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ALUMINUM-BASE ALLOY

Louis A. Conant, Tonawanda, N.Y., assignor to Union Carbide Corporation, a corporation of New York

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This invention relates to low density alloys having a high modulus of elasticity and, more particularly, to an aluminum-base alloy and a method of producing said alloy.

Aluminum alloys and other low density alloys have been the chief structural materials for applications requiring high strength-to-weight ratios in their construction materials. This has been especially the case in the aircraft industry where designers are now faced with the added problem of providing light-weight structural materials capable of withstanding the higher stresses associated with today's high speed aircraft and missiles.

In the selection of structural materials, however, other factors than strength-to-weight ratios must be considered. For example, the resistance to elastic deformation of the structural material must be considered. The resistance of a material to elastic deformation is known as stiffness and represents the extent of the elastic deformations or deflections which take place under given stresses. The most desirable structural material should not only be capable of withstanding high stresses, but should also exhibit relatively little deformation under these stresses. This resistance to elastic deformations is measured by the value of the modulus of elasticity of the material and is a separate function of the yield point or ultimate strength of the material. The actual deformations or deflections produced in stressed member depend on the modulus of elasticity of the material and the geometry of the member. It is often necessary, especially in structures made of aluminum, to design the members on the basis of their stiffness rather than on their strength. Many members are designed with larger cross-sections than are required to carry the given stresses because the larger cross-section is needed to give the structure the required stiffness. Because many low-density alloys, such as aluminum alloys, have a comparatively low-modulus of elasticity, the savings in weight that could be realized by the use of these materials is often offset by the need to design and use larger sections to provide the necessary stiffness.

The modulus of elasticity of pure aluminum is about 10×10^6 pounds per square inch while the modulus of elasticity of steel is about 30×10^6 pounds per square inch. Considerable effort has been spent in attempting to achieve a low density alloy having a high modulus of elasticity by incorporating in the metal a second phase material with an intrinsic modulus higher than that of any intermetallic compound that might be produced by the usual alloying elements. Intermetallic and refractory compounds such as titanium carbide, silicon carbide, and boron carbide, have been added to aluminum to increase the modulus of elasticity but the degree of improvement has not amounted to more than 28 percent.

Another factor to be considered in the selection of structural materials is the coefficient of expansion of the material. An excessively high rate of expansion can limit the usefulness of the material and a low coefficient of expansion is therefore desirable. Unfortunately many low-density alloys have high coefficients of expansion.

It is the primary object of this invention, therefore, to provide an aluminum-base alloy having a higher modulus of elasticity than pure aluminum and heretofore produced aluminum-base alloys.

It is also an object of this invention to provide an aluminum-base alloy having a high ratio of modulus of elasticity-to-density.

It is a further object of this invention to provide an aluminum-base alloy having a lower coefficient of expansion than pure aluminum and many heretofore produced aluminum alloys.

It is also an object of this invention to provide an aluminum alloy having a high strength-to-density ratio and which is suitable for use in applications requiring high wear resistance.

It is a further object of this invention to provide a method for producing the aluminum-base alloy described herein.

Other aims and objects of this invention will be apparent from the following description and appended claims.

In accordance with these objects a method for producing a high modulus aluminum-base alloy is provided which comprises dispersing finely divided particles of a refractory metal boride in an aluminum matrix. The process of the invention comprises preparing a mixture consisting essentially of from about 5 to about 50 volume percent of particles of borides of at least one metal selected from the group consisting of titanium, chromium, zirconium, tantalum, columbium, hafnium, vanadium and molybdenum, and the balance powdered aluminum material selected from the group consisting of aluminum and aluminum alloys, compacting the resulting mixture into a coherent slug, heating the resulting slug in the absence of air to a temperature at which the powdered aluminum material melts without substantial vaporization and below the melting point of the metal borides, and allowing the slug to cool. In a preferred embodiment the slug is cooled to a temperature below the freezing point of the aluminum material and worked into a desired shape by rolling, extrusion, forging, etc.

