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(54) **CONTAINERLESS INFILTRATION WITH ELECTROMAGNETIC LEVITATION**

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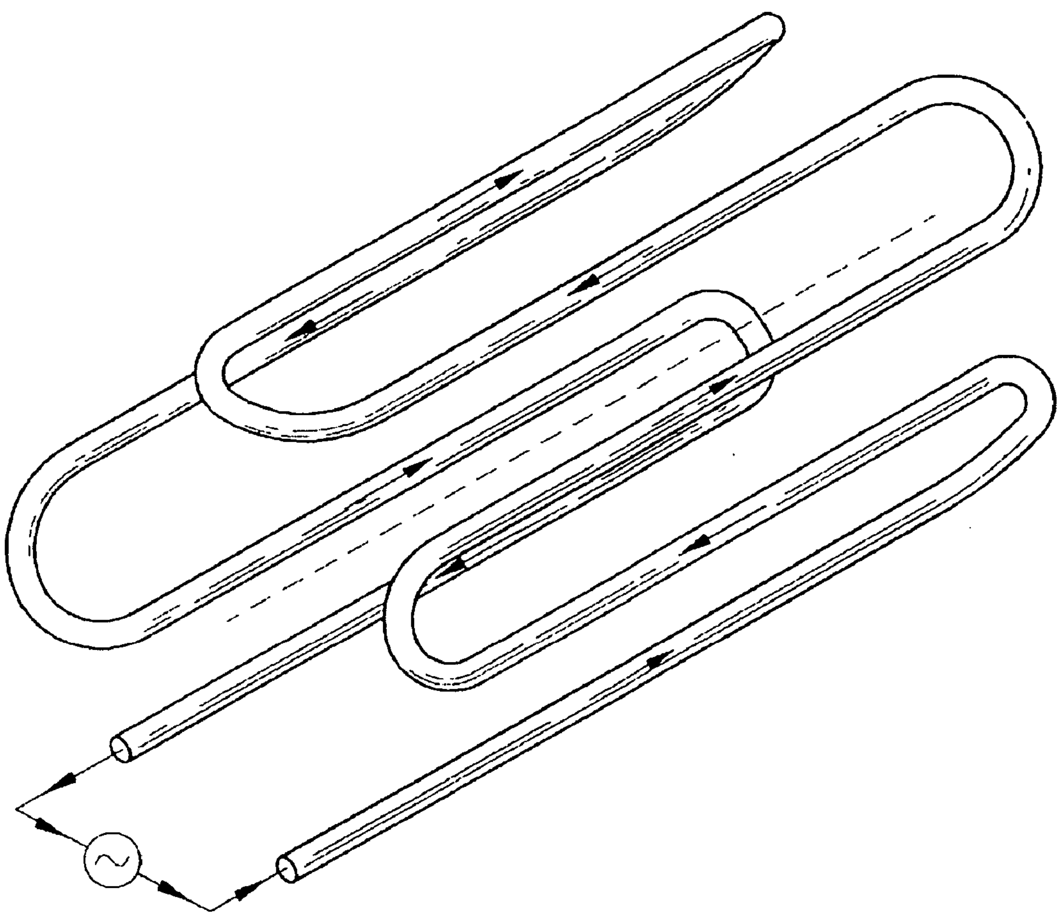
(57) **ABSTRACT**

The present invention is directed to new processes in which electromagnetic levitation forces are used to infiltrate a porous matrix with a solid infiltrant. In such processes, controlled heating of these components, melting the infiltrant while both components are subjected to levitation forces, and containerless transportation and subsequent contact of both components results in the infiltration of the porous matrix. Such containerless processing provides for infiltrated porous matrices which are free of contaminants generally introduced by the containers used in traditional methods of infiltration.



