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(54) CO-SINTERED MULTI-SYSTEM TUNGSTEN ALLOY COMPOSITE

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(57) **ABSTRACT**

A composite is produced by the steps of (a) blending a first mixture of metallic powders; (b) compacting the blended first mixture of metallic powders to a plurality of discretely shaped articles; (c) blending a second mixture of metallic powders; (d) mixing the plurality of discretely shaped articles with the blended second mixture of metallic powders to form a precursor blend; (e) compacting the precursor blend; and (f) sintering the precursor blend. The composite has a metallic matrix with embedded shapes dispersed throughout the matrix where the embedded shapes have an incipient liquid phase sintering temperature less than an incipient liquid phase sintering temperature of the matrix.

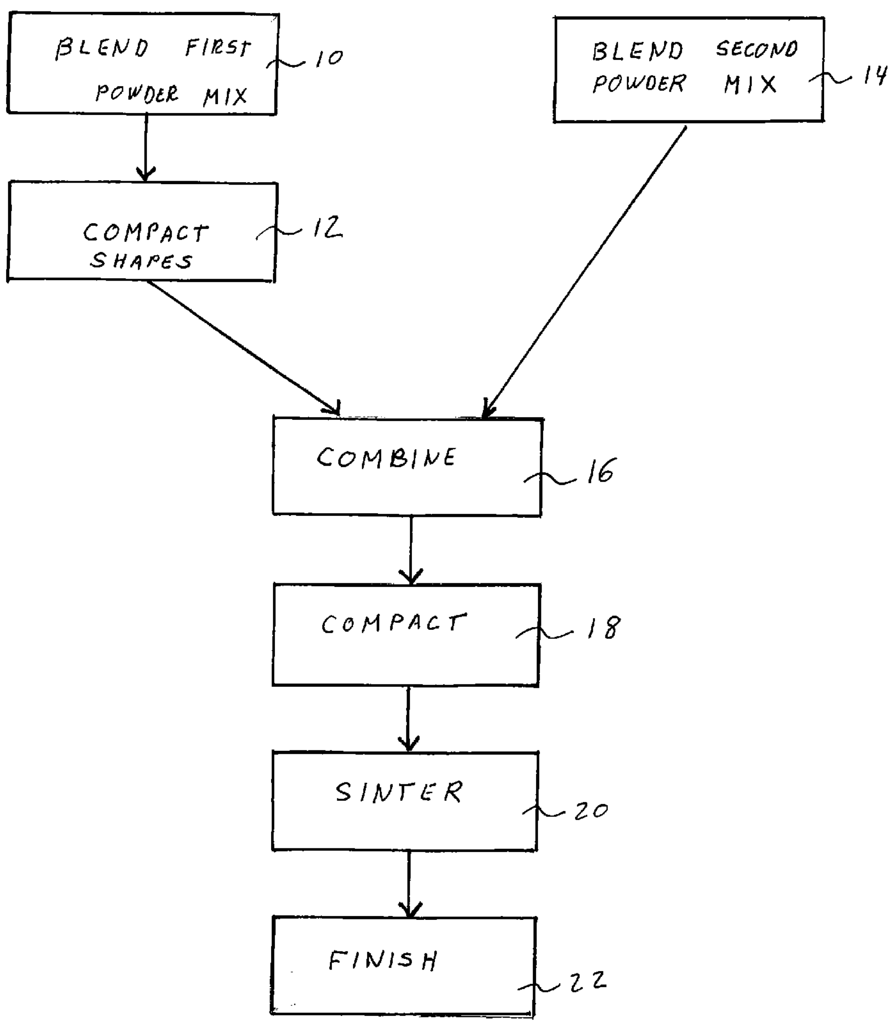
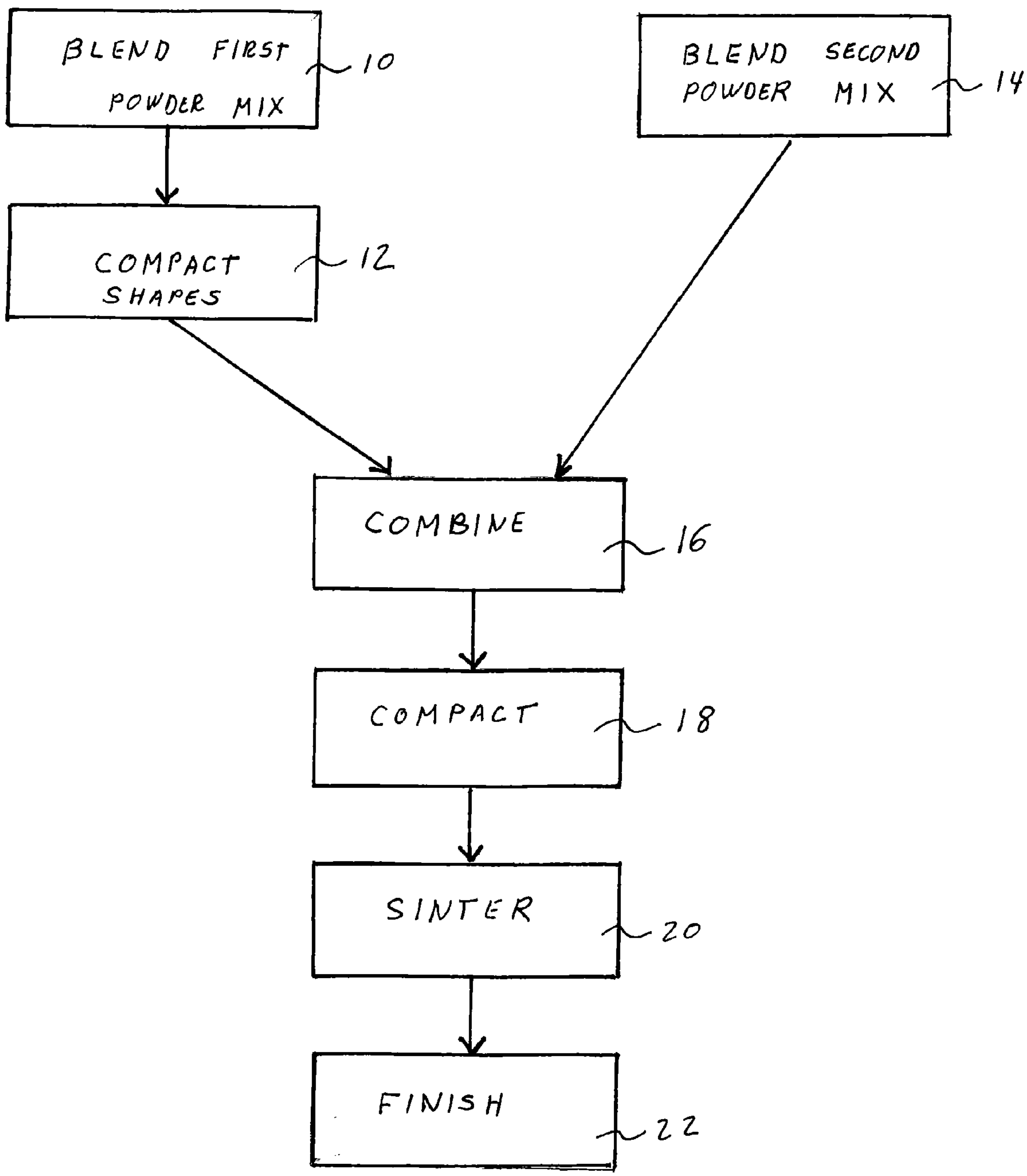