In the practice of the process of this invention an alloy is produced consisting essentially of from about 5 to about 50 volume percent of particles of borides of at least one metal selected from the group consisting of titanium, chromium, zirconium, tantalum, columbium, hafnium, vanadium and molybdenum, and the balance substantially all of a metal selected from the group consisting of aluminum and aluminum alloys, said particles of metal borides being dispersed in a continuous matrix of the selected metal.

Specifically an alloy is provided consisting essentially of from about 5 to 50 volume percent of titanium diboride dispersed in a continuous matrix of aluminum or an aluminum-base alloy.

A summary of the properties of the alloy of this invention, as compared to the properties of representative aluminum alloys, is presented in Table I. As may be seen from the table, the specific modulus, or ratio of modulus of elasticity-to-density, of the alloy of the invention, containing as little as 10 percent by volume of a dispersed phase of titanium diboride is increased by more than 15 percent. The resulting modulus of elasticity of this alloy is greater than that of some of the best commercial aluminum alloys as listed in Table I. When the amount of the dispersed titanium diboride phase is increased to 45 percent by volume of the alloy, the increase in specific modulus over the best commercial aluminum alloy is nearly 79 per cent.

The commercial aluminum alloys referred to in Table I have the following compositions. Alloy I is a sintered aluminum product containing 8 percent Al_2O_3; alloy II contains 6.0 percent copper, 0.3 percent manganese, 0.11 percent vanadium, and 0.15 percent zirconium; alloy III contains 4.5 percent copper, 1.5 percent magnesium, and 0.6 percent manganese; alloy IV contains 12.2 percent silicon, 0.9 percent copper, 1.1 percent magneisum, and

0.9 percent nickel; alloy V contains 6.3 percent silicon, and 3.5 percent copper.

TABLE I

	10 vol. percent TiB_2, 16 weight percent TiB_2	20 TiB_2-Al, 29 weight percent TiB_2	30 TiB_2-Al, 42 weight percent TiB_2	40 TiB_2-Al, 52 weight percent TiB_2	45 vol. percent TiB_2, 57 weight percent TiB_2	Alloy I	Alloy II	Alloy III	Alloy IV	Alloy V
Tensile Strength:										
Ultimate, 75° F	18,500	25,000	33,000	45,000	56,000	37,000	62,000	68,000	55,000	36,000
Yield, 75° F	13,500	13,000	18,500	27,000	37,000	24,000	43,000	47,000	46,000	24,000
Ultimate, 750° F	5,000	4,000	6,100	8,700	12,000	13,000	5,000	[1] 5,000	[1] 3,500	
Yield, 750° F			4,800	6,200	7,500	11,000	4,500	[1] 3,500	[1] 2,000	
Elongation, percent in 1.0 in.:										
75° F	15.0	24.0	16.0	6.0	2.0	17.0	15.0	19.0	9.0	2.0
750° F	30.0	48.0	27.0	14.0	8.0	5.0	65.0	[1] 100.0	[1] 90.0	
Reduction area, percent:										
75° F	31.0	45.0	22.0	7.0	4.0					
750° F	45.0	68.0	38.0	14.0	11.0					
Modulus of elasticity p.s.i. x 10^6		[2] 16.1	[3] 18.4	[3] 20.0	[2] 26.5	10.6	10.5	10.6	11.4	10.3
75° F	[2] 13.5	[3] 16.3	[2] 20.0	[2] 22.5	26.3					
750° F			[3] 12.8	[3] 17.66		6.6				
Density g./cc. (calc. mech. mixture)	2.88	3.06	3.24	3.42	3.5	2.74	2.82	2.77	2.69	2.79
Specific modulus (mod. of elas./density)	4.7	5.3	5.9	6.3	7.5	3.9	3.7	3.8	4.2	3.7
Thermal coefficient of linear expansion ° C. x 10^{-6}, 20-100° C		16.25	15.96	13.97	11.97	[4] 23.0	[4] 22.0	22.8	19.4	22.0
Condition	[5]	[6]	[7]	[7]	[7]	[7]	[7]	[8]	[9]	[10]

[1] Test conducted at 700° F. [2] Huggenberg extensometer. [3] Sonic test. [4] Approximately. [5] Cast forged rolled.
[6] As extruded, does not require heat treatment. [7] As extruded. [8] Solution heat treated and aged.
[9] Forged Solution heat treated and aged. [10] Cast solution heat treated and aged.