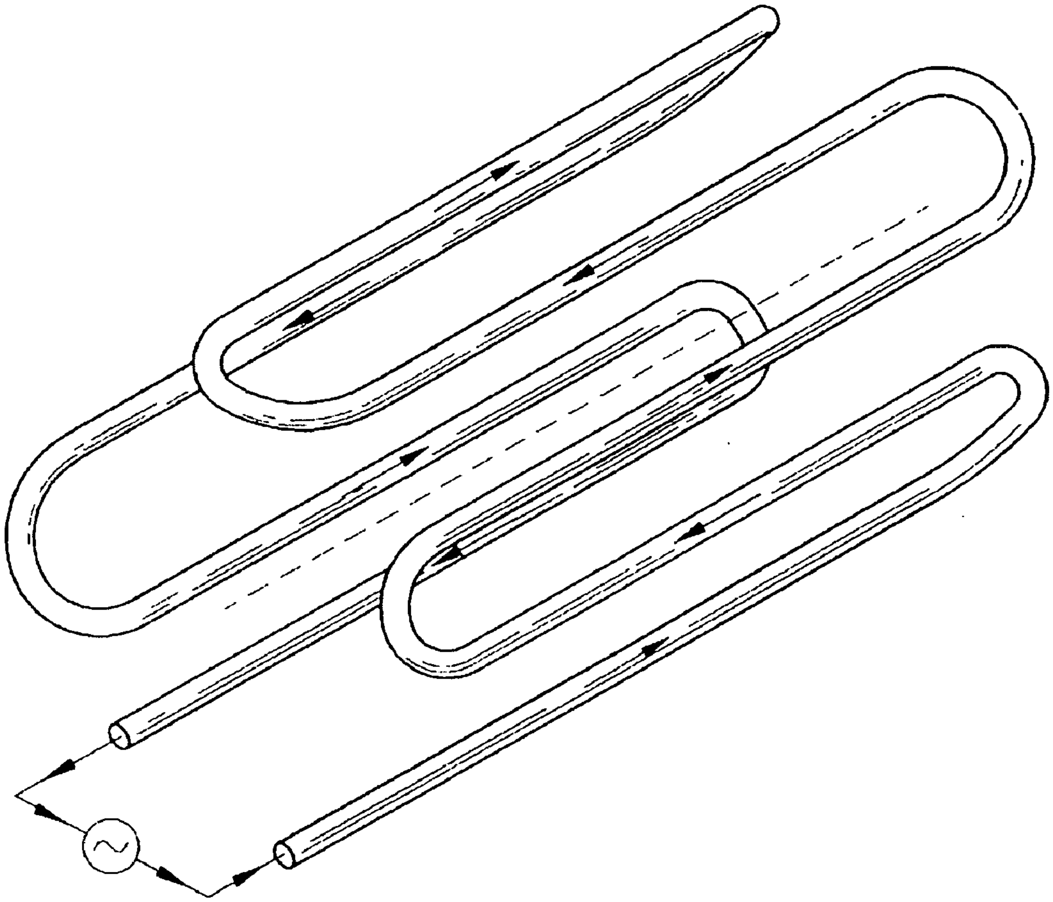


Fig. 1

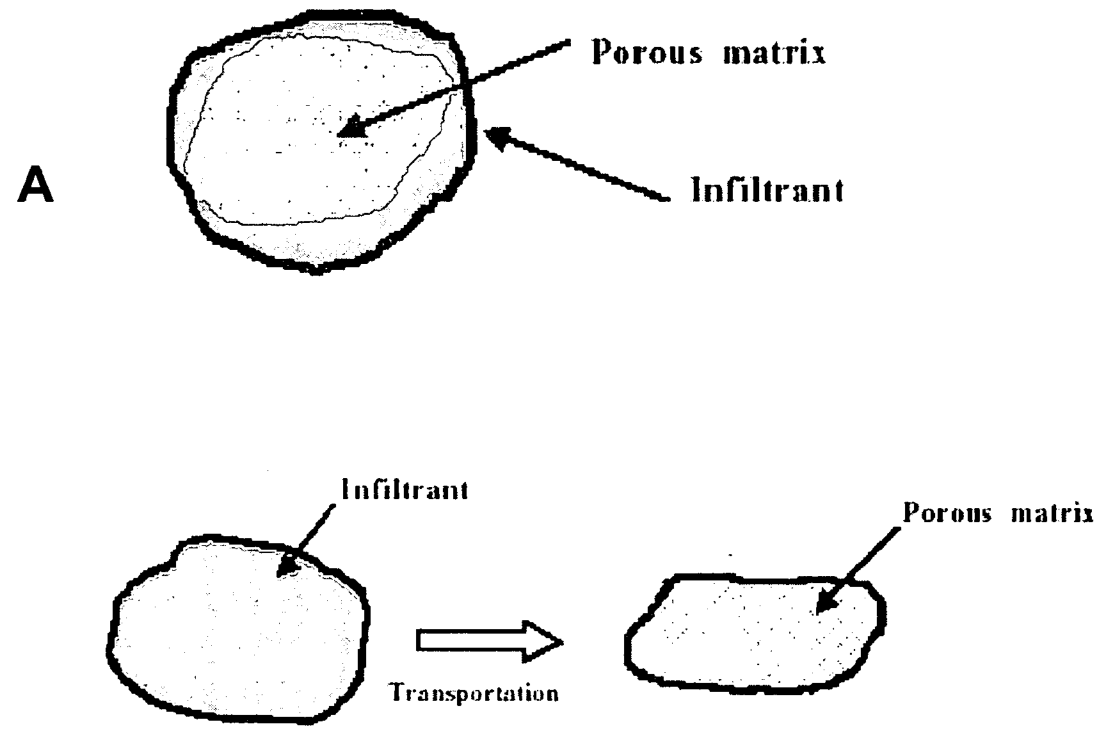

A
Porous matrix
Infiltrant
B
Infiltrant
Porous matrix
Transportation

Fig. 2

CONTAINERLESS INFILTRATION WITH ELECTROMAGNETIC LEVITATION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This Patent Application claims priority to U.S. Provisional Patent Application Serial No. 60/463,858, filed Apr. 18, 2003.

[0002] The present invention was made with support from the Texas Advanced Technology Program, TATP Grant No. 003604-056.

FIELD OF THE INVENTION

[0003] The present invention relates generally to methods for infiltrating porous matrices with a infiltrant, and more specifically to methods of infiltrating porous matrices with levitatable materials using electromagnetic levitation forces.

BACKGROUND OF THE INVENTION

[0004] Rapid prototyping (RP) and rapid manufacturing (RM) are technologies that can be used to form three-dimensional objects rapidly and automatically from three-dimensional computer data representing such objects. Such techniques can generally be considered to be methods of solid free-form fabrication (SFF), but further providing the integration of design and rapid fabrication. For discussions of such techniques, see S. Ashley, "Rapid Prototyping is Coming of Age,"*Mechanical Engineering,* July 1995: p.63; and K. G. Cooper, *Rapid Prototyping Technology, Selection and Application,* New York, N.Y.: Marcel Dekker, Inc., pp.138-146 (2001). One particular method of rapid prototyping is three-dimensional printing (3DP), wherein layers of a powdered medium are solidified by the selective deposition of a binder thereon. See U.S. Pat. No. 5,204,055 to Sachs.

[0005] Generally, objects made by rapid prototyping, rapid manufacturing, or other types of free-form fabrication (i.e., green bodies) must be densified and sintered into a final product. If binder is used in the fabrication of such objects, it is usually lost during a sintering process (binder burnout). However, densification is generally very incomplete, leaving the sintered product quite porous. Methods used to further densify the product include infiltrating the object with an infiltrant. Generally, infiltrants are materials with a melting point below that of the sintered product and which are capable of wetting the sintered product and being taken up into the product's pores via capillary action. Traditional methods of doing this infiltration