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ALUMINUM-MAGNESIUM CASTING ALLOYS

Charles B. Willmore, Newark, Ohio, assignor to William F. Jobbins, Incorporated, Aurora, Ill., a corporation of Illinois

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6 Claims. (Cl. 75—147)

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This invention relates to aluminum alloys constituted with magnesium as the major alloying element and, more particularly, it relates to new and improved aluminum-magnesium alloys for fabrication into finished products by the casting technique.

This application is a continuation-in-part of my copending application, Serial No. 71,015, filed on January 14, 1949, now Patent No. 2,564,044, and entitled Aluminum-Magnesium Casting Alloys.

Commercially, aluminum-magnesium casting alloys may be arranged into two distinct groups. Cast alloys having a magnesium content ranging from 9 to 12 percent by weight are responsive to heat treatment by which their physical properties are greatly improved. In this treatment, the aluminum-magnesium intermetallic compounds are put into solid solution from which they are reprecipitated at room temperature in finely divided form instead of the coarse crystals in which they existed in the original casting. The major portion of reprecipitation takes place within a few days of aging whereby improved physical properties are developed.

In the range of 3 to 9 percent magnesium, heat treatment has very little effect on the physical properties developed on casting. Alloys within this lower group form the subject matter of this invention. Their physical properties developed on casting are generally referred to as the "as cast" properties. Within this group, further subdivision is possible with respect to the method of casting; that is, casting may be made into sand molds, hereinafter referred to as sand casting, or it may be made into permanent molds, hereinafter referred to as chill casting. Permanent mold or chill casting may rely entirely on gravitational principles, or the use of positive pressure may be employed in filling the molds, as in die casting. A chief difference between the two types of casting resides in the rate of heat transfer through the mold walls, it being greater in chill casting with the result that crystallization and solidification are more rapid.

Chill casting usually has the effect of decreasing grain size of the cast alloys, especially when they are composed of an aluminum base. In aluminum-magnesium alloys, components, such as magnesium, present in quantities above their normal solid solubility limit at room temperature are retained in meta-stable condition of solid solution instead of precipitating out as in the slower cooling sand casting methods.

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Ordinarily, these characteristics in a metal or alloy lead to improved physical properties, but the reverse effects are obtained with aluminum-magnesium alloys. This reversal of expected properties are believed to result from conditions often referred to as "coring effect" by which is meant that the compositions of the grains vary from the center to the outside and such non-uniformity detracts from the physical properties. "Coring effect" is increased with non-equilibrium conditions existing in rapid freezing of chill casting. With most alloys this harmful effect is more than offset by benefits derived by finer grain size and greater proportions of material in solid solution but not so with aluminum-magnesium alloys. No one, to my knowledge, has been able to manufacture an aluminum-magnesium alloy for chill casting which has physical properties that are as high or higher than those obtained by casting the same alloy in sand. As will hereinafter appear, the usual loss of physical properties resulting from such "coring effect" during rapid freezing is not encountered with the improved compositions described and claimed herein.

It is an object of this invention to produce an aluminum-magnesium alloy which is not subject to the limitations of the prior art in that it can be used for both chill and sand casting without substantial difference in physical properties.

Another object is to produce an aluminum-magnesium alloy for casting into sand, refractory, or metal molds to provide a cast product having improved physical properties without the need for any heat treatment.

A further object is to produce an aluminum-magnesium casting alloy that has properties superior to any heretofore obtained by either sand casting or by heat treatment; that has excellent tensile strength and ductility without heat treatment; that is as resistant to corrosion as most of the aluminum-magnesium alloys, alloys which are distinguished by their excellent corrosion resistance and high luster; that has optimum machining properties; that acquires and retains a brilliant surface responsive to simple polishing; and that develops high mechanical properties immediately upon cooling to room temperature, which properties do not change with age as compared with heat treated castings which develop equivalent tensile strength with age but with a corresponding loss in elongation or ductility such that the product ultimately might become embrittled.

A still further object is to produce an aluminum-magnesium alloy which is particularly adapted to develop superior physical properties by chill casting although it may be successfully "sand cast."

A still further object is to produce an aluminum alloy constituted with 3 to 9 percent magnesium as the major alloying element and with other metals in various new arrangements to provide for specific improvements in the physical characteristics of the cast alloy whereby excellent combinations of tensile strength, yield strength, and elongation are developed without resorting to expensive heat treatment, which is also a deterrent to the rate of production.