The data presented in the table shows that by varying the amount of titanium diboride phase present in the matrix, a series of materials of different properties can be obtained. It is to be noted that the modulus of elasticity of a 30 volume percent titanium diboride-aluminum alloy is almost double that of pure aluminum and that the modulus of a 45 volume percent titanium diboride-aluminum alloy approaches the value of the modulus of elasticity of steel. It is also to be noted that the strength of the 40 to 45 volume percent titanium diboride-aluminum alloy compares favorably with such commercial alloys as alloy I (containing 8 percent by weight Al_2O_3 powder) and alloy II (6 percent copper, 0.3 percent manganese, 0.11 percent vanadium, and 0.15 percent zirconium). It has also been found that when titanium diboride or other metal borides are dispersed in high-strength commercial aluminum alloys such as those listed in Table I, a superior high-modulus alloy results.

Another feature of the alloy of this invention is its low coefficient of linear expansion in comparison with commercial aluminum alloys and carbon steels. The coefficients of linear thermal expansion for several materials are presented in Table II. A 45 volume percent titanium diboride-aluminum alloy has a coefficient about equal to that of carbon steel and only one half the normal coefficient of expansion of pure aluminum.

TABLE II

Material	Coefficient of expansion per degree C.	
	20°–100° C. x 10^6	20°–427° C. x 10^6
20 vol. percent TiB_2-Al	16.25	18.12
30 vol. percent TiB_2-Al	15.96	17.64
35 vol. percent TiB_2-Al	14.68	16.85
40 vol. percent TiB_2-Al	13.97	14.47
45 vol. percent TiB_2-Al	11.97	14.41
Aluminum-powder extruded	24.48	26.84
Alloy I	[1] 23.0	
Alloy II	[1] 22.0	
Alloy III	22.8	
Alloy IV	19.4	
Carbon steels	12.6	[2] 14.2

[1] Approximately. [2] 20°–500° C.

The alloys of this invention do not require further heat treatments to achieve their full properties. The alloys can also be easily fabricated and possess a ductility ranging from good to high.

The alloys of this invention have utility as heavy-duty bearing materials and wear-resistant materials, especially at elevated temperatures. A particular use for this alloy is to be found in pistons in engines. Since the titanium diboride-aluminum alloys can be readily welded and since they have the high elastic modulus required for thin stiff sections, and possess a low coefficient of expansion, they are suitable for use as a material of construction in cryogenic apparatus and containers. The usefulness of the alloys of this invention is further enhanced by their similarity to steels, especially with regard to the important properties of modulus of elasticity and coefficient of thermal expansion. This invention provides a light-weight structural alloy which is mechanically compatible with steel enabling both to be employed cooperatively in a wide variety of applications which previously were not possible.

The production of alloys having a high elastic modulus-to-density ratio is accomplished by dispersing finely divided particles of a metal boride in a low melting, ductile, light metal matrix such as an aluminum matrix. In order to assure that the desired effect is permanent, it is necessary that the constituents be mutually nonreactive and insoluble in each other. It has been found that, besides titanium diboride, zirconium and chromium diboride are also unreactive and insoluble in aluminum. The diborides of tantalum, columbium, hafnium, vanadium and molybdenum are all relatively insoluble and nonreactive in aluminum.