typically involve placing an object to be densified (before or after being sintered) in a ceramic crucible with a solid infiltrant material. At temperatures above the melting point of the solid infiltrant material, the infiltrant material becomes molten and flows over and/or wicks the object to be infiltrated. As the molten infiltrant wets the object, capillary forces drive the infiltrant into the pores of the object. When allowed to cool, this results in a densified object. See R. L. Anderson et al., "Rapid Manufacturing of Metal Matrix Composite Materials Using Three-Dimensional Printing (3DP™)," in *Rapid Prototyping of Materials,* F. D. S. Marquis and D. L. Bourell, Eds., The Minerals, Metals & Materials Society, pp. 43-52 (2002).

[0006] Problems in the above-described processes arise when the surface energy of the porous object being infiltrated is altered through oxidation or other contamination, either in the environment or from the crucible in which the object is resting. Such changes in the surface energy of either the porous object or the molten infiltrant can make wetting, and hence infiltration, difficult to impossible. While the process of infiltration can be done in an inert environment, problems of container cross-contamination still arise, often leading to poor wetting and precluding the fabrication of high-purity materials. Thus, a better method of containing the porous object and solid infiltrant during such infiltration processes is clearly needed.

SUMMARY OF THE INVENTION

[0007] The present invention is directed to novel processes comprising containerless processing, wherein electromagnetic levitation forces are applied to a solid infiltrant(s), and controlled heating of this infiltrant to provide a molten infiltrant that is subsequently contacted with and infiltrates a porous matrix for the general purpose of densifying the matrix.

[0008] In general, processes of the present invention comprise the steps of subjecting a porous matrix and a solid infiltrant to containerless processing; melting the solid infiltrant to provide a molten infiltrant; and contacting the porous matrix with the molten infiltrant to provide an infiltrated product, wherein the molten infiltrant wets and infiltrates the porous matrix via capillary action. Such containerless processing comprises electromagnetic levitation of at least the infiltrant via at least one electromagnetic levitation apparatus.

