particles 414 and metallic coating layers 216 that includes Al to form nanomatrix 416 and subjected to a shear stress sufficient to induce failure demonstrated transgranular fracture and a substantially higher fracture stress as described herein. Because these materials have high-strength characteristics, the core material and coating material may be selected to utilize low-density materials or other low-density materials, such as low-density metals, ceramics, glasses or carbon, that otherwise would not provide the necessary strength characteristics for use in the desired applications, including wellbore tools and components.

[0067] FIG. 12 illustrates a method 500 of controlling production in a borehole. The method is performed in conjunction with a gas lift tool such as the gas lift assembly 120. The method 500 includes one or more stages 510-550. Although the method is described in conjunction with the tool 120, the method can be utilized in conjunction with any gas lift device or system.

[0068] In the first stage 510, in one embodiment, the production string 112 and the gas lift assembly 120 is deployed to a downhole location. In one embodiment, the gas lift assembly 120 is assembled and secured in a portion of the production string or other carrier prior to deployment. The gas lift assembly 120 is then disposed with the production string 112. At this stage, the gas lift valve is configured as a dummy valve until the gas lift plug 142 is actuated.

[0069] In the second stage 520, hydrocarbon fluids and/or gases are produced to the surface via the production conduit 122. Stage 520 is performed in any suitable manner and may include various production methods and facilitating methods such as perforating the casing and/or borehole wall and fracturing. Production may include various additional procedures that may be performed to facilitate production. For example, after the completion and gas lift assemblies are disposed in the well, it may be desirable to test the annulus or tubing to insure the pressure integrity of the completion. In addition, some completion scenarios include circulating cement of other fluid down the tubing or annulus of the well. During these production procedures, the gas lift assembly 120 acts as
a blank or dummy to prevent any circulation through the gas lift assembly 120 and between annular regions and the production conduit 122.

In the third stage 530, the gas lift plug 142 is exposed to downhole fluids, such as production fluids and water, to actuate the gas lift plug 142 and cause the pressurized gas to enter the production conduit. In one embodiment, the gas lift plug is made from a corrodirble or dissolvable material. During production, production fluid, which may include water, hydrocarbon fluids and/or hydrocarbon gases (as well as other gases and chemical constituents) contacts the dissolvable/corrodible plug 142. Depending on the configuration and/or size of the plug 142, the plug 142 dissolves over a period of time until the plug 142 completely dissolves/corrodies or it is at least sufficiently reduced in size so that the pressurized gas can force the plug away from the gas lift assembly 120 and/or the production fluid can dislodge the plug 142 and carry it away.

In the fourth stage 540, over a period of time at least a portion of the gas lift plug 142 will dissolve, corrode and/or be removed without mechanical intervention to allow the gas lift assembly 120 to function as designed. In one embodiment, the plug is made of a material(s) having an approximately known dissolution or corrosion rate in the presence of the downhole fluids, and is shaped, sized or otherwise configured to dissolve or corrode over a pre-determined period of time.

In the fifth stage 550, the gas lift procedure may be commenced. Gas lift may be started any time after the plug is dissolved. This may be immediately or soon after the plug 142 is dissolved, or may be commenced at some later time dependent on, for example, the production pressure or flow rate of the fluid being produced through the production conduit 122.

In one embodiment, the gas lift procedure includes injecting pressurized gas from an annular area in the borehole 114 through the gas lift assembly 120, e.g., through the ports 124. The pressurized gas flows through the gas lift assembly 120, and into the production conduit 122, where the pressurized gas dissolves and/or aerates the production fluids and gases that enter flow to the surface. In one embodiment, the gas lift valve 132 is used to control flow of pressurized gas into the production conduit.

The apparatus and methods described herein provide various advantages over prior art techniques. For example, in instances where it is desirable to install the gas lift assembly after the production assembly is deployed downhole, the gas lift plug allows the gas lift assembly to act as a dummy or blank for a period of time. This eliminates the need to for using a separate dummy or blank which would require subsequent installation (e.g., slickline intervention) after the completion to remove the dummy valves and install live gas lift assemblies.