The dispersed phase must be not only unreactive and insoluble in the matrix, but it must also be subject to an intimate bond with the matrix under the varying temperature and pressure conditions of the metalworking operation. These conditions are particularly well met by the combination of a titanium diboride phase dispersed in an aluminum or aluminum alloy matrix. The aluminum completely wets the titanium diboride and yet shows no tendency to react chemically with it. For example, when titanium diboride is contacted with molten aluminum at 2462° F., an X-ray analysis reveals no evidence of reaction between the two. The unique character of the mixture is further illustrated by the fact that when an unsupported slug of the compacted powders, in which the low melting aluminum matrix occupies as much as 90 percent of the volume, is heated above the melting point of the aluminum, and maintained in that condition, the slug, although apparently molten, retains its original shape and does not slump into a formless pool of molten aluminum. This effect, believed to be caused by a strong tendency of the aluminum to wet the diboride phase, is also believed to be responsible for the excellent degree of dispersion of the diboride particles in the aluminum

matrix. Since heating is carried out in a vacuum or inert atmosphere, the fact that no gross melting occurs cannot be attributed to the presence of oxide or oxide coating acting as a skin to hold the shape of the article.

Melting or foundry techniques have also been used to prepare dispersions of titanium diboride in aluminum or aluminum alloys. This method is particularly advantageous in the preparation of materials with lower percentages of metal borides—up to about 20 percent by volume. Ten and fifteen percent by volume titanium diboride dispersions in aluminum have been prepared by melting ingot aluminum together with a titanium diboride powder at a temperature of about 1200° C. in a vacuum or argon atmosphere. The molten material was then poured into a steel mold to form an ingot 1¾ by 3 inches.

It has been found that the addition of about 2 percent by volume of misch metal to such a molten bath of aluminum and titanium diboride greatly aids in the suspension and dispersion of the titanium diboride. Misch metal is a combination of rare earth metals consisting primarily of cerium and lanthanum. The misch metal may increase the fluidity of the molten aluminum.

The most uniform dispersions of the titanium diboride phase in an aluminum matrix have been obtained by the use of a new technique combining compaction and controlled melting.

In this process, the powders of the diboride and the aluminum material are dry blended and cold compacted at a pressure of from about 30,000 to about 50,000 pounds per square inch into a slug of convenient dimensions. The powders of titanium diboride have an average size between 1.0 and 0.01 micron or finer. However the particle size may range up to 10 microns. The aluminum material may be powdered or atomized aluminum. Atomized aluminum is the powder produced by spraying molten aluminum and cooling it rapidly to form a powder. The slug is heated, in a vacuum or in an inert atmosphere, to between 1000 and 1150° C., which is far in excess of the melting point of aluminum (660° C.). Gross melting does not occur, probably as the result of capillarity due to the wetting of the titanium diboride particles by the molten aluminum.

While ordinary powder metallurgical techniques, such as cold pressing and sintering, or hot pressing can be used to produce articles of this alloy they do not produce the same superior alloy product as the compaction-controlled melting technique described herein. Although to all outward appearances the constitution of the alloy is the same, the two products have different properties. When identical mixtures of titanium diboride and aluminum powders are subjected to the same fabricating procedures, except that hot pressing is substituted for the compaction-controlled melting technique, the modulus of elasticity of the products differ. The sintered or hot pressed product has a modulus of only about 13×10^6 pounds per square inch while the product produced by the process of this invention has a modulus of about 16×10^6 pounds per square inch.

Since a dense, strong material is produced after the firing operation, it is practical to use the product in the as-fired condition, or to fabricate the as-fired composition by rolling, forging or swaging without the necessity of first extruding the product. This is in contrast to the present practice of forming aluminum materials by powder metallurgical techniques which requires an extrusion step following the compaction of the powder in order to densify the material.

The as-fired compact or ingot can also be directly rolled or worked by forging to produce a variety of articles. For example, hot-rolled sheet of 0.030 inch thickness has been produced from a composition containing 25 volume percent titanium diboride. This sheet was then further reduced to 0.005 inch thickness by cold-rolling.