A further object is to produce an aluminum-magnesium alloy which embodies alloying principles different from those heretofore followed to provide for improved characteristics in the alloy.

that copper, iron, silicon, zinc or zirconium have the properties of increasing hardness and strength of aluminum metal and its alloys, yet I have found that these same metals, when used in quantities which might be expected to improve the yield strength, are highly detrimental to the properties when alloyed with aluminum, magnesium, beryllium, and titanium.

Of the metals alloyed with aluminum, magnesium, beryllium, and titanium, I have found that chromium, with or without boron, has a very desirable effect in increasing the yield strength of the alloys beyond the ordinary value of 17,000 pounds per square inch. This may be illustrated by comparison of an alloy without chromium and boron with an alloy embodying the elements chromium and boron in accordance with this invention. The comparisons made below in Table I are of samples obtained in permanent mold (chill) casting.

TABLE I

	Percentage						Ultimate Strength, Lbs./Sq. In.	Yield Strength, Lbs./Sq. In.	Elongation, Percent/Inch	Brinell Hardness
	Mg	Be	Ti	Cr	B	Al				
A	7.5	0.01	0.20	0.00	0.005	Balance	40,200	19,900	9.6	91.5
B	7.5	0.01	0.20	0.25	0.005	do	43,400	21,400	11.5	100.0

TABLE I (a).—SAND CASTING

	Mg	Be	Ti	Cr	B	Al	Ultimate Strength, Lbs./Sq. In.	Yield Strength, Lbs./Sq. In.	Elongation, Percent/Inch	Brinell Hardness
A	6.5	0.01	0.20	0.00	0.000	Balance	39,800	19,100	11.4	74.0
B	6.5	0.01	0.20	0.20	0.000	do	41,000	21,100	12.0	74.0

Invention herein resides in the preparation of an alloy having aluminum and magnesium as the major alloying elements and small but important quantities of titanium, beryllium, boron and chromium as minor alloying elements in new and improved five- and six-component systems to form alloys having improved characteristics differing from those heretofore produced not only in composition but because of alloying principles heretofore unrecognized in the production of new and improved products. As previously pointed out, this invention is directed primarily to aluminum-magnesium alloys for use in "as cast" condition and, therefore, is limited to less than 9 percent magnesium content, it being understood that best properties are developed with magnesium present in the range of 6 to 8.5 percent. Heretofore, the best aluminum alloy, having 6 to 8.5 percent magnesium, gave a tensile strength of 32,000 pounds per square inch and elongation in the order of 10 percent "as cast" in sand and even lower properties "as cast" in permanent molds; whereas, by practicing my invention, an aluminum-magnesium alloy may be produced having "as cast" properties which measure 42,000 pounds per square inch tensile and 15 percent or more elongation, a combination of properties which exceeds that obtainable with heat treated cast aluminum alloys of the same magnesium content and is comparable in many instances to alloys with higher magnesium content.

I have found that known metallurgical data with respect to the effects of additions of metals to aluminum alloys for the purpose of securing greater strength and hardness does not particularly hold true for aluminum-magnesium alloys and especially for aluminum-magnesium alloys in which titanium and beryllium constitute alloying elements. For example, it has been suggested

It will be apparent from the table that when chromium is alloyed with the four basic materials in combination with boron, as illustrated by test B, each of the values of ultimate strength, yield strength, tensile strength and elongation are markedly improved.

In carrying out this invention, I prefer to hold the boron content, when employed, within the range of 0.001 to less than 0.01 per cent by weight. More boron may be used but the intermetallic compounds that seem to precipitate when concentration in excess of 0.01 percent are present, lowers the physical properties of the alloy. Improved results are also secured by the addition of chromium without boron but the improvement is not as great as when the two metals are both present in the alloy composition. It appears that maximum benefit is derived when titanium is present in amounts ranging from 0.01 to 0.25 percent by weight. Larger quantities, up to and including 0.40 percent by weight of titanium may be used; however, it seems that amounts in excess of 0.25 percent do not remain completely dissolved in the alloy throughout its freezing range and in such instances additional concentration has little benefit. Furthermore, as the molten alloy passes through its freezing range, the excess titanium appears to form precipitates of intermetallic compounds with other metals, which makes the melt more sluggish to the extent that excess titanium may be detrimental to the mechanical properties in some types of casting. For sand casting, it is best to hold the beryllium content to less than 0.03 percent by weight, but, preferably in the range of 0.0005 to 0.02 percent. For chill casting, the beryllium content may go as high as 0.2 percent by weight but it is more economical to hold the beryllium content to less than 0.07 percent by weight. In any event, in chill casting more than 0.001 percent by weight beryllium should be used. The amount of chromium which has been found most beneficial in alloys of the type described is in concentrations ranging from 0.15 to 0.5 percent by weight. However, chromium may be present in the broader range of 0.05 to 1.0 percent by weight.