While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications will be appreciated by those skilled in the art to adapt a particular instrument, situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

1. A production fluid control apparatus comprising:
   a gas lift assembly in fluid communication with a borehole production conduit, the gas lift assembly configured to control a flow of pressurized gas between an annular region of a borehole and the production conduit; and at least one plug disposed in operable communication with the gas lift assembly, the at least one plug configured to prevent fluid flow through the gas lift assembly and configured to be actuated to allow fluid flow through the gas lift assembly in response to exposure to a downhole fluid.

2. The apparatus of claim 1, wherein the at least one plug is made from a material configured to dissolve or corrode in the presence of the downhole fluid.

3. The apparatus of claim 2, wherein the downhole fluid is selected from at least one of water, salinated water and hydrocarbon fluid.

4. The apparatus of claim 1, wherein the at least one plug is disposed in a fluid path between the production conduit and the gas lift assembly.

5. The apparatus of claim 1, the apparatus of claim 1, wherein the gas lift assembly further includes a support component disposed in a fixed position relative to the production conduit, and a flow control device configured to control the flow of pressurized gas through the gas lift assembly.

6. The apparatus of claim 5, wherein the at least one plug is located within the flow control device.

7. The apparatus of claim 5, wherein the at least one plug is located in a fluid path between the flow control device and the production conduit.

8. The apparatus of claim 2, wherein the material includes:
   a substantially-continuous, cellular nanomatrix comprising a nanomatrix material;
   a plurality of dispersed particles comprising a particle core material that comprises Mg, Al, Zn or Mn, or a combination thereof, dispersed in the cellular nanomatrix; and a solid state bond layer extending throughout the cellular nanomatrix between the dispersed particles.

9. The apparatus of claim 8, wherein the material includes a plurality of dispersed second particles, wherein the dispersed second particles are also dispersed within the cellular nanomatrix and with respect to the dispersed particles.

10. The apparatus of claim 2, wherein the at least one plug is formed from a sintered powder comprising a plurality of powder particles, each powder particle having a particle core that upon sintering comprises a dispersed particle and a single metallic coating layer disposed thereon, and wherein the cellular nanomatrix between adjacent ones of the plurality of dispersed particles comprises the single metallic coating layer of one powder particle, the bond layer and the single metallic coating layer of another of the powder particles.

11. The apparatus of claim 2, wherein the at least one plug is formed from a sintered powder comprising a plurality of powder particles, each powder particle having a particle core that upon sintering comprises a dispersed particle and a plurality of metallic coating layers disposed thereon, and wherein the cellular nanomatrix between adjacent ones of the plurality of dispersed particles comprises the plurality of metallic coating layers of one powder particle, the bond layer and plurality of metallic coating layers of another of the
powder particles, and wherein adjacent ones of the plurality of metallic coating layers have different chemical compositions.

12. A method of producing hydrocarbon fluid from a borehole, comprising:
   disposing a production assembly in the borehole, the production assembly including a production conduit and a gas lift assembly in fluid communication with the production conduit, the gas lift assembly configured to control a flow of pressurized gas between an annular region of the borehole and the production conduit, the gas lift assembly including at least one plug disposed in operable communication therewith and configured to prevent fluid flow through the gas lift assembly;
   exposing the at least one plug to a downhole fluid; and
   actuating the at least one plug by dissolving at least a portion of the at least one plug in response to exposure to the downhole fluid to allow fluid to flow through the gas lift assembly.

13. The method of claim 12, further comprising injecting the pressurized gas into the annular region, and directing the annular gas to the production conduit via the gas lift assembly.

14. The method of claim 13, wherein the downhole fluid is a production fluid flowing through the production conduit.

15. The method of claim 12, wherein the at least one plug is made from a material configured to dissolve or corrode in the presence of the downhole fluid.

16. The method of claim 15, wherein the downhole fluid is selected from at least one of water, salinated water and hydrocarbon fluid.

17. The method of claim 12, wherein actuating the at least one plug includes contacting the at least one plug with downhole fluid flowing through the production conduit, and dissolving or corroding the at least one plug over a pre-selected time period.

18. The method of claim 12, wherein the gas lift assembly further includes a support component disposed in a fixed position relative to the production conduit, and a flow control device configured to control the flow of pressurized gas through the gas lift assembly.

19. The method of claim 18, wherein the at least one plug is located within the flow control device.

20. The method of claim 18, wherein the at least one plug is located in a fluid path between the flow control device and the production conduit.

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