[0009] In some embodiments of the present invention, the containerless processing further comprises containerless transport of one or both of the infiltrant and the porous matrix. The containerless processing of the present invention may be carried out in an environment that is non-oxidizing, such an environment being inert and/or reducing or slightly reducing.

[0010] The porous matrices can comprise a variety of materials and/or combinations of materials. In contrast, the solid infiltrant must be electrically conducting and generally comprise a melting point below that of the porous matrix. Additional components may be added to the infiltrant before or during processing to add additional dimensionality to the resulting infiltrated product.

[0011] In some embodiments of the present invention, the porous matrix is a porous free-form fabricated object. Containerless processes of the present invention may be used to infiltrate such porous free-form fabricated objects such that container-borne contamination, as typically encountered in traditional infiltration processes, is neither introduced nor interferes with the infiltration processes.

[0012] The present invention additionally provides for coating objects in a containerless manner. Such coating generally involves the coating of a porous matrix, once infiltrated, with molten infiltrant, and then cooling to provide a coated, densified product. However, such coating can be accomplished in lieu of infiltration. This latter scenario represents, in some applications, a viable alternative to infiltration—particularly when infiltration is not possible for one of a variety of reasons. Such coatings can be expected to have an interface that is virtually contaminate-free, possibly providing for better adhesion of the coating to the underlying surface.

[0013] The foregoing has outlined rather broadly the features of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

[0015] **FIG. 1** depicts a representative electromagnetic levitator apparatus suitable for use in some containerless infiltration processes of the present invention; and

[0016] **FIGS. 2A** and B depict the contacting of a molten infiltrant with a porous matrix (A); and the infiltration of the molten infiltrant into the porous matrix by capillary uptake.

DETAILED DESCRIPTION

[0017] While the making and/or using of various embodiments of the present invention are discussed below, it should be appreciated that the present invention provides many applicable inventive concepts that may be embodied in a variety of specific contexts. The specific embodiments discussed herein are merely illustrative of specific ways to make and/or use the invention and are not intended to delimit the scope of the invention.

[0018] While most of the terms used herein will be recognizable to those of skill in the art, the following definitions are nevertheless put forth to aid in the understanding of the present invention. It should be understood, however, that when not explicitly defined, terms should be interpreted as adopting a meaning presently accepted by those of skill in the art.

[0019] "Rapid prototyping," abbreviated "RP" and as defined herein, generally refers to the 3-D design and fabrication of objects from powder precursor and a selectively-applied binding agent (binder). "Rapid manufacturing," abbreviated "RM" and as defined herein, refers to manufacturing methods based on these same principles, wherein objects are manufactured "from the ground up." Such prototyping and manufacturing methods are generally referred to as "solid free-form fabrication," abbreviated "SFF" herein. Such fabrication yields a "green body" held together by binder which must ultimately be "burned out" in a high-temperature "sintering" process. This process typically yields a object with considerable porosity.

[0020] "Containerless processing" and manufacturing, abbreviated "CP" and as defined herein, refers to the use of high frequency electromagnetic (EM) fields for levitating materials. To be levitatable in such EM fields, the material must be electrically conducting.

[0021] A "porous matrix," as defined herein, generally refers to an undensified material, comprising pores, into which an "infiltrant" may flow via capillary forces. Typically, the infiltrant, while initially solid, is heated to a molten state in which it can flow. An infiltrated object results which, after cooling, results in a densified infiltrated product.

[0022] Many industries are currently implementing a variety of solid free-form fabrication techniques to develop both rapid prototypes (i.e., rapid prototyping) and final tools and parts (i.e., rapid manufacturing). Applications ranging from high-performance aerospace components to parts designed for medical, electronic, and structural purposes incorporate these methods to manufacture many high-value, small parts, such as ball bearings, seals, gears, screws, dental and medical surgical implants, as well as other specialized components. Developing innovative new manufacturing techniques, or enhancing current techniques to exceed capabilities of current processes, would benefit both currently existing and future designs used in environments with an extremely low tolerance for contamination. The need for such processes and the articles that can be manufactured with it attest to the utility of the present invention, as evidenced by those currently manufacturing under other techniques.

[0023] In current SFF methods, green powder metallurgy parts can use any of several methods to initially hold the metal powder together in the form of an object, but such methods generally comprise a binding agent or binder. This green body or object is later subjected to high temperatures to remove the binder and slightly sinter the particles together in the form of a porous compact. Based on desired final part dimensions, the porous compact or free-form fabricated object may have a density as low as 60% of its maximum theoretical bulk density. Once the powder metal part has been initially formed, consolidation and densification may be performed by different costly procedures at high temperature or high pressure, either alone or in combination with others of these processes. Most densification techniques require expensive tooling and are not amenable to modifications in part specifications.

