United States Patent Office

3,475,142

Patented Oct. 28, 1969

3,475,142

TITANIUM ALLOY BERYLLIUM COMPOSITES

Stanley Abkowitz and Warren L. Larson, Lexington, and Fortunato J. Rizzitano, Needham, Mass.; said Abkowitz and said Larson assignors, by direct and mesne assignments, of two-thirds to Whittaker Corporation, Los Angeles, Calif., a corporation of California

No Drawing. Filed May 13, 1966, Ser. No. 549,781

Int. Cl. B22f 7/02

U.S. Cl. 29—192 2 Claims

ABSTRACT OF THE DISCLOSURE

A wrought composite mill product comprising bonded particles of Ti–6Al–4V alloy and beryllium having room temperature properties of about 7.5% elongation, 17% reduction of area, and 188,000 p.s.i. yield strength, the particles being blended in volume proportion of 10% beryllium particles and 90% titanium alloy particles and bonded by hot compaction and extrusion at 1300° F. to avoid intermetallic compound formation; the composite mill product being particularly useful in the construction of aircraft.

The invention relates to composites of titanium base alloys and beryllium, and more particularly to titanium alloy beryllium composites in which the titanium alloy component of the composite, for example, may provide very high yield and tensile properties in combination with good ductility, and in which the beryllium component of the composite improves the modulus of elasticity and the strength-to-density ratio, while the ductile matrix of the titanium phase is maintained.

Titanium products having presently unobtainable combinations of properties continue to be in demand, particularly in the construction of aircraft such, for example, as supersonic transport planes.

For certain applications, known commercial titanium alloys have not been available which combine the properties or characteristics of very high yield and tensile properties, good ductility, a favorable modulus of elasticity, and a high strength-to-density ratio. Such material is needed particularly where high temperature strength has been required. For lower temperature applications toughness and ductility combined with an improved modulus of elasticity and strength-to-density ratio are a desired combination of properties not available in commercial titanium alloys.

Accordingly, objectives of the invention are to satisfy the existing need; to provide new high temperature strength titanium alloy beryllium composites which have an improved strength-to-density ratio and an improved modulus to density ratio, along with very high yield strength and tensile properties and good ductility; to provide new titanium alloy beryllium composites for lower temperature applications which combine toughness, ductility and improved modulus of elasticity and strength-to-density ratio; to provide new procedures for the manufacture of such composites whereby the stated extraordinary combination of properties may be obtained; and to achieve the stated objects simply and effectively thereby solving existing problems.

These and other objects and advantages may be obtained, the stated results achieved and the described difficulties overcome by the concepts, discoveries, principles, procedures, methods, steps, treatments, compositions, composites, products and combined properties which comprise the present invention, the nature of which is set forth in the following general statements, preferred embodiments of which—illustrative of the best modes in which applicants have contemplated applying the principles—are set forth in the following description, and which are particularly and distinctly pointed out and set forth in the appended claims.

The nature of the concepts and discoveries of the invention relating to high temperature strength composites of a titanium alloy and beryllium may be stated in general terms as comprising a ductile composite mill product having room temperature properties of about 7.5% elongation, 17% reduction of area, and 188,000 p.s.i. yield strength, formed of a titanium base alloy (Ti–6Al–4V) and beryllium, the titanium alloy and beryllium components of the composite being formed as microquenched age-formed "shot," the components being blended in the proportions by volume of 90% titanium base alloy and 10% beryllium, and the blended components being hot compacted and extruded at 1300° F. to form the composite mill product.

The nature of the concepts and discoveries of the present invention relating to titanium alloy beryllium composites for lower temperature applications comprise a mill product consisting of from 20% to 75% beryllium and the balance a titanium alloy formed as a composite from microquenched age-formed beryllium and titanium alloy component materials blended, compacted and extruded at 1300° F.

The nature of the concepts and discoveries of the invention relating to the manufacture of the improved composites may be stated in general terms as including the steps of providing titanium alloy and beryllium component materials for a composite to be formed in microquenched age-formed particle state; blending the particles in the desired proportions; consolidating and extruding the blended particles at a temperature not in excess of 1300° F. to bond the component particles together; and controlling the temperature of the components during compacting, bonding and extrusion to below that temperature at which harmful diffusion of the components with one another can occur.

