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METHOD FOR THE PRODUCTION OF LIGHT METAL ARTICLES

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The invention relates to light metal bodies and their production.

Aluminum and its alloys are used for this purpose on a very large scale and this particularly is due to their light weight. On the other hand, pure aluminum has only restricted mechanical properties and particularly a poor strength and hardness. The tensile strength even in the annealed state is 7 to 9 kg./mm.^{2} and the Brinell hardness 20 to 25 kg./mm.^{2}. By cold working the tensile strength may be raised to 20 kg./mm.^{2} and the Brinell hardness to 40 kg./mm.^{2}. The mechanical quality of the aluminum may be improved by the admixture to the same of certain other metals, for instance, copper or magnesium. Several of these alloys are hardenable by a heat treatment; their tensile strength and their hardness in particular may be improved by annealing, quenching and storing at room or at an elevated temperature; in this manner a tensile strength of above 50 kg./mm.^{2} and a Brinell hardness of up to 150 kg./mm.^{2} may be obtained.

When the light metal articles during use are exposed to elevated temperatures of particularly above 200° C., reliance on the above given high mechanical properties is out of question, as the material hardened by cold working as well as the age-hardened material is softened and their mechanical properties consequently decrease until they are not superior to those of the soft annealed materials.

Up to now it was not considered possible to manufacture light aluminum alloys which do not lose their high mechanical properties by annealing at about 200–500° C.

This invention relates to light metal articles and their manufacture having a spec. weight of up to 5 g./cm.^{3} and preferably up to 3 g./cm^3, having a tensile strength exceeding 30 kg./mm.^{2} and a Brinell hardness exceeding 80 kg./mm.^{2} in the annealed state. These metal articles are produced in a manner similar to those of the so-called powder metallurgy by compressing and sintering superficially oxidized pure or alloyed aluminum flakes which must be free or substantially free from grease and lubricants and having such a fineness that at least 50 percent of the powder particles have at least one dimension, for example, a thickness in the case of flake-like grains, smaller than 2 microns (2μ); the invention also relates to the thus produced bodies.

It is generally known to compress and sinter metal powders and also aluminum powder and to thus produce solid metal bodies; however, it could not be expected that it would be possible to produce solid metal bodies from pure aluminum powder, whose tensile strength may be raised by cold working at the best to about 20 kg./mm.^{2} and which decreases by annealing below 10 kg./mm.^{2}, said metal bodies adapted to attain a tensile strength of, for example, 35 kg./mm.^{2} and this property

being substantially preserved after annealing at a temperature below the melting point for instance at 600° C. This aluminum powder may, for instance, be produced by stamping or in a ball mill.

The instant method cannot be carried-out with the commercial and so-called commercial "atomized" aluminum powder which is produced by spraying molten aluminum powder, or with aluminum grit, as their particles have not the necessary thinness; therefore, the mechanical properties of light-metal bodies obtained by compression and sintering the "atomized" aluminum powder or aluminum grit are below those mentioned before. As a matter of fact, bodies sintered from atomized Al powder attain a yield strength of 12 kg./mm.^{2}, for instance, a tensile strength of 18 kg/mm.^{2} and a Brinell hardness of 44 kg./mm.^{2}. Sintered bodies from aluminum grit have a yield strength of about 7 kg./mm.^{2}, a tensile strength of 12 kg./mm.^{2} and a Brinell hardness of 32 kg./mm.^{2}.

The surprising fact that high-strength metal bodies are produced from pure aluminum powder may be due to the influence of the particle size in its relation to the thickness of the oxidic film covering the surface of each particle.

The commercially available flaky aluminum powder is usually sufficiently oxidized and suited to carry-out the instant method when it is free or substantially free from grease or other lubricants and of suitable particle size.

Experiments have shown that aluminum powder not possessing the critical thickness of the flakes in accordance with the invention which is substantially free from oxide or not only contains minor percentages cannot be satisfactorily treated according to the instant method as it was found that the thus produced light metal bodies lack tensile strength and hardness. It is true that the tensile strength and the hardness do not increase abruptly when the percentages of oxide content is raised. However, this invention pertains to all light metal bodies where with an increase of the oxide content, the yield strength, the tensile strength and the Brinell hardness reach at least the previously mentioned values. The size of the powder particles being discovered to be a factor having an important influence on the results the factor of a minimum required oxide content cannot be prestated with sufficient accuracy, but these two factors can easily be coordinated and in any given circumstance or with given materials simple tests or trials will predetermine whether a given powder is suitable for the instant method and the light-metal articles produced thereby.

