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TITANIUM-BERYLLIUM COMPOSITES AND METHODS OF MAKING

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ABSTRACT OF THE DISCLOSURE

Composites of titanium and beryllium are formed which have a high modulus of elasticity, low density and useful ductility. Titanium-beryllium composites in accordance with this invention comprise from 90 to 40% titanium and from 10 to 60% by volume beryllium. The composites are formed by consolidation of irregular shaped particles of titanium and beryllium under conditions which prevent alloying or compounding of the two metals.

BACKGROUND OF THE INVENTION

Much research and development has been carried out in recent years in connection with titanium alloys and composites for commercial use in high temperature applications such as jet engine parts and the like. Titanium alloys and composites are preferred for use in such applications because of their good heat resistance and light weight which are important factors. Titanium alloys are conventionally made by melting methods used to form ingots of the alloys after which the ingots are worked by conventional forging and/or other mechanical shaping techniques.

Titanium metal is rarely used in industry by itself particularly for aircraft applications since there are alloying metals such as aluminum which can be used to decrease density while improving over-all mechanical properties of titanium alloys. Thus, aluminum has become a major alloy metal for use with titanium.

Beryllium is a metal that would ordinarily suggest itself for alloying with titanium in order to obtain good stiffness at low density in alloys. Beryllium has extremely high stiffness with a modulus of elasticity of 40×10^6 p.s.i. and a density of 0.066 lb. per cu. in. as compared to aluminum which has a modulus of elasticity of 10×10^6 p.s.i. and a density of 0.098 lb. per cu. in. However, it is known that titanium-beryllium alloys are extremely brittle because of the formation of titanium-beryllium compounds. Such brittleness adversely affects possible use of titanium-beryllium alloys in commercial applications.

It is an important object of this invention to provide titanium-beryllium composites which have a high modulus of elasticity, low density and useful ductility.

Another object of this invention is to provide titanium-beryllium composites in accordance with the preceding object which can be made efficiently and which are useful as final products or as preforms for further mechanical operations to form final commercial products.

Another object of this invention is to provide an efficient method of manufacture of titanium-beryllium composites in accordance with the preceding objects.

SUMMARY OF THE INVENTION

Titanium-beryllium composites according to this invention have a high modulus of elasticity, low density and useful ductility with the beryllium preferably being present in a titanium matrix comprising from 90 to 40%

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titanium and from 10 to 60% by volume beryllium, with the percentages being by volume of the total metals used.

The composites are formed by mixing together irregular shaped particles of titanium and beryllium in the desired proportions and consolidating the particles to form the composites at a temperature no higher than 1100° F. to prevent formation of unwanted alloys and compounds of beryllium and titanium. In the preferred method, an as-pressed preform is formed by cold compacting to mechanically interlock the particles at pressures of at least 10,000 p.s.i. After formation of the preform, it is worked by conventional mechanical working techniques including forging and the like or extrusion at temperatures no higher than 1100° F.

The composites of this invention can be relatively inexpensively formed and provide significant advantages in that the ratios of modulus of elasticity to density are extremely high and preferably well over the 100×10^6 in. ratios encountered in conventional titanium alloys. Yet, such composites have good ductility preferably with elongations of at least 3% at standard room temperature (72° F.). The starting materials for forming the composites are commercially available in substantially pure forms which permit economical manufacture by efficient methods.

BRIEF DESCRIPTION OF PREFERRED EMBODIMENTS

The titanium-beryllium composites of the present invention preferably consist essentially of from 90 to 40% by volume titanium and from 10 to 60% by volume beryllium with a preferred range of from 80 to 60% by volume titanium and from 20 to 40% by volume beryllium. The beryllium in the composites is embedded in a general titanium matrix. When amounts of beryllium exceed 60% by volume, ductility is sacrificed and the composites become too brittle for ordinary usage in most commercial applications while when the amount of beryllium falls below 10%, no significant improvements are obtained.

The term "composite" is used in its ordinary sense in the metallurgical arts to indicate that the identity and favorable properties of each component (i.e. beryllium and titanium) survive in the composite and substantially no alloying or compounding occurs.

The composites of this invention are made by conventional powder metallurgical techniques using available, commercially pure titanium powder (99.5% pure, O₂ content no more than 0.12%) and commercially pure beryllium powder (98% pure). Particles of the powders are irregularly shaped which is important to permit consolidation of the particles by cold pressing techniques to form the desired composites. Thus if regular particles such as the type made by the rotating electrode technique (spherical particles) are used, the advantages of this invention are not obtained because of the difficulties in pressing. Thus high temperatures are required to consolidate and alloys or compounds rather than composites are often formed.

Preferably the particle size of both the beryllium and titanium particles are below 100 mesh A.S.T.M. Commercially pure titanium powder useful in this invention has no more than 0.12% oxygen as is known in the art. Additional amounts of oxygen add to tensile strength of the final product but the percent elongation and consequently ductility drops rapidly as the oxygen impurity increases.

Predetermined quantities of particles of the titanium and beryllium to be used are preferably uniformly mixed together in a conventional powder technology blender and then cold pressed preferably at pressures in the range

of from 10,000 p.s.i. to 60,000 p.s.i. to form bar stock or preforms of final products suitable for extrusion or metal-working such as forging, sheet rolling and the like. The cold pressing operation results in preforms or bar stock as desired preferably having densities of at least 60%. When bar stock is formed, it can be warm extruded at temperatures of from 700° F. to 1100° F. and preferably of from 900 to 1000° F. and at pressures of from 100,000 p.s.i. and up, using conventional techniques. For example, the bar stock can be encased in a steel cylinder and extruded as is known in the art to obtain 100% dense composites. The particular temperatures and pressures used during extrusion can vary greatly depending upon the size of the extrusion and the reduction in diameter desired.