When the fired product is extruded, it can be fabricated into useful shapes by conventional working techniques.

The alloy of this invention can be readily welded. During the welding operation the melted portion of the article does not lose its dispersed phase as do many other aluminum materials produced by powder metallurgical techniques. After the alloy of this invention is welded, the dispersion of titanium diboride is the same in the heated zone as it is in the unheated zone.

It is also possible to "weld" or "heat" small cracks or other imperfections by heating the titanium diboride-aluminum material above its melting point.

The following examples are presented to illustrate the practice of the invention.

Example I

Fifty two percent by weight (40 volume percent) of dry, finely divided titanium diboride was blended with 48 percent by weight (60 volume percent) of "atomized" aluminum, and the mixture was cold compacted at 30,000 p.s.i. into 1 7/16-inch diameter slugs approximately 2½ inches long. A slug was heated under vacuum conditions to 1150° C., or approximately 472° C. above the melting point of the aluminum, and held there for about 15 minutes. Gross melting did not occur but rather the slug retained its shape while the molten aluminum flowed completely in and around each particle of titanium diboride producing thereby the desired dispersion. After this heat treatment, the slug was cooled below the point at which the aluminum solidified, and removed to an extrusion press where it was reduced from a 1 7/16-inch ingot to a rod ⅜ inch in diameter, or a 16:1 reduction in area, by the application of about 30,000 p.s.i. The density of the rod in the as-extruded condition was about 3.42 g./cc. and it exhibited a Young's modulus of elasticity at 75° F. of about 22.5×10^6 p.s.i. as determined by a Huggenberg Extensometer. The coefficient of linear expansion in the range of 20° to 100° C. was found to be 13.97×10^{-6}. These and other properties are contained in Table I.

Example II

Sixteen percent by weight (10 volume percent) of finely divided titanium diboride was dry blended with 84 percent by weight (90 volume percent) of "atomized" aluminum and 2 percent by weight "misch metal." The mixture was melted in an Al_2O_3 crucible at 2336° F. and 200 microns pressure. The melt was then cast into a steel mold, forming an ingot 1¾ inches in diameter by 2¼ inches long. The ingot was hot forged and rolled at 900° F. into a cylindrical rod ⅝ inch in diameter. Specimens were cut from the rod and subjected to physical property tests. The results of these tests are given in Table I.

Example III

The general procedure of Example I was employed except as follows. A commercial aluminum alloy containing 94.5 percent aluminum, 4.5 percent magnesium, and 0.75 percent manganese was used as the base material. Two compositions of this alloy with titanium diboride additions were prepared. Composition A contained 23.3 percent by weight titanium diboride (15 percent by volume), 72.5 percent by weight aluminum, 3.5 percent by weight magnesium, and 0.7 percent by weight manganese. Composition B contained 36.2 percent by weight titanium diboride (25 percent by volume), 60.2 percent by weight aluminum, 3.0 percent by weight magnesium, and 0.6 percent by weight manganese. These compositions were heated at a temperature of 900° C.

The strength properties of these compositions are shown in Table III. Specimens of the composition were tested in the as-extruded condition as well as the extruded and swaged condition. Also presented in the table are the published strength values of the commercial alloy base material and the values for two aluminum-titanium

diboride alloys—a 20% volume titanium diboride-aluminum alloy and a 30% volume titanium diboride-aluminum alloy. It can be seen that the swaging produces a strain-hardened condition that significantly increases the yield strength and to a lesser extent the ultimate strength. The ductility as measured by the elongation in the swaged samples has decreased, but ductility measured by contraction, or reduction in area has remained unchanged or, in some cases, increased.