In accordance with the invention, a desired titanium base alloy having usual typical mechanical properties as to strength and ductility is converted to high purity powder form to produce microquenched age-formed particles of the alloy in the manner set forth in Kauffman Pat. No. 3,099,041. The conversion of the selected titanium alloy material to microquenched, age-formed particles substantially improves the mechanical properties of the alloy as compared with the typical properties of the alloy, such that very high yield and tensile properties in combination with good ductility are provided.

Also, in accordance with the invention beryllium similarly is converted in the manner set forth in Pat. No. 3,099,041 into beryllium "shot," that is microquenched, age-formed particles of beryllium. Beryllium has a high modulus of elasticity and a lower density than titanium

and its alloys. Thus, the formation of a composite of a selected titanium alloy and beryllium will improve the modulus of elasticity and the strength-to-density ratio of the composite as compared to these properties of the titanium alloy component while maintaining the ductile matrix of the titanium phase in accordance with the concepts of the invention.

The titanium alloy and beryllium in "shot" form then are blended in the desired proportions to obtain the desired combination of properties. The blend of "shot" then is heated, compacted, consolidated, bonded and extruded by plastic deformation reduction and working to the necessary extent or degree to form the desired mill product.

In accordance with the invention and illustrative of the new concepts, a titanium alloy having desired properties is employed as a component of the composite to be formed. For example, the Ti–6Al–4V alloy typically has a tensile strength of 150,000 p.s.i. with 19% elongation. We have discovered that the Ti–6A1–4V alloy when converted into microquenched age-formed particles or "shot" and the "shot" compacted and extruded under controlled temperature conditions, in accordance with the procedures set forth in the Abkowitz copending application Ser. No. 335,799 (now patent number 3,343,998, dated Sept. 26, 1967) and in the Abkowitz et al. copending application Ser. No. 447,119 (now Patent No. 3,368,881, dated Feb. 13, 1968), it develops a tensile strength of 202,000 p.s.i. with 14% elongation. However, such alloy material for certain applications also should desirably have a higher strength-to-density ratio and a more favorable modulus of elasticity.

Beryllium has these desired properties of low density and a high modulus. However, when beryllium is introduced into a titanium alloy as an alloying element or by interdiffusion, brittle intermetallic compounds are produced which are detrimental to mechanical properties of the alloy.

However, we have discovered that if beryllium also is converted to microquenched, age-formed, "shot," it may be blended, compacted, bonded and extruded with similar titanium alloy "shot" to form a composite which, when the temperature is critically controlled at about 1300° F. during compacting and extrusion of the composite material, retains to a high degree the favorable properties of both components of the composite.

Various titanium alloy beryllium composites of the invention were manufactured in accordance with the procedures described below. After the titanium alloy and beryllium separately were converted to microquenched age-formed particles or "shot," the "shot" was weighed and appropriate amounts of each component were mixed or blended to obtain as uniform a mixture as possible. The blended mixture was then introduced into cans or containers preferably formed of seamless low carbon steel tubing with welded-in end plates. As the cans or containers were filled with the blend, the "shot" in the cans was cold compacted with an hydraulic press prior to welding the top end plate for the can.

The steel end plate at the top of each can of cold compacted "shot" blend then was welded closed, and during welding a flow of argon was directed through an evacuation tube connected with the interior of the can to prevent oxidation of the "shot" from heating. The can of cold compacted "shot" then was evacuated to a final pressure of less than 0.5 micron while being heated at 800° F. After three hours of such hot outgassing, the can was cooled to room temperature after which the evacuation tube was hot forge-sealed.

Hot compacting of the material in the cans then was carried out in a liner of an extrusion press using penetrating tools heated to about 900° F. placed at both the front and rear of the can containing the "shot" material. During application of a 600-ton load, the press ram forced the penetrators against the end plates into the inside of the steel can after shearing the welds between the end plates and the can. The billets or cans to permit hot-compacting were heated to the same temperature subsequently used as an extrusion temperature for the material as described below.