The aluminum may be pure or it may contain also other elements for example copper, magnesium or silicon. These other substances may be added to the aluminum powder in the elementary state separately or combined together or may be provided as powdered master-alloys; in any case these other elements may form alloys with the aluminum by diffusion during the sintering. Of course, still other substances compatible with the instant method may be added so long as the specific weight of the body is not caused to be higher than 5 g./cm.^{3}, preferably not higher than 3 g./cm.^{3}, and so long as the tensile strength of the produced body is not caused to be lower than 30 kg./mm.^{2} and the Brinell hardness not lower than 80 kg./mm.^{2} even in the annealed state. Alloying metals include Zn, W, Mn, Be and Mo.

For the production of the light metal bodies according to the invention, it is necessary to apply pressure and heat. In the heated state a sintering takes place. If the pressure and the heat are applied simultaneously, it may happen that the duration of the application of

heat is not long enough for causing a sufficient sintering. In this case, a special heating for sintering purposes may be carried-out after the combined compressing and heating step.

Obviously the invention may be realized in a different manner or series of general steps and in a different succession, such as the following:

(*a*) 1. Cold pre-pressing
2. Sintering
3. Hot pressing
(*b*) 1. Cold pre-pressing
2. Hot pressing and sintering
(*c*) 1. Hot pressing and sintering

Of course other operations may be inserted between the above mentioned steps.

It is advantageous to carry out the relatively cold pre-pressing step with a pressure of about 2 metric tons per square centimeter. For the hot pressing the pressure is raised, if possible, up to the safe limit of pressure which the press and tools can stand, and preferably up to or beyond about 6 metric tons per square centimeter.

The temperature of the hot pressing and sintering steps should be so high that the desired properties of the light metal bodies of Al or its light alloys may be obtained in an economical period of time. On the other hand, the temperature must be well below the melting point and not so high as to produce a casting instead of a sintered body, since with casting the mentioned high strength cannot be reached. The temperature should exceed 400° C., and advantageously lie between 550 and 600° C.

The duration of pressing and sintering, in whichever order these combined operations are performed, may vary in a wide range according to the temperature employed and to the desired properties of the light metal body. The higher the temperature, the shorter may be the duration of pressing and sintering. The temperature also influences the pressing as at increasing temperatures the metal body can be compressed more easily and rapidly.

The hot pressing operation may be associated with a special shaping action; in other words, a hot pressure molding, so that bodies are produced which need only minor or no subsequent machining operations.

The invention is illustrated by the following examples.

Example 1

Pure aluminum flakes consisting wholly of particles with at least one dimension smaller than 1 micron, therefore well under 2 microns, was first cold-pressed and thereafter compressed into solid metal shapes or bodies at about 600° C. under a pressure of about 6 metric tons per square centimeter, with these conditions maintained for a duration of about 1 minute. The articles or bodies thus produced have approximately the following properties:

Specific weight (density)	g./cm.³	2.2
Yield strength	kg./mm.²	28 to 30
Tensile strength	kg./mm.²	32 to 36
Elongation (δ 10)	percent	2 to 5
Brinell hardness	kg./mm.²	85 to 100

Example 2

Some of the bodies obtained according to Example 1, were additionally annealed for 48 hours at 630° C. and tested again after cooling. The strength was closely the same as before the annealing step.

Example 3

After annealing during 28 days at 200° C., and also at 400° C., some products or bodies obtained according to Example 1, likewise no substantial alteration of strength properties thereof could be observed.

Surprisingly it was found with regard to each of Examples 1, 2 and 3, that the light metal bodies produced according to the invention can be worked, e. g. by extrusion, at elevated temperature, e. g. at 450° C.

Such additional hot working is advantageous in view of the thus improved properties and also in view of the increase of the specific weight of the articles.

Example 4

By cold pre-pressing, and subsequent hot pressing at 600° C., pure aluminum flakes of such a fineness that all particles had at least one dimension smaller than 1 micron, under a pressure of 6 metric tons per square centimeter maintained during about 1 minute, bodies of a specific weight of 2.2 g./cm.³ were obtained. The specific weight could be increased thereabove to about 2.7 g./cm.³, which is the specific weight of aluminum, by applying prolonged pressure at high temperature, but the cost of the method and product would be thereby raised considerably. However, if the compressed body is also extruded, as into a rod, the higher specific weight may be reached in a relatively short time, and the final product or article may thus be obtained in a much more economical manner than by prolongating the hot pressing. Some of the product bodies satisfactorily made according to this example were produced by extrusion at 450° C. through a die having an inside diameter of 15 mm. and a specific weight was attained of 2.7 g./cm.³ while simultaneously the elongation factor was improved, the tensile strength, yield strength and Brinell hardness remaining on the whole substantially unchanged. The mechanical properties were the following when practicing Example 4 with hot extrusion as described:

		Light metal body according to the invention after extrusion	Ordinarily extruded pure aluminum rods
Yield strength	kg./mm.²	27 to 30	2.5 to 5
Tensile strength	kg./mm.²	32 to 35	7 to 10
Elongation (δ 10)	percent	5 to 8	20 to 35
Brinnel hardness	kg./mm.²	85 to 100	18 to 28

Some of the bodies obtained according to Example 4 were subjected for comparison purposes after the extrusion to temperatures of 200 or 400 or 630° C. during different lengths of time, but resulting in no perceptible change of mechanical properties. For determining the resulting changes after a cold working treatment, several bodies produced in the same way as recited in Example 4, with extrusion, were cold-drawn through a die with a degree of deformation of about 70 percent, and were thereafter annealed at about 500° C. during 14 hours. Tests on such rod by the methods already stated showed the following properties:

		Extruded	Cold Drawn	Annealed
Yield strength	kg./mm.²	25.7	34.3	28.9
Tensile strength	kg./mm.²	35.3	37.2	37.0
Elongation (δ 10)	percent	5.0	1.0	2.5
Brinell hardness	kg./mm.²	85	91	91

As is seen from the above the cold working raises the yield and tensile strengths but the elongation becomes decreased. The subsequent annealing causes only a recovery of the crystal formation, but not a real recrystallization, as was determined by X-ray tests.

The light metal bodies produced according to this invention have higher yield and tensile strengths and higher hardness, not only at room temperature, but also at elevated temperatures, as is clearly shown in the following tables, where the pressed article made according to the invention is compared in its properties with two prior

art products, one of which is the known alloy "Avional D," which is an Al base alloy containing Cu 4.0 percent, Si 0.7 percent, Mn 1.0 percent and Mg 1.0 percent; the other of which is soft pure aluminum.

YIELD STRENGTH IN KG./MM.²

	20°	200°	300°	400°	500°
Pressed body according to Example 1 of the invention	25.5	17.7	15.7	10.5	9.5
Avional–D	8.5	6.5	5	3	------
Pure aluminum, soft	3.0	1.7	1.5	1.3	------

TENSILE STRENGTH IN KG./MM.²

Pressed body according to Example 1 of the invention	34.8	21.0	17.4	11.2	9.7
Avional–D	17.0	12.5	7.0	3.2	------
Pure aluminum, soft	8.0	4.1	2.6	2.4	------

BRINELL HARDNESS IN KG./MM.²

Pressed body according to Example 1 of the invention	92	52	42	30	------
Avional–D	45	21	9	------	------
Pure aluminum, soft	18	6	1	------	------

A further advantage consists therein that the light metal bodies according to the invention have a relatively high conductivity, both electrical and thermal, in comparison with the tabulated and other aluminum base alloys of similar strength properties, at room temperature. Moreover, the coefficient of the linear expansion of the product of the invention is at or near the lower limits of that of the known aluminum-base piston alloys.

A further advantage is the permanence of volume of the light metal bodies according to the invention, as they do not show any permanent increase of volume after having been heated.

The creep resistance of various bodies or products of the new method of this invention is incomparably higher than that of conventionally known aluminum alloys. The creep rate of typical articles made under this invention is of the order of 0.62×10^{-3} percent per hour at 250° C. between the 25th and the 35th hour of strain under a charge of 9 kg./mm.², whereas under the same conditions the creep rate of a known heat-treated aluminum base alloy, containing copper, magnesium and silicon, is 295×10^{-3} percent per hour, consequently about 500 times greater than under the new method.

When the bodies are produced by the instant method from pure aluminum powder alone they have the same corrosion resistance as does pure aluminum, as proven by the salt spray test.

As already stated above, the most favorable temperature for sintering is about 550 to 600° C.

Tests made with the new method have surprisingly proven that aluminum bodies with a tensile strength of at least 25 kg./mm.², preferably of more than 30 kg./mm.² in at least one direction and with a Brinell hardness of at least 75 kg./mm.² even in the annealed state can be obtained by cold pressing and hot working (hot deformation at temperatures above 350° C.) therefore it is not necessary to exceed 500° C. without special sintering or hot pressing operations.