Other physical properties are presented in Table III*a*.

group consisting of titanium, chromium, zirconium, tantalum, columbium, hafnium, vanadium and molybdenum, and the balance at least one powdered aluminum material selected from the group consisting of aluminum and aluminum alloys, compacting the resulting mixture into a coherent slug, heating the resulting slug in the absence of air at a temperature at which the aluminum material melts without substantial vaporization and below the melting temperature of the metal borides, cooling the slug to a temperature below the freezing temperature of

TABLE III

STRENGTH PROPERTIES OF TITANIUM DIBORIDE-ALUMINUM MATERIALS

Composition	Condition	Tensile Strength						Percent elongation	Percent reduction in area
		75° F. temperature		Percent elongation	Percent reduction in area	750° F. temperature			
		Yield	Ultimate			Yield	Ultimate		
Commercial alloy	Strain hardened	33,000	46,000	16	(1)	4,000		130	
Composition A	As extruded	28,500	48,300	8	10	5,000		23	26
Do	Extruded and swaged	56,300	63,800	2.5					
Composition B	As extruded	36,000	60,000	6	8	5,200		16	15
Do	Extruded and swaged	52,000	63,000	2.0	15.5				
20% vol. TiB and aluminum alloy	As extruded	13,000	25,000	24	45	4,000		48	68
Do	Extruded and swaged	23,500	28,000	12	43				
30% vol. TiB and aluminum alloy	Extruded	18,500	33,000	16	22	4,800	6,000	27	38
Do	Extruded and swaged	35,000	36,500	5	23				

[1] Not tested.

TABLE III*a*

PHYSICAL PROPERTIES OF TITANIUM DIBORIDE-ALUMINUM MATERIALS

Composition	Modulus of elasticity p.s.i. x 10^6	Density 9/cc.	Specific modulus, modulus/density	Thermal coefficient of expansion ° C. x 10^6		
				RT to 100° C.	RT to 300° C.	RT to 482° C.
Commercial alloy	10.3	2.64	3.9	24	26	(1)
Composition A	16.0	2.92	5.5	17.7		21.6
Composition B	19	3.1	6.1	16.1		18.3
20% vol. TiB and aluminum alloy	16.0	3.06	5.3	16.25		18.32
30% vol. TiB and aluminum alloy	19.0	3.24	5.9	15.9		17.8

[1] Not tested.

Example IV

In general, the procedure of Example I was followed except that 37.13 parts by weight (30 volume percent) of chromium diboride powder was blended with 41.87 parts by weight (70 volume percent) of "atomized" aluminum. Results are given in Table IV below for room temperature conditions.

TABLE IV

Yield strength, p.s.i.	Ultimate strength p.s.i.	Elongation, percent	Reduction area, percent	Modulus of elasticity, p.s.i. x 10^6
23,100	34,600	1.5	2.2	17.7

What is claimed is:

1. The method of preparing an aluminum-base alloy product characterized by an increased modulus of elasticity and a decreased coefficient of thermal expansion which comprises preparing a mixture consisting essentially of from about 5 to about 50 volume percent of particles of borides of at least one metal selected from the group consisting of titanium, chromium, zirconium, tantalum, columbium, hafnium, vanadium and molybdenum, and the balance at least one powdered aluminum material selected from the group consisting of aluminum and aluminum alloys, compacting the resulting mixture into a coherent slug, heating the resulting slug in the absence of air at a temperature at which the aluminum material melts without substantial vaporization and below the melting temperature of the metal borides, cooling the slug to a temperature below the freezing temperature of the selected aluminum material, and forming the slug into a desired shape.

2. The method of preparing an aluminum-base alloy product characterized by an increased modulus of elasticity and a decreased coefficient of thermal expansion which comprises preparing a mixture consisting essentially of from about 5 to about 50 volume percent of particles of borides of at least one metal selected from the group consisting of titanium, chromium, zirconium, tantalum, columbium, hafnium, vanadium and molybdenum, and the balance at least one powdered aluminum material selected from the group consisting of aluminum and aluminum alloys, compacting the resulting mixture into a coherent slug having a desired shape, heating the resulting slug in the absence of air at a temperature at which the aluminum material melts without substantial vaporization and below the melting temperature of the metal borides, and cooling the slug.