The hot compacted cartridge thus formed after proper machining to accommodate subsequent extrusion operations then was repeatedly extruded while jacketed or canned through a number of reductions to form extruded rods in the manner described in detail in said Abkowitz application Ser. No. 335,799 (patent number 3,343,998). Various hot compacted blend proportions of composite components in preparation for extrusion were heated to extrusion temeratures of 1100° F., 1300° F., and 1600° F. for comparable evaluation of the extruded composite products. Heat treatments of the extruded rods were carried out prior to the removal of the steel canning material. For rods extruded at 1100° F. and 1300° F., the heat treatment comprised aging at 1050° F. for three hours and then air cooling. The rods extruded at 1600° F. were solution heat treated for fifteen minutes at 1600° F. followed by a water quench and then aging at 1300° F. for three hours and then air cooling. Other rods extruded at 1600° F. were annealed at 1300° F. for three hours and then air cooled. Test specimens were machined from heat treated rods for evaluation of mechanical properties. The mechanical test properties of the composites are summarized in Table I on the following page.

Metallographic examination of the 10 v/o beryllium composites extruded at 1100° F. (both primary and secondary extrusions) indicated smooth interfaces between the beryllium and titanium phases, with no evidence of voids or compound formation. Similar composites extruded at 1600° F. revealed considerable amounts of intermetallic compound between the beryllium particles and the titanium alloy matrix, and also many associated void areas. The 20 v/o beryllium composite, extruded at 1600° F., had many more void areas in the structure because of the greater number of beryllium particles. The presence of considerable amounts of both brittle intermetallic compound and void areas in the structure account for the lowered strengths and ductilities obtained in the 1600° F. extruded composites, with the 20 v/o beryllium samples showing lower properties than those with 10 v/o beryllium.

The composites with 10 v/o beryllium extruded at 1100° F. provided high strength but low ductilities resulted rendering such material unsatisfactory. Similar 10 v/o beryllium composites extruded at 1600° F. involved excessive interaction between the beryllium and titanium phases which resulted in lower mechanical properties with essentially no ductility.

Subsequent metallographic investigation of samples of the 10 v/o beryllium composite heat treated at 1200° F., 1300° F., 1400° F. and 1500° F. for three hours disclosed that there was no intermetallic reaction at 1200° F. or 1300° F. However, at 1400° F. some compound formation was evident and at 1500° F. considerable compound was formed, as well as the usual void areas.

These discoveries led to further evaluation of billets extruded at 1300° F. formed of composites of 10 v/o and 75 v/o beryllium, and also one of 100 v/o beryllium or all beryllium. The mechanical test properties of these composites extruded at 1300° F. also are listed in Table I. The 1300° F. extrusion temperature used for these composite products is within the aging temperature range that must not be exceeded in heat treating microquenched age-formed materials in order that the obtained combination of strength and ductility achieved through microquenching and age-forming is not lost.

The mechanical properties of the 10 v/o beryllium composite extruded at 1300° F. are a distinct improvement over those obtained with the 1100° F. or 1600° F. processing temperatures. An excellent combination of tensile strength, ductility, and impact properties is indicated. Thus, referring to samples, the L-samples in Table I, the material