[0024] Infiltration is a cost-effective and efficient way to densify and enhance the properties of a porous metal part created by a variety of SFF techniques. It allows for evenly distributed alloy compositions that are generally not attainable with other manufacturing methods. The metal or metal alloy infiltrant melts and infiltrates the porous part via different methods including direct contact so that the infiltrant enters the surfaces and infiltrates the part or, for instance, by first following a porous gate or stilt to aid in controlled fluid flow. These infiltration techniques more specifically may combine a liquid metal infiltrant and porous metal matrix using capillary forces to fill interconnected pores and create a nearly fully dense final part. The infiltration process may be combined with debinding and sintering (a one-step process) or may be a separate operation (two-step process). Note also that precise control of heating rates may be necessary to reduce excessive thermal gradients within the parts.

[0025] The atmosphere provided during sintering and infiltration is important to the completeness of infiltration, as well as the properties of the final part, and as such should be controlled throughout part processing. Depending on the matrix and infiltrant components and the desired properties of the final part, the atmosphere could be an inert gas, a vacuum, a particular reactive gas, or combinations. The atmosphere used for sintering has generally been selected by considering a variety of criteria. A controlled atmosphere, such as dissociated ammonia or a combination of 96% argon and 5% hydrogen, is chosen to reduce the oxides that may form at increased temperatures since they will decrease properties and inhibit infiltration by altering wettability via changes in surface energy. Note, however that as a part goes through a typical sintering temperature profile, it is initially subjected to an oxidizing atmosphere, then heats up to a reducing atmosphere, and then finally re-enters an oxidizing atmosphere as the part cools down. By infiltrating a part with a liquid metal infiltrant before cooling down to an oxidizing atmosphere (i.e., using a one-step process) the oxides that inhibit infiltration will not be present. Also note that in the case of the contamination of stainless steel parts infiltrated with bronze, the oxygen and water vapor in the atmosphere result in the formation of chromium oxide (Cr_2O_3), thus limiting the dew point at sintering temperatures.

[0026] Many current infiltration methods attempt to counteract contamination that results from contact with the containers within which the processes occur. Counteracting contamination is of heightened importance when considering highly reactive materials and applications, such as aerospace or medical, where even small amounts of contamination have detrimental effects. In addition, such current processes attempt to reduce contamination during infiltration by preventing contact with the container (e.g., a graphite crucible) by applying a non-reactive coating such as a boron nitride paint to the container's surface. A support powder (e.g., Al_2O_3) that exhibits limited reaction with the metal components may then be placed on the surface. While a castable ceramic crucible could be used to reduce the preparation and setup time, it would be much more costly and it is difficult to handle. Containerless processing and/or manufacturing, in accordance with processes of the present invention, can help eliminate contact with the manufacturing containers, and thus, help eliminate contamination that occurs when part components contact and react with external surfaces.

[0027] Containerless processing (CP) using EM levitation offers a viable solution to the problem of contamination and handling of high-temperature molten materials in a controlled, non-oxidizing and/or reducing environment. In the past, EM levitation has been a critical research tool for investigating various aspects of materials processing of reactive metal alloys, oxides and ceramic materials (cermets). See U.S. patent application Ser. No. 10/182,081 by Barrera et al.

[0028] The present invention provides for containerless infiltration processes, with or without containerless sintering. Such processes of the present invention hold tremendous promise for solid freeform fabrication (SFF) manufacturing, particularly with respect to overcoming contamination-induced wettability problems encountered in the prior art. Also, the ability to fabricate high-purity objects is no longer hindered by contamination from the processing container. For some applications, the non-contact processes of the present invention are expected to improve or replace many current SFF methods. For instance, the fabrication of small and expensive parts using layer-by-layer processes for advanced material system components can benefit from the containerless infiltration processing of the present invention. In an exemplary embodiment, a porous metal part can be levitated on one end of a longitudinal levitator (for a description of such a longitudinal levitator, see U.S. Pat. No. 5,887,018 to Bayazitoglu et al.) and with external or electromagnetic heating the molten infiltrant can be levitated and heated on the other end. It is also possible to wrap a material that cannot be levitated with one that can so that the combination will be levitated. Containerless transportation and contact between the porous compact and the molten metal will induce the infiltration.