FIG. 1


BLEND FIRST POWDER MIX
10
COMPACT SHAPES
12
BLEND SECOND POWDER MIX
14
COMBINE
16
COMPACT
18
SINTER
20
FINISH
22

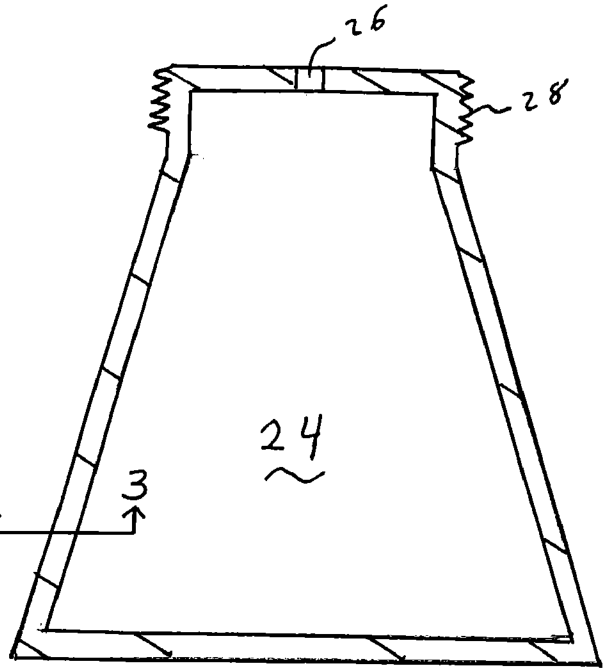


FIG. 2

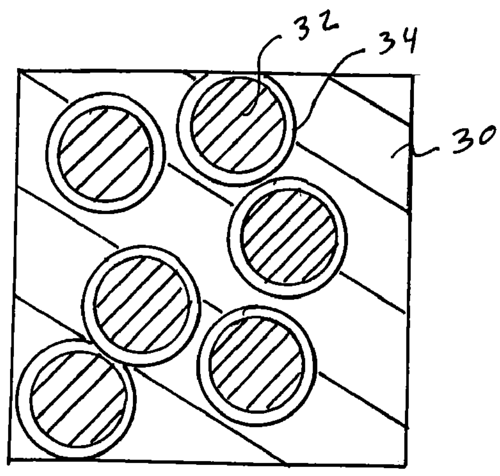


FIG. 3

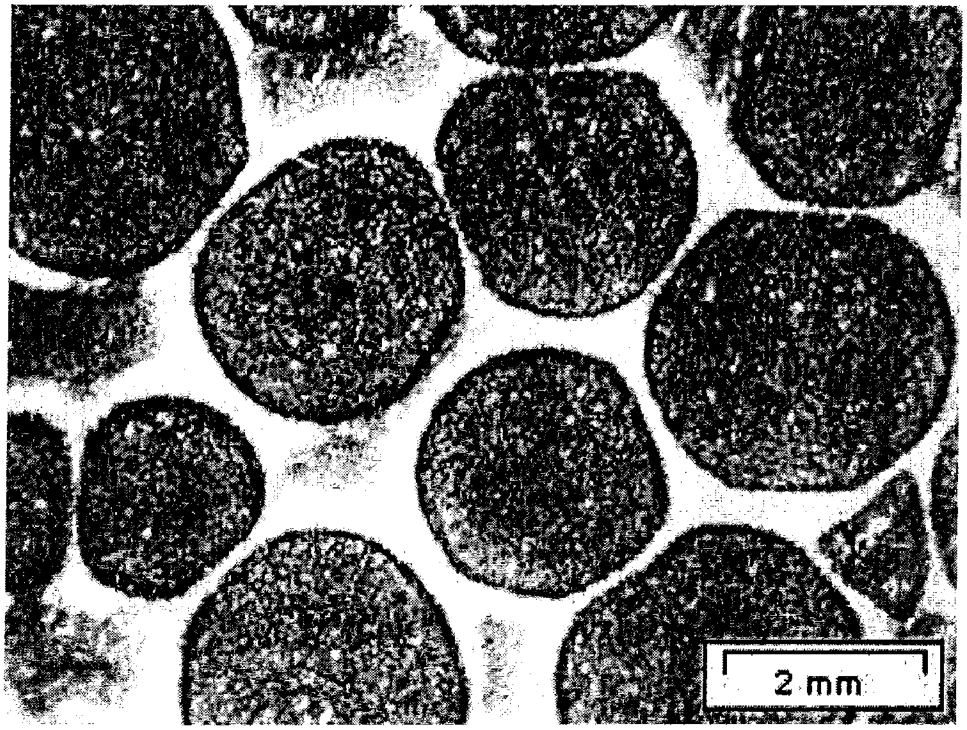


FIG. 4

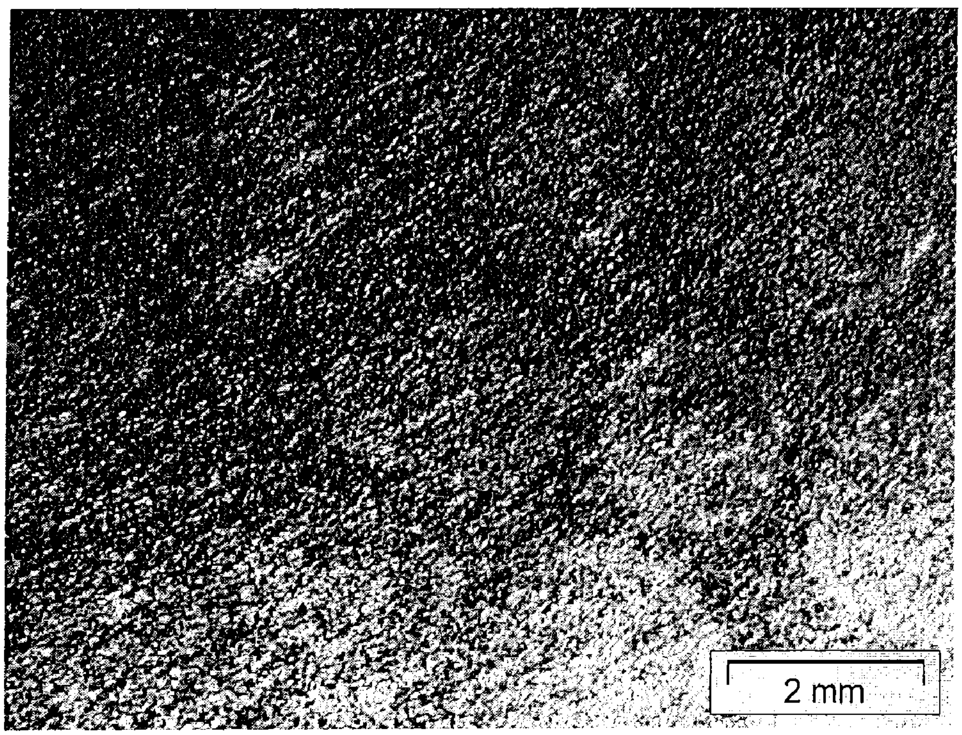


FIG. 5

CO-SINTERED MULTI-SYSTEM TUNGSTEN ALLOY COMPOSITE

CROSS REFERENCE TO RELATED APPLICATION(S)

[0001] This patent application claims priority to U.S. Provisional Patent Application Ser. No. 60/815,730, titled "Co-Sintered Multi-System Tungsten Alloy Composite," that was filed on Jun. 20, 2006. The subject matter of that provisional patent application is incorporated by reference in its entirety herein.

U.S. GOVERNMENT RIGHTS

[0002] N.A.

BACKGROUND OF THE INVENTION

[0003] 1. Field of the Invention

[0004] This invention relates to a composite material and a method for the manufacture of that composite material. The composite material has discrete liquid phase sintered tungsten heavy alloy shapes embedded in a solid state sintered matrix. Both the liquid phase sintering of the embedded shapes and the solid state sintering of the matrix are performed at the same temperature using a single co-sintering process. The co-sintering process allows for uniform sintering shrinkage of the embedded shapes and the surrounding matrix and thereby avoids the formation of defects such as pores and cracking that can occur by conventional processes. In one embodiment, the composite is formed into a component for a fragmentation device having sufficient strength and generating sufficient momentum to penetrate fortified defenses prior to detonation. On detonation, the component releases discrete, high density fragments.

[0005] 2. Description of the Related Art

[0006] The military has a need for devices that can be deployed from a safe distance and distribute a lethal cloud of fast-moving fragments on detonation. Such devices presently use an embossed steel shell that breaks apart along a pattern of thin sections on detonation. Due to the relatively low density of steel, this configuration is not effective for penetrating defensive fortifications, such as concrete or steel lined bunkers, prior to detonation.