TABLE I

Sample No.	Composition, Ti-6Al-4V plus—	Heat Treatment: Solution Degrees	Solution Minutes	Aging Degrees	Aging Hours	Extrusion Temperature, ° F.	0.2% Offset Yield Strength, p.s.i.	Tensile Strength, p.s.i.	Percent Elongation	Percent Reduction of Area	Modulus 10^6: Autographic	Modulus 10^6: Ultrasonic	Charpy Impact (Ft.-Lbs.), −40° F.	Hardness, Average RC	Remarks
B-1	Ti Alloy Only	1,600	15	1,050	3	1,600	154.2	163.0	19.3	42	17.22				
B-2	do	1,600	15	1,050	3	1,600	154.5	160.0	19.7	41	16.3				
BA-1	do	1,600	15	1,050	3	1,600	150.7	158.2	16.0	50.4	14.5	16.69	14.9	37.4	
BA-2	do	1,600	15	1,050	3	1,600	150.4	154.5	16.0	36.0	14.9		15.8	36.9	
C-1	do			1,300	3	1,600	144.8	148.1	21.8	44					
C-2	do			1,300	3	1,600	143.8	147.5	23.1	49					
CA-1	do			1,300	3	1,600	140.0	146.2	19.0	50.8	14.0	16.23	14.5	35.5	
CA-2	do			1,300	3	1,600	142.0	149.0	10.0	13.4	14.0		*80.9	44.5	*Unable to penetrate.
D-1	do			1,050	3	1,100	>181.0	202.0	14.3	38	16.75				
D-2	do			1,050	3	1,100	202.0	203.0	3.3	4	14.48				Flaw in SPM.
D-3	do			1,050	3	1,100	201.0	203.0	4.0	6	15.95				Do.
DA-1	do			1,050	3	1,100		118.0				16.17	6.4	42.6	SPM Fractured.
DA-2	do			1,050	3	1,100							6.0	42.3	Do.
E-1	10 v/o Be			1,050	3	1,100	>166.0								Broke in Threads.
E-2	10 v/o Be			1,050	3	1,100	>181.0								Do.
E-3	10 v/o Be			1,050	3	1,100	130.5	130.5	1.1		15.88				Broke Outside Gauge.
E-4	10 v/o Be			1,050	3	1,100	193.5	193.5	1.44		15.42				Fracture—SPM Yielded.
EA-1	10 v/o Be			1,050	3	1,100		167.0	3.1	3.48	13.8	18.49			SPM Fractured.
G-3	10 v/o Be	1,600	15	1,050	3	1,600	142.3	142.3	0.64		14.95				Broke Outside Gauge.
G-4	10 v/o Be	1,600	15	1,050	3	1,600	136.7	136.7	0.9		15.52				Do.
GA-1	10 v/o Be	1,600	15	1,050	3	1,600					15.6		2.1	36.3	Shoulder Break.
GA-2	10 v/o Be	1,600	15	1,050	3	1,600	152.0	152.0	1.5	1.5	14.8		2.3	38.8	
H-1	10 v/o Be			1,300	3	1,600	103.6	103.6	0.5		15.89				Broke Outside Gauge.
H-2	10 v/o Be			1,300	3	1,600	100.0	100.0	0.56		15.19				Do.
HA-1	10 v/o Be			1,300	3	1,600					14.2	15.46	3.5	40.2	Shoulder Break.
HA-2	10 v/o Be			1,300	3	1,600					14.4		3.9	34.7	
J-1	20 v/o Be	1,600	15	1,050	3	1,600	95.0	95.0	0.3		12.6				
J-2	20 v/o Be	1,600	15	1,050	3	1,600	99.9	99.5	0.3		12.95				Broke Outside Gauge.
JA-1	20 v/o Be	1,600	15	1,050	3	1,600					12.9		0.8	37.8	Shoulder Break.
JA-2	20 v/o Be	1,600	15	1,050	3	1,600					13.5		0.5	40.2	
K-3	20 v/o Be			1,300	3	1,600	78.2	78.2	0.3		13.55				
K-4	20 v/o Be			1,300	3	1,600	87.0	87.0	0.3		13.15				Broke Outside Gauge.
KA-1	20 v/o Be			1,300	3	1,600	76.0	77.5	1.5	0.99	13.9				
L-1	10 v/o Be			1,050	3	1,300	188.5	188.5	7.5	17	16.35		25		
L-2	10 v/o Be			1,050	3	1,300	186.5	186.5	6.5	12	21.1		27.5		
LA-1	10 v/o Be			1,050	3	1,300	176.5	177.0	6.3	11.2	14.5	18.75	16.0	40.9	
LA-2	10 v/o Be			1,050	3	1,300	178.5	179.0	6.3	18.9	13.8				
R-1	75 v/o Be			1,050	3	1,300	48.1	48.1					0.75		
R-2	75 v/o Be			1,050	3	1,300	54.7	54.7			35.5		1.0		
RA-1	75 v/o Be			1,050	3	1,300					27.7	25.70	0.5	21.3	SPM Broke.
O-1	100 v/o Be			1,050	3	1,300	74.4	74.4	0.3				0.25		
O-2	100 v/o Be			1,050	3	1,300	79.5	79.5	1.5		42.9		0.25		
OA-1	100 v/o Be			1,050	3	1,300		77.0			40.0	40.0	0.3		Do.