[0029] In general terms, the innovative containerless manufacturing processes of the present invention can be achieved by electromagnetically levitating at least one of at least two components (a porous matrix and a solid infiltrant), heating such that at least one infiltrant component becomes molten, and then combining these at least two components by the contacting and subsequent infiltration of the porous matrix by the molten infiltrant, wherein such contacting may comprise containerless transport and wherein infiltration occurs via the wetting and subsequent uptake by capillary forces of the molten infiltrant by the porous matrix. Generally, after uptake of the molten infiltrant by the porous matrix, the infiltrated product is cooled to provide a densified, infiltrated product. While the processes of the present invention can use a variety of levitator designs, they are particularly useful in combination with a new class of electromagnetic levitators introduced by researchers at Rice University (Houston, Tex.). An exemplary EM levitator that can be used is disclosed in U.S. Pat. No. 5,887,018 to Bayazitoglu et al.

[0030] The levitation coils of the EM levitator can be formed by bending copper tubing so that a set of parallel conductors is formed, with neighboring conductors passing current in opposite directions, as shown in the accompanying **FIG. 1**. These longitudinal conductors can also be curved along their length, and the surface they define is not limited to a cylinder. A large, high frequency current is allowed to flow through the coil and set up an alternating magnetic field. The coil creates a magnetic field with a region of minimum field strength. When an electrically conducting sample is placed in this gap, the eddy currents heat and the Lorentz forces levitate. Such process does not require a physical crucible and provides a solution to the problem of contamination due to containers.

[0031] Such an above-described levitator has the following features that alleviates the problems suffered by other previous levitator designs: it is capable of supporting spherical and non-spherical sample shapes, such as cylinders with a large aspect ratio, rectangular blocks, etc.; the design has very good visual access to the sample; and the position of the sample in the levitator can be controlled precisely. The temperature of the sample can be controlled independently by using an auxiliary heat source. The present laboratory system at Rice University can already support samples that are an order of magnitude more massive than the samples supported by previous levitators (e.g., conical levitators), as well as the components planned for these efforts, and this process can be scaled for larger size production. In addition, multiple specimens can be simultaneously levitated and controlled.

[0032] While the solid infiltrant must be electrically conducting to be levitatable, the porous matrix can be either levitatable or not. This provides a greater range of materials for the porous matrix. In such embodiments wherein the porous matrix is not levitated, it can be supported or suspended by any suitable mechanism such that levitated molten infiltrant can then be transported to, and contacted with, the supported or suspended porous matrix. Thus, the porous matrix can be of any material or combination of materials (e.g., metal, alloy, ceramic, fibrous, etc.) provided that it can withstand the processing temperatures involved and does not decompose upon contact with the molten infiltrant.

[0033] The molten infiltrant, according to the present invention, may comprise any material(s) capable of being electromagnetically levitated. Exemplary infiltrant materials include, but are not limited to, iron (Fe), aluminum (Al), titanium (Ti), cobalt (Co), and alloys and combinations thereof Selection should be guided, however, by the need for it to have a melting point below that of the porous matrix, and for its surface tension in the molten state to be sufficiently compatible with the porous matrix material so as to allow for surface wetting and capillary uptake of the molten infiltrant by the porous matrix for a porous matrix of a particular and/or range of compositions and/or pore sizes.

[0034] In some embodiments of the present invention, the infiltrant comprises at least one other additional material (i.e., additives) selected from the group consisting of nanofibers, nanotubes, nanoparticles, polymeric materials, and combinations thereof Such additional material may be present in the solid infiltrant material, or it can be added subsequent to the step of melting the solid infiltrant. As the infiltrant infiltrates a porous matrix, it further infiltrates the porous matrix with this additional material as well. Such material combinations give rise to densified, infiltrated products having potentially unique compositions. Note that such additional material need not itself be levitatable, but can be "carried along" by the levitatable material in which it is interspersed.

[0035] Melting of the solid infiltrant can be induced by the levitator apparatus itself (e.g., via eddy currents), or it can be accomplished via an external heat source. Examples of external heat sources include, but are not limited to, lasers, microwave radiation, induction heating, and combinations thereof Methods of heating that do not involve a direct thermal contact of a heating element with the solid infiltrant are particularly favored.

[0036] As in other infiltration techniques described above which attempt to minimize contamination, the processes of the present invention are typically carried out in an environment that is non-oxidizing, reducing, slightly reducing, and/or combinations of such environments during various stages of the processing. Examples of such environments include, but are not limited to, vacuum, Ar, N_2, He, Kr, H_2, NH_3, and combinations thereof Additionally or alternatively, in some embodiments, reactive species may be added to the environment to induce surface alterations via chemical reaction, wherein such surface alteration may serve to facilitate wetting and capillary uptake of the molten infiltrant by the porous matrix. Note that in some embodiments, the environment comprises a particle-seeded gas.