When the preforms are forged or worked into final products, density can be increased to 100% during conventional metal working techniques. In such techniques, the temperature is maintained below 1100° F. as in extrusion to prevent alloying or compound formation.

In all cases, consolidation by pressing and extrusion is carried out below 1100° F. to minimize the formation of alloys or compounds of beryllium and titanium which compounds and alloys are detrimental to the ductility properties of the desired material. When cold pressing is used followed by forging or working, the temperature employed is in the range of from 700° F. to 1100° F.

In another method of forming the composites of this invention, it is possible to eliminate cold pressing by directly extruding the powders of titanium and beryllium. For example, the desired proportion of blended powders as described above are encased in a steel container which is heated in the range of from 700° F. to 1100° F. and extruded in a press to obtain initial compaction and full densification in one operation. The extrusion pressures used are preferably at least 100,000 p.s.i.

This invention encompasses formation of preforms in the as pressed condition which can be sold as is for later working and/or highly densified final products and preforms which can be further worked by extrusion, forging, sheet rolling and the like.

In a specific example of this invention, commercially pure titanium powder (99.5% pure, less than 0.12% oxygen) having acicular particles of -100 mesh, is blended with commercially pure beryllium powder (98% pure) having acicular particles of -100 mesh, in amounts of 80% by volume titanium and 20% by volume beryllium. A homogeneous mixture is formed which is then cold pressed at standard room temperature into a cylindrical bar having a diameter of 1½ inch and a length of 5 inches at a pressure of 60,000 lbs. p.s.i. The preform thus manufactured is then encased in a steel can, heated to 1000° F. and then double extruded in a press at 185,000 p.s.i. to obtain a final extruded completely densified bar having a diameter of ½ inch and a length of approximately 40 inches. A second experiment is carried out exactly as described above except that the titanium particles are present in an amount of 60% by volume and the beryllium particles are present in an amount of 40% by volume of the mixture.

The composites so formed were then tested for tensile strength by A.S.T.M. method E8-66 with the results indicated below:

Sample	Yield strength at 2% offset, p.s.i.	Tensile strength, p.s.i.	Modulus of elasticity, p.s.i.	Elongation, percent	Reduction of area, percent
80% Ti, 20% Be.....	50,800	61,000	20.3×10 ⁶	12.0	5.6
60% Ti, 40% Be.....	65,400	87,300	25.2×10 ⁶	5.8	3.2

The results of the test indicated above clearly show that titanium-beryllium composites having ductility of at least 3% (elongation) and higher can be obtained with high modulus of elasticities and low densities giving good ratios of stiffness to weight. Thus, stiff, lightweight, ductile composites are formed by this invention which are highly useful to reduce weight in titanium materials for use in jet engine parts and the like.

It should be noted from the above table, that the ratios of modulus of elasticity to density in each of the composites formed is extremely high; that is, 142×10⁶ inch in one case and 203×10⁶ in the second case. These ratios are much higher than that obtained with conventional titanium alloys such as Ti-6 Al-4 V where the ratio is approximately 100×10⁶ inch.

Thus, the present invention provides for high ratios of modulus of elasticity to density in lightweight composites having the advantageous properties of titanium and beryllium, yet, being ductile enough to permit use in desired commercial applications.

While specific embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that many modifications thereof can be made within the scope of this invention.

What is claimed is:

1. A method of forming a titanium-beryllium composite comprising,

forming a uniform powder mixture of acicular particles of commercially pure titanium and commercially pure beryllium with said particles having a size below 100 mesh A.S.T.M.,

said titanium and beryllium being present in amounts of from 80 to 40% by volume titanium and 20 to 60% by volume beryllium,

and consolidating said mixture at a temperature no higher than 1100° F. to form said composite.

2. A method in accordance with the method of claim 1 wherein said consolidating comprises pressing in the range of from 10,000 p.s.i. to 60,000 p.s.i.

3. A method in accordance with the method of claim 2 wherein said consolidating further comprises the step of compacting by extrusion at a temperature in the range of from 700° F. to 1100° F. at a pressure of at least 100,000 p.s.i. to obtain said composite having a density of 100% theoretical density with a ratio of modulus of elasticity to density of over 100×10⁶ inch and an elongation of at least 3%.

4. A method in accordance with the method of claim 3 wherein said temperature of extrusion is in the range of from 900° F. to 1100° F.

5. A method in accordance with the method of claim 4 wherein said further consolidating is carried out by forging.

6. A method in accordance with the method of claim 4 wherein said further consolidating is carried out by sheet rolling.

7. A titanium-beryllium composite having a modulus of elasticity to density ratio of over 100×10⁶ inch and an elongation of at least 3%,

said composite consisting essentially of titanium and beryllium in an amount of from 90 to 40% by volume titanium and 10 to 60% by volume beryllium, said composite being formed from a powder mixture of acicular particles of beryllium and titanium having a size below 100 mesh A.S.T.M. and being consolidated at a temperature no higher than 1100° F.

8. A titanium-beryllium composite in accordance with claim 7 wherein said titanium and beryllium are commercially pure and said beryllium is present in an amount of from 20 to 60% by volume.

9. A titanium-beryllium composite in accordance with claim 7 wherein said composite has a density of 100% of theoretical density.

10. A titanium-beryllium composite in accordance with claim 9 wherein said consolidating was carried out by

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extrusion at a temperature in the range of from 700° F. to 1100° F.

11. A titanium-beryllium composite preform formed from a uniform powder mixture of acicular particles of titanium and beryllium having a size below 100 mesh A.S.T.M. and being consolidated at a temperature no higher than 1100° F., said composite consisting essentially of titanium and beryllium in an amount of from 90 to 40% by volume titanium and from 10 to 60% by volume beryllium.

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