The hot pressing step for compressing and shaping a light-metal body, as mentioned, must not be mistaken with the hot working operation mentioned. During the hot pressing the powder particles are pressed together without a true flowing thereof; and this is usually carried out by pressing in strong compression within a hollow cylinder. On the contrary, during the hot working (extruding, hot pressing in a die, and the like) the powder particles flow, that is, move or glide one upon another. It is to be understood that the hot working is a hot pressing involving or associated with a kneading action or its equivalent. It is impractical to define or indicate a minimum degree of deformation during the kneading; but the difference between mere compressing of a mass or body and working is well understood. For the purposes hereof simple tests or trials will readily predetermine the action in any given case. A degree of deformation of at least 50 percent is desirable; with extrusion, for example, this degree must exceed 50 percent and preferably reach 70 percent or more.

In proceeding without intermediate operations directly from the cold pre-pressing to the hot working, time is saved as well as energy, particularly because operations may be carried-out at less high temperatures for obtaining equivalent results.

Theoretically this method could be practiced without the cold pre-pressing step in advance of hot pressing or working; but this would incur technical difficulties which would make a possible saving of time economically illusory.

Example 5

Commercially pure aluminum flakes, having an extremely fine flake form being free from grease, and having a thickness of less than 1 micron was cold-pressed in a hollow cylinder or compression chamber of 100 mm. inside diameter, using a pressure of 5 metric tons per square cm., and a 200 mm. long cylindrical product or body was obtained. Thereafter such body was heated to 500° C. and extruded through a die with aperture of 50 mm. diameter; the apparatus also having been heated to about 500° C. The thus obtained rod of 50 mm. thickness had the following properties:

Yield strength	kg./mm.²	25 to 28
Tensile strength	kg./mm.²	30 to 35
Elongation	percent	6 to 8
Brinell hardness	kg./mm.²	80 to 95

The product or light metal bodies produced according to the invention are of such properties as to be, for instance, suitable for purposes wherein high mechanical strength is needed even with high temperatures; typical cases being the production of pistons of internal combustion engines, piston rings, the vanes of vapor and gas turbines, parts of jet-engines, etc.

The advantageous properties afforded by the practice of the above described method, and being presented in the products of the same, are numerous, and the details thereof with comparison with prior known products, have been hereinabove set forth.

The more important of said properties for practical purposes may be considered is the low metric density of the product, of the order of that of ordinary aluminum products, and the high mechanical strength, particularly tensile strength of the product, and its high Brinell hardness; other properties being its high yield strength, and low elongation, high conductivity both thermal and electric, high permanence of volume without appreciable increase, and high creep resistance or low creep rate. The products or mechanical parts possessing these main advantages, are believed to be novel, no prior instances thereof, of whatever composition, being known to this applicant. In one aspect the general object of the present invention may be said to consist in the ability to supply to various industries the aforesaid low density and high strength products or parts, such as problem having been herein met by the described methods embodying the present invention and employing a finely subdivided powder composed predominantly of aluminum and treated under elevated temperature and pressure in the manner set forth.

Since certain changes in carrying out the above invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description shall be interpreted as illustrative and not in a limiting sense.

It will be apparent to those skilled in the art that the novel principles of the invention disclosed herein in connection with specific exemplifications thereof will sug-

gest various other modifications and applications of the same.

It is accordingly desired that in construing the breadth of the appended claims they shall not be limited to the specific exemplifications of the invention described herein.

I claim:

1. A sintered pressed metal article consisting predominantly of aluminum and having without further treatment a specific weight of 2.2 to 5.0 grams per cubic centimeter, a tensile strength exceeding 25 kilograms per square millimeter and a Brinell hardness exceeding 75 kilograms per square millimeter, more than 50% of the sintered particles containing aluminum and having at least one dimension smaller than 2 microns.

2. The metal article of claim 1 wherein the sintered particles containing aluminum are superficially oxidized.

3. The metal article of claim 1 wherein the sintered particles containing aluminum are flakes.

4. The metal article of claim 1 wherein the sintered particles containing aluminum are superficially oxidized flakes.

5. Method of manufacturing metal bodies which comprises simultaneously hot-compressing and sintering metallic powder consisting predominantly of aluminum, said powder being of such fineness that at least 50% of the single metallic particles have at least one dimension smaller than 2 microns.

6. The method of claim 5 wherein the metallic powder is hot-compressed in a shaping mold.

7. The method of manufacturing metal bodies which comprises compressing, without heating metallic powder consisting predominantly of aluminum, said powder being of such fineness that at least 50% of the single metallic particles have at least one dimension smaller than 2 microns, and thereafter sintering said compressed mass of metallic powder.

8. The method of claim 7 wherein the metallic powder is compressed in a shaping mold.

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