has a high tensile strength of 188,500 p.s.i. with 7.5% elongation and 17% reduction of area which represents reasonable ductility. Charpy impact test results for this composite show values which are higher than for beryllium alone. The density of the 10 v/o beryllium composites is 4.17 gms./cm.^{3} compared with 4.43 gms./cm.^{3} for the Ti–6Al–4V alloy.

Based on data in Table I, the strength/density ratio of the composite 188,000/4.17 is much higher than the similar ratio for the commercial Ti–6Al–4V alloy of 150,000/4.43. 150,000 p.s.i. yield strength of commercial Ti–6Al–4V alloy is a typical value in published literature concerning this alloy for solution treated and age-hardened material in thin sections. In heavier sections the material has lower strength.

Metallographic examination of the 10 v/o beryllium composite showed a structure similar in appearance to that of material extruded at 1100° F. It is apparent, however, that the bonding mechanism between the titanium and beryllium phases has changed to a degree to allow ductility to be obtained in the L-samples of Table I extruded at 1300° F. as compared with the E-samples of Table I extruded at 1100° F.

Similarly, the L-samples modulus values (16.35) for the 10 v/o beryllium composite extruded at 1300° F. are equivalent to or slightly greater than the E-samples modulus values for Ti–6Al–4V alloy, so that the modulus-to-density ratio 16.35/4.17 is improved for the 10 v/o beryllium composite as compared with a similar ratio 16.35/4.43 for the Ti–6Al–4V alloy.

Comparing the properties of the Ti–6Al–4V alloy and the 10 v/o beryllium composite data in Table I, the B-samples represent about the highest strengths and ductility that can be obtained for the Ti–6Al–4V alloy even using microquenched material which is not age-formed, since the extrusion temperature of 1600° F. is above the age-forming temperature range; and it is only by forming below age-forming temperature that maximum strength is obtained.

Similarly, the C-samples in Table I illustrate that a different heat treatment reduces strength somewhat from the B-samples but gives increase ductility for the Ti–6Al–4V alloy. The D-samples illustrate excellent mechanical properties obtained by processing the Ti–6Al–4V material by microquenching and age-forming. Tensile strength of above 200,000 p.s.i. and ductilities as high as 14% elongation were obtained.

Referring to the E-samples, with the addition of 10% beryllium in a composite extruded at 1100° F. in an attempt to impart the favorable properties of beryllium to the composite resulted in low ductilities.

Increasing the extrusion temperature for the 10 v/o beryllium composite to 1600° F. with different heat treatments (H-samples and J-samples) resulted in reduced strengths with essentially no ductility.

The L-samples show that using the critical extrusion temperature of 1300° F., the 10 v/o beryllium composite retains the high tensile strength of the D-samples with substantial ductility, and with improved strength-to-density and modulus-to-density ratios as well as favorable impact properties. Thus, the 10 v/o beryllium composite provides an extraordinary combination of tensile strength, ductility, improved impact properties and improved strength-to-density and modulus-to-density ratios.

Thus, in accordance with the invention using the 1300° F. extrusion temperature, the microquenched "shot" of the blend is easily consolidated and bonded with minimum diffusion, and at the same time age-forming is possible to retain the benefits of microquenched, age-formed material by which high strength with ductility is obtained. To these advantages is the added further advantage of the ability to add beryllium to the high strength material to impart the favorable properties of beryllium to the composite.

Strength properties of the improved titanium alloy beryllium composites may be predicted reliably in accordance with the arithmetic proportion of the component from which the property is derived that is present in the composite.