3. The method of preparing an aluminum-base alloy product characterized by an increased modulus of elasticity and a decreased coefficient of thermal expansion which comprises preparing a mixture consisting essentially of from about 5 to about 50 volume percent of particles of borides of at least one metal selected from the group consisting of titanium, chromium, zirconium, tantalum, columbium, hafnium, vanadium and molybdenum, and the balance at least one powdered aluminum material selected from the group consisting of aluminum and aluminum alloys, compacting the resulting mixture at a pressure of from about 30,00 to 50,000 pounds per square inch into a slug having a desired shape, heating the resulting slug in the absence of air at a temperature between the melting temperature of the selected aluminum material and about 1350° C., and cooling the slug.

4. The method of preparing an aluminum-base alloy product characterized by an increased modulus of elasticity and a decreased coefficient of thermal expansion which comprises preparing a mixture consisting essentially of from about 5 to about 50 volume percent of particles of borides of at least one metal selected from the group consisting of titanium, chromium, zirconium, tantalum, columbium, hafnium, vanadium and molybde-

num, said particles having an average size up to about 10 microns, and the balance at least one powdered aluminum material selected from the group consisting of aluminum and aluminum alloys, compacting the resulting mixture at a pressure of from about 30,000 to 50,000 pounds per square inch into a slug, heating the resulting slug in the absence of air at a temperature between the melting temperature of the selected aluminum material and about 1350° C., cooling the slug to a temperature below the freezing temperature of the selected aluminum material, and forming the slug into a desired shape.

5. The method of preparing an aluminum-base alloy product characterized by an increased modulus of elasticity and a decreased coefficient of thermal expansion which comprises preparing a mixture consisting essentially of from about 5 to about 50 volume percent of particles of borides of at least one metal selected from the group consisting of titanium, chromium, zirconium, tantalum, columbium, hafnium, vanadium and molybdenum, and the balance at least one powdered aluminum material selected from the group consisting of aluminum and aluminum alloys, compacting the resulting mixture at a pressure of from about 30,000 to 50,000 pounds per square inch into a slug, heating the resulting slug in the absence of air at a temperature between the melting temperature of the selected aluminum material and 1150° C., cooling the slug to a temperature below the freezing temperature of the selected aluminum material, and forming the slug into a desired shape.

6. The method of preparing an aluminum-base alloy product characterized by an increased modulus of elasticity and a decreased coefficient of thermal expansion which comprises preparing a mixture consisting essentially of from about 5 to about 50 volume percent of particles of titanium diboride, and the balance substantially all powdered aluminum, compacting the resulting mixture into a coherent slug, heating the resulting slug in the absence of air at a temperature at which the aluminum melts without substantial vaporization and below the melting temperature of the metal borides, cooling the slug to a temperature below the freezing temperature of the aluminum, and forming the slug into a desired shape.

7. The method of preparing an aluminum-base alloy product characterized by an increased modulus of elasticity and a decreased coefficient of thermal expansion which comprises preparing a mixture consisting essentially of from about 5 to about 50 volume percent of particles of titanium diboride, and the balance substantially all powdered aluminum, compacting the resulting mixture into a coherent slug having a desired shape, heating the resulting slug in the absence of air at a temperature at which the aluminum melts without substantial vaporization and below the melting temperature of the metal boride for at least a time sufficient for the aluminum to melt, and cooling the slug.

8. The method of preparing an aluminum-base alloy product characterized by an increased modulus of elasticity and a decreased coefficient of thermal expansion which comprises dry blending a mixture consisting essentially of from about 5 to about 50 volume percent of particles of titanium diboride, and the balance substantially all powdered aluminum, compacting the resulting mixture at a pressure of from about 30,000 to about 50,000 pounds per square inch into a slug having a desired shape, heating the resulting slug in the absence of air at a temperature between about 660° C. and 1150° C., and cooling the slug.