[0037] The present invention additionally provides for coating objects in a containerless manner. Such coating generally involves the coating of a porous matrix, once infiltrated, with molten infiltrant, and then cooling to provide a coated, densified product. However, such coating can be accomplished in lieu of infiltration. This latter scenario represents, in some applications, a viable alternative to infiltration—particularly when infiltration is not possible for one of a variety of reasons. Such coatings can be expected to have an interface that is virtually contaminate-free, possibly providing for better adhesion of the coating to the underlying surface.

[0038] In some embodiments of the present invention, the porous matrix is a porous free-form fabricated object. Containerless processes of the present invention may be used to infiltrate such porous free-form fabricated objects such that container-borne contamination, as seen in traditional infiltration processes, is neither introduced nor interferes with the infiltration processes.

[0039] Broad applications of electromagnetic containerless processing are possible. Many industries currently utilize a variety of small powder metallurgy parts (objects fabricated from metal powders), such as ball bearings, seals, gears, screws, dental and medical surgical implants, as well as other specialized applications in the automotive, electronic, and aerospace industries. The processes of the present invention can be used to conserve expensive components and valuable resources and to create value added small parts with enhanced properties. The advanced manufacturing process of the present invention could be incorporated into both custom products and mass production operations. By slightly modifying the processes of the present invention it is further possible to apply coatings to small parts. Also, modifications could be made to increase the size of parts manufactured.

[0040] In some exemplary embodiments, processes of the present invention comprise electromagnetic levitation forces applied to a porous matrix and a solid infiltrant; controlled heating of one or both of these components, and melting the infiltrant while both components are levitated, as shown in **FIG. 2A**. The containerless transportation and subsequent contact of both components results in the infiltration of the porous matrix subject to the electromagnetic levitation forces, as shown in **FIG. 2B**.

[0041] In some or other embodiments, processes of the present invention comprise levitating a porous metal part on one end of a longitudinal levitator and melting and electromagnetically levitating a molten infiltrant on the other end of the levitator. Containerless transportation and contact between the porous compact and the molten metal will induce infiltration. Though levitation melting, levitation transportation, capillary motion and heat transfer of liquid metals in porous media, and magneto-hydrodynamics have been used for some industrial applications, the techniques have heretofore not been used in combination to fabricate a finished product.

[0042] Thus, developing a containerless process for both sintering and infiltration processes would help eliminate the time-consuming and labor-intensive set up process of a graphite crucible, for example. However, in order to use a purely containerless process for certain thin parts or those with specific binders, additional steps must be taken to prevent sagging during heating.

[0043] All patents and publications referenced herein are hereby incorporated by reference. It will be understood that certain of the above-described structures, functions, and operations of the above-described embodiments are not necessary to practice the present invention and are included in the description simply for completeness of an exemplary embodiment or embodiments. In addition, it will be understood that specific structures, functions, and operations set forth in the above-described referenced patents and publications can be practiced in conjunction with the present invention, but they are not essential to its practice. It is therefore to be understood that the invention may be practiced otherwise than as specifically described without actually departing from the spirit and scope of the present invention as defined by the appended claims.

What is claimed is:

1. A process comprising the steps of:

a) subjecting a porous matrix and a solid infiltrant to containerless processing;

b) melting said solid infiltrant to provide a molten infiltrant; and

c) contacting said porous matrix with said molten infiltrant to provide an infiltrated product.

2. The process of claim 1 further comprising a step of cooling the infiltrated product to provide a densified, infiltrated product.

3. The process of claim 1, wherein the infiltrated product is additionally coated with the infiltrant material.

4. The process of claim 1, wherein said containerless processing comprises electromagnetic levitation of the infiltrant.

5. The process of claim 1, wherein said containerless processing comprises electromagnetic levitation of the infiltrant and the porous matrix.

6. The process of claim 1, wherein the porous matrix is supported during at least a portion of the containerless processing.

7. The process of claim 1, wherein said porous matrix comprises material selected from the group consisting of metals, fibers, ceramics, and combinations thereof.

8. The process of claim 1, wherein said solid infiltrant comprises a material selected from the group consisting of Fe, Al, Ti, Co, alloys thereof, and combinations thereof.