For example, conventionally heat treated commercial Ti–6Al–4V alloy has an average yield strength of about 150,000 p.s.i. Beryllium has an average yield strength of about 75,000 p.s.i. It is possible to calculate the yield strength of the 10 v/o beryllium composite by adding 90% of 150,000 or 135,000 to 10% of 75,000 or 7,500 which equals 142,500 which approximates the yield strength of the G-samples of a composite formed without age-forming.

Similarly, adding 90% of 200,000 (the approximate yield strength of the D-samples) or 180,000, to 10% of 75,000 or 7,500 equals 187,500 p.s.i. yield strength for the 10 v/o beryllium composite formed from microquenched age-formed material. This is substantially exactly the strength value of the L-samples.

Referring to the 75 v/o beryllium composite and the 100 v/o beryllium material (R-samples and O-samples of Table I), extruded at 1300° F., while low tensile strengths and ductility are present, there is improved impact strength for the 75 v/o beryllium composite as compared with the 100 v/o beryllium, as well as high modulus values.

It is evident from comparison of the similarity of the H and J-samples extruded at 1600° F. of 10 v/o and 20 v/o beryllium composites with the 10 v/o beryllium composite L-samples extruded at 1300° F., that composites of from 20 v/o to 75 v/o beryllium will have improved ductility when extruded at 1300° F.

Although the invention has been described with reference to composites formed of beryllium and the Ti–6Al–4V alloy, it is understood that composites of beryllium and other titanium alloys or unalloyed titanium processed in accordance with the invention with microquenched age-formed material extruded at 1300° F. will exhibit improved properties as compared with the commercial titanium alloys themselves.

Accordingly, the invention provides new titanium alloy beryllium composites having extraordinary combinations of properties which satisfy existing needs and solve problems in the art, and provides new procedures for the manufacture of such composites in a simple and effective manner.

In the foregoing description certain terms have been used for brevity, clearness and understanding; but no unnecessary limitations are to be implied therefrom beyond the requirements of the prior art, because such terms are used to descriptive purposes and are intended to be broadly construed.

Moreover, the description and illustration of the invention and the new procedures and products are by way of example and the scope of the invention is not limited to the exact details described, because various products may be manufactured without departing from the fundamental concepts and principles of the invention.

Having now described the features, concepts, discoveries and principles of the invention, the characteristics and properties of the new products, the preferred procedures to be used, and the advantageous, new and useful results obtained; the new concepts, discoveries, principles, procedures, methods, steps, treatments, compositions, composites, products and combined properties, and mechanical equivalents obvious to those skilled in the art are set forth in the appended claims.

We claim:

1. A ductile composite mill product consisting essentially of a mixture of microquenched, age-formed shot particles of Ti–6Al–4V alloy and microquenched, age-formed shot particles of beryllium in the proportion by volume of 10% beryllium and the balance Ti–6Al–4V alloy, said particles being bonded together free of intermetallic compound formation between the Ti–6Al–4V alloy and beryllium particles by hot compaction and extrusion of the mixed particles at 1300° F. such that the extruded mill product has room temperature properties of from 6.3 to 7.5% elongation, 11.2 to 18.9% reduction of area and 176,500 to 188,500 p.s.i. yield strength.

2. A composite mill product consisting essentially of a mixture of microquenched, age-formed shot particles of Ti–6Al–4V alloy and microquenched, age-formed shot particles of beryllium in the proportion by volume of from 10% to 75% beryllium and the balance Ti–6Al–4V alloy, said particles being bonded toegther free of intermetallic compound formation between the Ti–6Al–4V alloy and beryllium particles by hot compaction and extrusion of the mixed particles at 1300° F.

References Cited

UNITED STATES PATENTS

2,754,204	7/1956	Jaffee	75—175.5
3,099,041	7/1963	Kaufmann	264—8
3,196,007	7/1965	Wikle	29—182 X
3,325,257	6/1967	Ang	75—150

CARL D. QUARFORTH, Primary Examiner

A. J. STEINER, Assistant Examiner

U.S. Cl. X.R.

29—182.2, 420.5; 75—226