[0007] Momentum is a function of (mass) x (velocity). Accordingly, shaped charge liners and fragmentation devices are frequently formed from a tungsten-base alloy. Commonly owned U.S. Patent Application Publication No. US2005/0241522A1 titled "Single Phase Tungsten Alloy for Shaped Charge Liner," published Nov. 3, 2005, discloses a cast metal alloy for forming a shaped charge liner, fragmentation warhead, warhead casing and the like that is an alloy of cobalt, tungsten and nickel. U.S. Pat. No. 6,960,319 titled "Tungsten Alloys for Penetrator Application and Method of Making Same" discloses a kinetic energy penetrator formed from an alloy of tungsten, one or more elements selected from the group consisting of nickel, iron, chromium and cobalt and one or more elements selected from the group consisting of titanium and aluminum. The kinetic energy penetrator is formed by blending a mixture of the powdered elemental components or alloys and then consolidating by solid state sintering. U.S. Pat. No. 6,827,756 titled "Tungsten Heavy Alloy for Penetrating Splinter Shell and Forming Method Thereof" discloses a tungsten-molybdenum-nickel-iron shell formed by compacting elemental or alloy powders of the desired composition to form a green blank and then liquid phase sintering to consolidate. All three of U.S. Patent Application Publication No. US2005/0241522A1 and U.S. Pat. Nos. 6,960,319 and 6,827,756 are incorporated by reference in their entireties herein.

[0008] There remains, therefore, a need for a high density, high strength, component for a fragmentation device that does not have the limitations of the prior art.

BRIEF SUMMARY OF THE INVENTION

[0009] In accordance with the invention, there is provided a composite metal component. This composite has a metallic matrix and embedded shapes dispersed throughout the matrix where the embedded shapes have an incipient liquid phase sintering temperature less than the incipient liquid phase sintering temperature of the matrix.

[0010] In one embodiment of the invention, the composite is produced by the steps of (a) blending a first mixture of metallic powders; (b) compacting the blended first mixture of metallic powders to a plurality of discretely shaped articles; (c) blending a second mixture of metallic powders; (d) mixing the plurality of discretely shaped articles with the blended second mixture of metallic powders to form a precursor blend; (e) compacting the precursor blend; and (f) sintering the precursor blend.

[0011] The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. **1** illustrates in flow chart representation a method for the manufacture of a composite metal component in accordance with the invention.

[0013] FIG. **2** illustrates a nosecone component formed from the composite metal component of the invention.

[0014] FIG. **3** illustrates a portion of the nosecone component of FIG. **2** in magnified cross-sectional view.

[0015] FIG. **4** is a photomicrograph illustrating the structure of the composite of the invention.

[0016] FIG. **5** is a photomicrograph illustrating the structure of a composite formed contrary to the invention.

[0017] Like reference numbers and designations in the various drawings indicated like elements.

DETAILED DESCRIPTION

[0018] Throughout this patent application, the following definitions are employed.

[0019] Incipient Liquid Phase Sintering Temperature—the minimum temperature effective for liquid phase sintering of a metallic compact.

[0020] Liquid phase sintering—sintering of a compact or loose powder aggregate under conditions where a liquid phase is present during part of the sintering cycle.

[0021] Solid state sintering—a sintering procedure for compacts or loose powder aggregates during which no component melts.

[0022] Tungsten-base—an alloy or other mixture of metals having a minimum of 50%, by weight, of tungsten.

[0023] FIG. **1** illustrates in flow chart representation a method for the manufacture of a composite metal component in accordance with the invention. A first mixture of metallic powders is blended **10** to form a substantially homogeneous mixture. The powder constituents of this first powder mix are selected to have a liquid phase sintering temperature less than the liquid phase sintering temperature of a second powder mix, but above the solid state sintering temperature of the second powder mix as described hereinbelow. To enhance the momentum of the composite metal component, the first powder mix preferably includes significant amounts of one or more high density metallic constituents. Most preferably, the first powder mix is tungsten-base, molybdenum-base, or a mixture of tungsten- and molybdenum-base. Alloys and compounds of these metals, such as ferrotungsten, may also be employed. In addition, one or more elements that depress the melting temperature of the powder mix are present. Such melting point depressors include copper, cobalt, manganese and combinations of metals with a melting point less than the matrix material.

[0024] The blended first powder mix is then compacted **12** into a desired shape. This shape may be spheres, cubes, rectangular blocks or some other desired configuration with a diameter or major axis length of at least 2 millimeters and typically in the range of 2 mm to 50 mm. Typically, the blended first powder mix will be inserted into a die cavity having the desired shape and then compacted under a pressure of from about 200 MPa to 700 MPa forming a green compact of the desired shape.