9. The process of claim 8, wherein said solid infiltrant further comprises at least one additional material dispersed within the solid infiltrant, said additional material being selected from the group consisting of nanoparticles, nanotubes, nanofibers, polymeric materials, and combinations thereof.

10. The process of claim 1, wherein said melting is carried out using a heat source, wherein said heat source is selected from the group consisting of laser-generated radiation, microwave radiation, induction heating, and combinations thereof, and wherein said heat source provides for controlled heating.

11. The process of claim 1, wherein said contacting comprises infiltrating said porous matrix with said molten infiltrant.

12. The process of claim 11, wherein said contacting further comprises containerless transportation.

13. The process of claim 11, wherein such infiltrating occurs via capillary uptake.

14. The process of claim 1 further comprising a step of adding additional species to the infiltrant while it is in a molten state and being levitated, wherein said additional species are selected from the group consisting of nanoparticles, nanofibers, nanotubes, polymeric material, and combinations thereof.

15. The process of claim 14, wherein said porous matrices are infiltrated by both the solid infiltrant material and said additional species.

16. The process of claim 1, wherein said process is carried out in an environment selected from the group consisting of Ar, N_2, He, Kr, H_2, NH_3, vacuum, and combinations thereof.

17. A process comprising the steps of:

a) providing a porous matrix;

b) levitating a solid infiltrant using electromagnetic levitation;

c) melting said solid infiltrant to provide a molten infiltrant; and

d) infiltrating said porous matrix with said molten infiltrant to provide an infiltrated product, wherein such infiltration occurs via capillary uptake.

18. The process of claim 17 further comprising a step of cooling the infiltrated product that provides a densified, infiltrated product.

19. The process of claim 17, wherein the infiltrated product is additionally coated.

20. The process of claim 17, wherein said porous matrix is levitated while it is infiltrated with said molten infiltrant.

21. The process of claim 17, wherein the porous matrix is supported during at least a portion of the infiltrating.

22. The process of claim 17, wherein said porous matrix comprises material selected from the group consisting of metals, fibers, ceramics, and combinations thereof.

23. The process of claim 17, wherein said solid infiltrant comprises a material selected from the group consisting of Fe, Al, Ti, Co, alloys thereof, and combinations thereof.

24. The process of claim 23, wherein said solid infiltrant further comprises at least one additional material dispersed within the solid infiltrant, said additional material being selected from the group consisting of nanoparticles, nanofibers, nanotubes, polymeric material, and combinations thereof.

25. The process of claim 24, wherein said additional material is dispersed during the step of melting.

26. The process of claim 17, wherein said melting is carried out using a heat source, wherein said heat source is selected from the group consisting of laser-generated radiation, microwave radiation, induction heating, and combinations thereof, and wherein said heat source provides for controlled heating.

27. The process of claim 17, wherein said process is carried out in an environment selected from the group consisting of Ar, N_2, He, Kr, H_2, NH_3, vacuum, and combinations thereof.

28. A process comprising the steps of:

a) providing a porous free-form fabricated object;

b) electromagnetically levitating a solid infiltrant;

c) melting said solid infiltrant to provide a molten infiltrant; and

d) contacting said porous free-form fabricated object with said molten infiltrant so as to infiltrate the porous free-form fabricated object and provide an infiltrated product.

29. The process of claim 28 further comprising a step of cooling the infiltrated product that provides a densified, infiltrated product.

30. The process of claim 28, wherein the infiltrated product is additionally coated.

31. The process of claim 28, wherein the porous matrix is supported during at least a portion of the contacting.

32. The process of claim 28, wherein said porous matrix comprises a material selected from the group consisting of metals, fibers, ceramics, and combinations thereof.

33. The process of claim 28, wherein said solid infiltrant comprises a material selected from the group consisting of Fe, Al, Ti, Co, alloys thereof, and combinations thereof.

34. The process of claim 33, wherein said solid infiltrant further comprises at least one additional material dispersed within the solid infiltrant, said additional material being selected from the group consisting of nanoparticles, nanofibers, nanotubes, polymeric material, and combinations thereof.

35. The process of claim 34, wherein said additional material is introduced during the melting of said solid infiltrant.

36. The process of claim 28, wherein said melting is carried out using a heat source, wherein said heat source is selected from the group consisting of laser-generated radiation, microwave radiation, induction heating, and combinations thereof, and wherein said heat source provides for controlled heating.

37. The process of claim 36, wherein such infiltrating occurs via capillary uptake.

38. The process of claim 28, wherein said process is carried out in an environment selected from the group consisting of Ar, N_2, He, Kr, H_2, NH_3, vacuum, and combinations thereof.

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