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MAGNESIUM-BASED ALLOYS

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7 Claims. (Cl. 75—168)

This application is a division of U.S. application Serial No. 78,849, filed December 28, 1960.

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

Magnesium 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 and other transportation vehicles and additionally in many consumer items such as household goods, office equipment, instruments and sporting goods.

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 members depend on the modulus of elasticity of the material and the geometry of the member. It is often necessary, especially in structures made of magnesium, to design the members on the basis of their stiffness rather than on their strength. Many members are designated 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 materials, such as magnesium and its 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 magnesium is about 6.5×10^6 pounds per square inch while the modulus of elasticity of steel is about 30×10^6 pounds per square inch. It is easily seen how important a factor the low modulus of magnesium has been in preventing the full employment of this metal's valuable properties.

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 a magnesium-base alloy having a higher modulus of elasticity than pure magnesium and heretofore produced magnesium-base alloys.

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

It is a further object of this invention to provide a magnesium-base alloy having a lower coefficient of expansion

than pure magnesium and many heretofore produced magnesium alloys.

It is a further object of this invention to provide a method for producing the magnesium-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 magnesium-base alloy is provided which comprises dispersing finely divided particles of a refractory metal boride in a magnesium matrix. The process of the invention comprises preparing a mixture consisting essentially of from about 10 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 magnesium material selected from the group consisting of magnesium and magnesium-base alloys, compacting the resulting mixture into a coherent slug, heating the resulting slug in the absence of air to a temperature at which the magnesium 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 magnesium material and worked into a desired shape.

In the practice of the process of this invention an alloy is produced consisting essentially of from about 10 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 magnesium and magnesium alloys, said particles of metal borides being dispersed in a continuous matrix of the magnesium material.

Specifically an alloy is provided consisting essentially of from about 10 to 50 volume percent of titanium diboride dispersed in a continuous matrix of magnesium or a magnesium-base alloy.

A particularly useful matrix material is a magnesium-aluminum alloy consisting of about 5 percent by weight aluminum and the balance magnesium. This alloy was used as the matrix material in most of the examples following. In making the alloys of this invention the magnesium-base alloy used as the matrix material is reported on the basis of its constituents by weight percent while the amount of borides making up the dispersed phase is reported in volume percents. The magnesium material is reported in weight percents because this is the common method of reporting such alloys. However, to more clearly define the invention the amount of borides dispersed in the matrix is defined in volume percents because the volume percent actually suggests the amount of dispersed phase in a cross-section of the matrix. Since the densities of the borides and the matrix of materials differ, it would not be suggestive of the true amount of dispersed phase present if it were reported in weight percents.

A summary of the properties of the alloy of this invention, as compared to the properties of a commercial magnesium alloy is presented in Table 1. 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 in a magnesium-5 percent aluminum alloy is increased by more than 13 percent. The resulting modulus of elasticity of this alloy is greater than that of one of the best commercial magnesium alloys as listed in Table 1. When the amount of the dispersed titanium diboride phase is increased to

40 percent by volume of the alloy, the increase in specific modulus over the best commercial aluminum alloy is nearly 72 percent.

The commercial aluminum alloy referred to in Table 1 has the following compositions: 8.5 percent aluminum, 0.5 percent zinc, 0.15 percent manganese and the balance magnesium.

ally nonreactive and insoluble in each other. The diborides of tantalum, zirconium, chromium, columbium, hafnium, vanadium and molybdenum are all relatively insoluble and nonreactive in magnesium materials.

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 tem-

TABLE I

	10 vol. percent TiB ₂ in Magnesium—5 weight percent aluminum alloy	20 vol. percent TiB ₂ in Magnesium—5 weight percent aluminum alloy	40 vol. percent TiB ₂ in Magnesium—5 weight percent aluminum alloy	Commercial alloy
Tensile Strength: Ultimate 75° F	47,200	55,000	44,425	53,000
Yield 75° F		41,000		40,000
Tensile Strength: Ultimate 750° F	3,090	3,550	3,600	
Yield 750° F	2,810	3,000		
Elongation, percent in 1.0 in.—75° F	7.5	5		7
750° F	11	12	3.7	
Reduction Area, Percent—75° F	5.4	4.5		
750° F	17.6	8.5	3.9	
Modulus of Elasticity p.s.i. × 10 ⁶ , 75° F	8.3	11	17.6	6.5
Density g./cc.	2.02	2.3	2.85	1.8
Specific Modulus (Mod. of Elas./Density)	4.11	4.7	6.17	3.6
Thermal Coefficient of Linear Expansion ° C. × 10 ⁻⁴ , 24–427° C.	28.32	21.32	19.59	29.8
Condition	As Extruded	As Extruded	As Extruded	

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. Significant improvements in properties can be achieved with as little as 5 volume percent of titanium diboride dispersed in aluminum metal, and compositions containing as high as 50 volume percent titanium diboride show an increase in elastic modulus. It is to be noted that the modulus of elasticity of a 20 volume percent titanium diboride magnesium alloy is almost double that of pure magnesium. It is also to be noted that the strength of the 20 volume percent titanium diboride-aluminum alloy compares favorably with the commercial alloy. It has also been found that when titanium diboride or other metal borides are dispersed in high-strength commercial magnesium alloys such as that 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 magnesium alloys. The coefficients of linear thermal expansion for several materials are presented in Table II. A 40 volume percent titanium diboride-magnesium alloy has a coefficient nearer that of carbon steel and only about two-thirds the normal coefficient of expansion of pure magnesium.