[0025] A second powder mix is then blended **14** to form a mixture having a liquid phase sintering temperature higher than the liquid phase sintering temperature of the first powder mix and a solid state sintering temperature less than the liquid phase sintering temperature of the first powder. To enhance momentum, the second powder mix is preferably predominantly formed of high density metals such as tungsten and molybdenum. Most preferably, the second powder mix is tungsten-base, molybdenum-base or a mixed tungsten- and molybdenum-base. Alloys and components of these metals, such as ferrotungsten, may also be used. In one embodiment, the second powder mix is a tungsten heavy alloy (WHA) matrix with a composition, by weight, of 10% to 100% tungsten and the balance nickel, iron, cobalt and/or copper. The first powder mix and the second powdered mix are selected such that the incipient liquid phase sintering temperature of the first powder mix is at least 10° C. less than the incipient liquid phase sintering temperature of the second powder mix and more preferably, the temperature differential is from 20° C. to 50° C. The melting temperature differential is essential as co-sintering of the first powder mix and the second mix without this differential will result in a homogeneous microstructure.

[0026] The blended second powder mix **14** and compacted shapes **12** are then combined **16** to form a substantially homogeneous suspension of compacted shapes **12** in the second powder mix. The ratio of compacted shapes to second powder mix can be from about 10% to 70% by weight such that the compacted shapes form a discontinuous second phase of embedded shapes in a matrix formed of the second powder mix. The combination is then compacted **18**, such as by placing the mix in a die of a desired shape and compacting under a pressure of from 200 MPa to 700 MPa to form a green compact. This green compact is then sintered **20** at a temperature which meets all three of the following requirements: (a) above the incipient liquid phase sintering temperature of the embedded shapes of the first powder; (b) below the incipient liquid phase sintering temperature of the second powder mix; and (c) above the incipient solid state sintering temperature of the second powder mix. A typical sintering **20** temperature is between 1200° C. and 1350° C. and preferably between 1225° C. and 1275° C.

[0027] The sintered composite metal component may be used as is or finished **22** by additional forming or machining to form the component of the desired configuration.

[0028] The composite metal component is particularly suited for formation into a nose cone for a fragmenting warhead **24** as shown in cross-sectional representation FIG. **2**. Subsequent to sintering, additional features such as apertures **26** and threads **28** may be added during the finishing step.

[0029] FIG. **3** illustrates in magnified cross-sectional view, a portion of the composite metal component formed into the nose cone **24** of FIG. **2**. The composite metal component includes a metallic matrix **30** and embedded shapes **32** dispersed throughout the matrix. Following sintering in accordance with the invention, the matrix **30** has a microstructure commensurate with solid state sintering and the embedded shapes **32** have a microstructure commensurate with liquid phase sintering. An intermetallic rich diffusion layer **34** bonds the matrix and embedded shapes. On detonation, the matrix fragments release the embedded shapes as high momentum shrapnel. The intermetallic phase also aids in the fracture and separation of the embedded shapes into discrete fragments.

[0030] The advantages of the invention will become more apparent from the examples that follow.

EXAMPLES

Example 1

[0031] Two grain spheres compacted from, by weight, 95% tungsten-3% nickel-2% copper were embedded in a matrix of, by weight, 72.2% tungsten-19.5% nickel-8.3% iron and sintered at 1250° C. for 5 hours in a hydrogen atmosphere. The resulting microstructure, illustrated at 15× in the photomicrograph of FIG. **4**, shows fully developed liquid phase sintered spheres surrounded by an intermetallic rich diffusion layer and a solid state sintered matrix. The density was measured at approximately 14.6 grams per cubic centimeter with an elongation of between 1% and 4% and an ultimate tensile strength of between 5 ksi and 20 ksi. The yield was not measurable and fracture appeared to occur in the intermetallic region following the contours of the spheres. It is believed that the bulk properties of the composite can be further improved to approach those of the matrix phase through the use of secondary heat treatment.

Example 2

[0032] The same spheres as used in Example 1 were embedded in a matrix of, by weight, 95.5% tungsten-3.15% nickel-1.35% iron, a conventional tungsten heavy alloy, and then sintered at 1,300° C. for five hours in hydrogen. Both the spheres and the matrix underwent liquid phase sintering and the microstructure of this sample is illustrated at 15× in FIG. **5**. The microstructure shows liquid phase sintered spheres in a liquid phase sintered matrix with no apparent intermetallic regions formed. The density was 18.0 grams per cubic centimeter and fracture did not follow the contours of the spheres such that the spheres of this example would not be released on detonation of a fragmenting warhead.