9. The method of preparing an aluminum-base alloy product characterized by an increased modulus of elasticity and a decreased modulus of thermal expansion which comprises preparing a mixture consisting essentially of from about 5 to about 50 volume percent of particles of titanium diboride having an average size up to about 10 microns, and the balance substantially all atomized aluminum, compacting the resulting mixture at a pressure of from about 30,000 to about 50,000 pounds per square inch inch into a slug, heating the resulting slug in the absence of air at a temperature between the melting temperature of the aluminum and 1350° C., cooling the slug to a temperature below the freezing temperature of the aluminum, and forming the slug into a desired shape.

10. The method of preparing an aluminum-base alloy product characterized by an increased modulus of elasticity and a decreased modulus of thermal expansion which comprises preparing a mixture consisting essentially of from about 5 to about 50 volume percent of particles of titanium diboride having an average size up to about 10 microns, and the balance substantially all atomized aluminum, compacting the resulting mixture at a pressure of from about 30,000 to about 50,000 pounds per square inch into a slug, heating the resulting slug in the absence of air at a temperature between about 660° C. and 1150° C., cooling the slug to a temperature below the freezing temperature of the aluminum, and forming the slug into a desired shape.

11. The method of preparing an aluminum-base alloy product, characterized by an increased modulus of elasticity and a decreased coefficient of thermal expansion which comprises preparing a mixture consisting essentially of from about 5 to about 50 volume persent of particles of borides of at least one metal selected from the group consisting of titanium, chromium, zirconium, tantalum, columbium, hafnium, vanadium, and molybdenum, and the balance at least one powdered aluminum material selected from the group consisting of aluminum and aluminum alloys, melting the resulting mixture in the absence of air, and casting the molten alloy into a desired shape.

12. The method of preparing an aluminum-base alloy product characterized by an increased modulus of elasticity and a decreased modulus of thermal expansion which comprises preparing a mixture consisting essentially of from about 5 to about 50 volume percent of particles of titanium diboride, and the balance substantially all powdered aluminum, melting the resulting mixture in the absence of air, and casting the molten alloy into a desired shape.

13. The method of preparing an aluminum-base alloy product characterized by an increased modulus of elasticity and a decreased modulus of thermal expansion which comprises preparing a mixture consisting essentially of from about 5 to about 50 volume percent of particles of titanium diboride, and the balance substantially all powdered aluminum, melting the resulting mixture in the absence of air, casting the molten alloy into an ingot, and forming the ingot into a desired shape.

14. The method in accordance with claim 13 wherein the ingot is formed by extrusion.

15. A fused alloy product produced by preparing a mixture consisting essentially of from 5 to 50 volume percent of particles of borides of at least one metal selected from the group consisting of titanium, chromium, zirconium, tantalum, columbium, hafnium, vanadium, and molybdenum, and the balance at least one powdered aluminum material selected from the group consisting of aluminum and aluminum alloys, compacting the resulting mixture into a coherent slug, heating the resulting slug in the absence of air at a temperature at which the aluminum material melts without substantial vaporization and below the melting temperature of the metal borides, and cooling the slug to a temperature below the freezing temperature of the selected aluminum material.

16. The fused alloy product produced in accordance with claim 15 in which the selected boride is titanium diboride.

(References on following page)

References Cited in the file of this patent

UNITED STATES PATENTS

2,578,098	Southard	Dec. 11, 1951
2,783,530	Conant	Mar. 5, 1957
2,802,748	Glaser	Aug. 13, 1957
2,823,988	Grant	Feb. 18, 1958
2,840,891	Nachtman	July 1, 1958

2,852,367	Goetzel et al.	Sept. 16, 1958
2,913,312	Dubeck	Nov. 17, 1959

OTHER REFERENCES

Metal Powder Report, vol. 11–12 (September 1956-August 1958), pp. 144 and 145.

The Iron Age, Jan. 20, 1949, pp. 66–70.

Journal of Metals, March 1959, pp. 189–194.