From the practical standpoint, the five- and six-component systems constituting the principal features of this invention have the advantage that defined characteristics apply to both sand casting and chill casting. This is unusual in aluminum-magnesium alloys because of the vast differences that exist in their rate of crystallization and freezing whereby finer grain size and the retention of excess metals as solid solutions are more characteristic of chill casting. For most aluminum alloys, the physical properties developed by chill casting are superior to those secured by sand casting, but for aluminum-magnesium alloys, the reverse is more often true. This is best illustrated by Table No. II, which shows the physical properties determined in alloys processed by sand casting and chill casting. To the best of my knowledge, no one before has developed an aluminum-magnesium alloy which is capable of giving physical properties by chill casting which are substantially the same as the properties secured by casting the alloy in green sand or by die casting.

TABLE II

	Chill Casting Method			Sand Casting Method	
	Mg	Ti	Be	B	Al
Percentage Alloying Metals	6.5	.15	.005	.006	balance
Ultimate Strength, Lbs./Sq. In.	36,300			38,500	
Yield Strength, Lbs./Sq. In.	16,900			17,100	
Percentage Elongation	12.9			16.0	

In accordance with the practice of this invention, it is possible to formulate alloys wherein the properties developed by chill casting, especially when formed in molds heated to 600° to 900° F., are even better in many respects than the properties secured by the most favorable alloys for sand casting, as illustrated in the following Table III. In many instances, the same alloy embodying features of this invention may be used for sand casting and for chill casting interchangeably, with the same type of improvement in physical properties. The formulation of a single alloy which may be used in all types of casting techniques has been a goal of the aluminum industry for a long time and has been the subject of concentrated research.

TABLE III

	Chill Casting Method			Sand Casting Method	
	Mg	Ti	Be	B	Cr
Percentage Alloying Metals	7.5	.20	.01	.005	.25
Ultimate Strength, Lbs./Sq. In.	43,400			36,500	
Yield Strength, Lbs./Sq. In.	21,400			21,200	
Percentage Elongation	11.5			6.1	
Brinell Hardness Number	100			70	

The above data illustrates another important improvement in alloys of the type described by the practice of this invention. Hardness calculated as Brinell Number 100 in "as cast" condition is obtained by very few aluminum alloy compositions, limited mostly to compositions having a large amount of copper present. It is believed that this is the first time that high hardness is obtained with little, if any, sacrifice in ductility. For example, the hard alloys containing large amounts of copper usually have elongation values in the range of 1.0% or less, compared with the elongation of 11.5% shown above with the hardness of 100.

For chill casting, the boron content should be less than 0.01 percent by weight but more than 0.001 percent by weight to be effective. Beryllium, in amounts up to 0.05 percent, is very effective, while excellent physical properties have been developed when as much as 0.2 percent beryllium has been present, but because of its high cost, more than 0.07 percent by weight beryllium is seldom used. The titanium content should be held below 0.40 percent, and preferably below 0.25 percent by weight, and best results are secured when the amount of titanium is above 0.10 percent by weight.

In production, the alloy may be compounded by the addition of the metallic components to molten aluminum maintained at least 100 degrees above melting temperature. To the molten aluminum, the other elements may be added in any desirable order conforming to accepted metallurgical practices limited to the production of an end product having the elements present in the desired amounts and relatively free of harmful impurities. For some of the elements it is best to alloy with pure metals or with master alloys, while with others additions may best be made by reduction from inorganic salts such as the fluorborates or halides, from which the metal is made available and from which benefit can be secured for sweeping out the alloy upon the release of gases. For example, beryllium is best incorporated as a master alloy with aluminum, while titanium and boron are added to greatest advantage as inorganic salts, because it is possible to cause the titanium to remain in solution in the alloy when added in this form even when the amount of titanium exceeds 0.25 percent by weight.