[0033] It is apparent that the process and composites of the invention eliminate the problems of the prior art because both the embedded shapes and the matrix exhibit the same shrinkage but the embedded shapes undergo liquid phase sintering at the sintering temperature while the matrix is limited to solid state sintering such that two discreet phases remain present. The invention has a reduced amount of material requirements and a reduced number of processing steps required to form a finished product.

[0034] One or more embodiments of the present invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. Accordingly, other embodiments are within the scope of the following claims.

What is claimed is:

1. A method for the manufacture of a composite metal component, comprising the steps of:

a) blending a first mixture of metallic powders;

b) compacting said blended first mixture of metallic powders to a plurality of discretely shaped articles;

c) blending a second mixture of metallic powders;

d) mixing said plurality of discretely shaped articles with said blended second mixture of metallic powders to form a precursor blend;

e) compacting said precursor blend; and

f) sintering said precursor blend.

2. The method of claim **1** wherein said sintering is at a temperature effective to liquid phase sinter said discretely shaped articles and solid state sinter said second mixture of powders.

3. The method of claim **2** wherein both said first mixture of powders and said second mixture of powders are tungsten-base.

4. The method of claim **3** wherein said sintering temperature is between 1200° C. and 1350° C.

5. The method of claim **4** wherein said sintering temperature is between 1225° C. and 1275° C.

6. The method of claim **4** wherein said first mixture of powders is selected to further contain copper and said second mixture of powders is selected to further contain at least one of iron, nickel and cobalt.

7. The method of claim **6** including the additional step of machining said sintered precursor blend to a finished component.

8. The method of claim **7** wherein said machining step forms a nosecone for a fragmenting warhead.

9. A method comprising:

forming a first mixture of a first set of metallic powder constituents, the first mixture having a first incipient liquid phase sintering temperature;

forming a second mixture of a second set of metallic powder constituents, the second mixture having a second incipient liquid phase sintering temperature and an incipient solid phase sintering temperature,

wherein the first incipient liquid phase sintering temperature is less than the second incipient liquid phase sintering temperature and greater than the incipient solid phase sintering temperature;

compacting the first mixture into a plurality of compacted shapes;

forming a combination including a suspension of the compacted shapes in the second mixture;

compacting the combination; and

sintering the compacted combination.

10. A method according to claim **9**, wherein the first mixture includes at least 50% by weight of tungsten, molybdenum or a mixture thereof.

11. A method according to claim **10**, wherein the first mixture further includes a constituent effective to depress the melting point of said first mixture.

12. A method according to claim **11**, wherein said constituent includes copper, cobalt, manganese or a combination thereof.

13. A method according to claim **9**, wherein the second mixture includes at least 50% by weight of tungsten, molybdenum or a mixture thereof.

14. A method according to claim **9**, wherein the second mixture is a tungsten heavy alloy matrix including 10% to 100% by weight of tungsten, with the balance including nickel, iron, cobalt and/or copper.

15. A method according to claim **9**, wherein the first incipient liquid phase sintering temperature is at least 10° C. less than the second incipient liquid phase sintering temperature.

16. A method according to claim **15**, wherein the first incipient liquid phase sintering temperature is from 20° C. to 50° C. less than the second incipient liquid phase sintering temperature.

17. A method comprising:

mixing a first plurality of metallic powders to form a first mixture having a first incipient liquid phase sintering temperature;

mixing a second plurality of metallic powders to form a second mixture having a second incipient liquid phase sintering temperature and an incipient solid phase sintering temperature;

compacting the first mixture into shapes of a desired configuration;

forming a metallic matrix including the second mixture with a plurality of said shapes embedded therein; and

sintering the matrix so that the matrix has a microstructure commensurate with solid state sintering and the embedded shapes have a microstructure commensurate with liquid state sintering.

18. A method according to claim **17**, wherein the sintering is performed at a temperature above the first incipient liquid phase sintering temperature, below the second incipient liquid phase sintering temperature, and above the incipient solid phase sintering temperature.

19. A method according to claim **17**, wherein the first incipient liquid phase sintering temperature is from 20° C. to 50° C. less than the second incipient liquid phase sintering temperature.

20. A method according to claim **17**, wherein the sintering is performed so that an intermetallic rich diffusion layer bonds the matrix and the embedded shapes.

* * * * *