TABLE II

Material:	Coefficient of expansion per ° C., 20°–427° C., ×10 ⁶
10 vol. percent TiB ₂ in magnesium—5% Al alloy	28.32
20 vol. percent TiB ₂ in magnesium—5% Al alloy	21.32
40 vol. percent TiB ₂ in magnesium—5% Al alloy	19.59
Commercial alloy	29.8
Pure magnesium	29
Steel	13

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 a magnesium material matrix. In order to assure that the desired effect is permanent, it is necessary that the constituents be mutu-

perature and pressure conditions of the metalworking operation. These conditions are particularly well met by the combination of a titanium diboride phase dispersed in a magnesium or magnesium alloy matrix. The magnesium material completely wets the titanium diboride and yet shows no tendency to react chemically with it. 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 magnesium matrix occupies as much as 40 percent of the volume, is heated above the melting point of the magnesium, and maintained in that condition, the slug, although apparently molten, retains its original shape and does not slump into a formless pool of molten magnesium. This effect, believed to be caused by a strong tendency of the magnesium to wet the diboride phase, is also believed to be responsible for the excellent degree of dispersion of the diboride particles in the magnesium 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.

The most uniform dispersions of the titanium diboride phase in a magnesium 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 magnesium 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 magnesium material may be powdered or atomized magnesium. Atomized magnesium is the powder produced by spraying molten magnesium and cooling it rapidly to form a powder. The slug is heated, in a vacuum or in an inert atmosphere, to about 800° C. which is about 225° C. in excess of the melting point of magnesium. Gross melting does not occur, probably as the result of capillarity due to the wetting of the titanium diboride particles by the molten magnesium material.

While ordinary powder metallurgical techniques, such as cold pressing and sintering, or hot pressing can be

5

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. Were identical mixtures of titanium diboride and magnesium powders to be 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 would differ. The sintered or hot pressed product would have a modulus much less than that of the product produced by the process of this invention.

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.

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

The following example is presented to illustrate the practice of the invention.

Example

Thirty-nine percent by weight (20 volume percent) of dry, finely divided titanium diboride was blended with 61 percent by weight (80 volume percent) of a mixture containing 5 percent by weight of "atomized" aluminum and the balance "atomized" magnesium and the mixture was cold compacted at 40,000 p.s.i. into 1 and 1/2 inch diameter slug approximately 2 inches long. The slug was heated under vacuum conditions to 800° C. and held there for about 15 minutes. Gross melting did not occur but rather the slug retained its shape while the molten magnesium-aluminum alloy 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 magnesium-aluminum alloy solidified, and removed to an extrusion press where it was reduced from a 1 and 1/2 inch ingot to a rod 3/8 inch in diameter by the application of about 60,000 p.s.i. The density of the rod in the as-extruded condition was about 2.3 g./cc. and it exhibited a Young's modulus of elasticity at 75° F. of about 11×10^6 p.s.i. as determined sonic means. The coefficient of linear expansion in the range of 20° to 427° C. was found to be 21.32×10^{-6} . These and other properties are contained in Table I. The other alloys noted in Table I were made in the same manner as above.

In another example 52.5 percent by weight titanium diboride (30 volume percent) was mixed with 47.5 percent by weight powdered magnesium metal (70 volume percent). This mixture was cold compacted into a coherent slug. The slug was heated under vacuum conditions at about 770° C. There was no gross melting but rather the magnesium metal melted and flowed around the diboride particles to form the desired matrix. The fired slug was then extruded into a desired shape at around 480° C.

It is to be noted that while the description of the invention has been in terms of magnesium and magnesium-

6

aluminum alloys as matrix materials, that other magnesium materials such as any of the many commercial magnesium-base alloys are included. It is only necessary that the magnesium-base alloy used be low melting, ductile and light weight and that it be mutually non-reactive and insoluble with the borides used in the dispersed phase and that the magnesium-base alloy have the property of flowing around and wetting the dispersed particles when the compacted slug of these materials are heated above the melting point of the magnesium-base alloy.

What is claimed is.

1. A magnesium-base alloy consisting essentially of from about 10 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 a magnesium material selected from the group consisting of magnesium and magnesium-base alloys, said particles of metal borides being dispersed in a matrix composed of the selected magnesium material.

2. A magnesium-base alloy consisting essentially of from about 10 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 substantially all magnesium, said particles of metal borides being dispersed in the magnesium matrix.

3. The alloy in accordance with claim 2 wherein the selected metal boride is titanium diboride.

4. A magnesium-base alloy consisting essentially of from about 10 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 substantially all of magnesium base alloy, said particles of metal borides being dispersed in the magnesium-base alloy matrix.

5. The alloy in accordance with claim 4 wherein the selected metal boride is titanium diboride.

6. A magnesium-base alloy consisting essentially of from about 10 to 50 volume percent of particles of titanium diboride, and the balance substantially all of magnesium-base alloy containing about 5 percent by weight aluminum and the balance substantially all magnesium and incidental impurities, the titanium diboride particles being dispersed in the magnesium-base alloy matrix.

7. A magnesium-base alloy consisting essentially of about 40 volume percent of particles of titanium diboride, and the balance all a magnesium-base alloy containing about 5 percent by weight aluminum and the balance substantially all magnesium and incidental impurities, the titanium diboride particles being dispersed in the magnesium-base alloy matrix.

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DAVID L. RECK, *Primary Examiner*.