By way of illustration but not by way of limitation, the invention may be described as being embodied in an aluminum-magnesium alloy having the elements present in the following amounts:

	Per cent
Magnesium	1.0 –9.0
Titanium	0.001–0.40
Chromium	0.05 –1.0
Beryllium	.001– .20
Boron	Less than 0.01
Aluminum	Balance

A preferred range of materials is as follows:

	Per cent
Magnesium	6.0 –8.5
Titanium	0.10 –0.25
Chromium	0.15 –0.50
Beryllium	0.001–0.03
Boron	0.001–0.01
Aluminum	Balance, plus impurities

For sand casting magnesium content of 6–7 percent is preferred while 7–8 percent magnesium is preferred for permanent mold casting and 7.5–8.5 percent is preferred for die casting.

For best results the total impurities, which include the metals of the type copper, iron, and silicon, should be kept below 0.45 percent with 0.25 percent by weight being the maximum for any one of the aforementioned metallic impurities. Since alkali metals, especially sodium, are very deleterious to the physical properties of the alloy, inclusion of more than 0.001 percent by weight thereof should be avoided.

By way of illustration, the following formulae embodying features of this invention constitute alloys which give excellent physical properties for sand and chill casting:

Example 1

	Per cent
Magnesium	7.0
Titanium	0.2
Beryllium	0.02
Boron	0.003
Chromium	0.15
Copper	0.01
Iron	0.10
Silicon	0.08

The balance being aluminum plus other impurities.

Example 2

	Per cent
Magnesium	7.5
Titanium	0.20
Chromium	0.30
Beryllium	0.01
Aluminum	Balance, plus impurities

It will be apparent from this description that I have conceived of heretofore unknown alloying principles which have led to the inclusion of various alloying elements to produce aluminum-magnesium alloys having characteristics far superior to those presently known, as produced by sand casting or chill casting with or without heat treatment. Of considerable importance is the possibility of using the resulting compositions interchangeably for casting in permanent molds or green sand without deleteriously affecting the physical properties.

Evident also is the fact that for the first time in aluminum-magnesium alloys, elements may be incorporated for the purpose of increasing yield strength to a desirable high value without the lowering of ultimate strength and elongation. These and other concepts have led to the production of aluminum-magnesium alloys having considerable advantage over those heretofore produced.

It will be understood that numerous changes may be made in the amounts of materials and methods of incorporation and fabrication into a cast product without departing from the spirit of my invention, especially as defined in the following claims.

I claim:

1. An aluminum base alloy consisting essentially of 1 to 9 percent magnesium, less than 0.01 percent by weight boron, 0.0005 to 1.2 percent beryllium, 0.001 to 0.4 percent titanium, 0.05 to 1.0 percent chromium, and the rest being aluminum and impurities in amounts less than about 0.45 percent by weight.

2. An aluminum base alloy comprising 1 to 9 percent magnesium, less than 0.01 percent boron, 0.10 to 0.25 percent titanium, 0.001 to 0.07 percent beryllium, and 0.15 to 0.50 percent chromium, the balance being aluminum and impurities in amounts less than about 0.45 percent by weight.

3. An aluminum base alloy consisting essentially of 1 to 9 percent magnesium, 0.001 to less than 0.01 percent boron, 0.01 to 0.25 percent titanium, 0.001 to 0.07 percent beryllium, 0.15 to 0.50 percent chromium, the balance being aluminum and less than about 0.45 percent impurities.

4. An aluminum base alloy for sand casting comprising 3 to 9 percent magnesium, 0.001 to less than 0.01 percent boron, 0.10 to 0.25 percent titanium, 0.001 to 0.03 percent beryllium, 0.15 to 0.50 percent chromium, the balance being aluminum and less than about 0.45 percent impurities.

5. An aluminum base alloy for chill casting comprising 3 to 9 percent magnesium, less than 0.01 percent boron, 0.01 to 0.25 percent titanium, 0.001 to 0.07 percent beryllium and 0.15 to 0.50 percent chromium, the balance being aluminum and less than about 0.45 percent impurities.

6. An aluminum base alloy as claimed in claim 2 in which the amount of iron in the impurity does not exceed about 0.25 percent by weight.

CHARLES B. WILLMORE.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,870,732	Iytaka	Aug. 9, 1932

OTHER REFERENCES

"Foundry Trade Journal," November 17, 1938, pages 373 and 374.