Sept. 25, 1956 C. B. WILLMORE 2,764,482

ALUMINUM-MAGNESIUM CASTING ALLOYS

Filed Aug. 24, 1950 2 Sheets-Sheet 1

CHART I: SHOWING EFFECT OF BORON AND BERYLLIUM AS INTENSIFIER FOR THE GRAIN REFINING OF TITANIUM IN AL-MAG ALLOYS HAVING 6.5 PER CENT MAGNESIUM

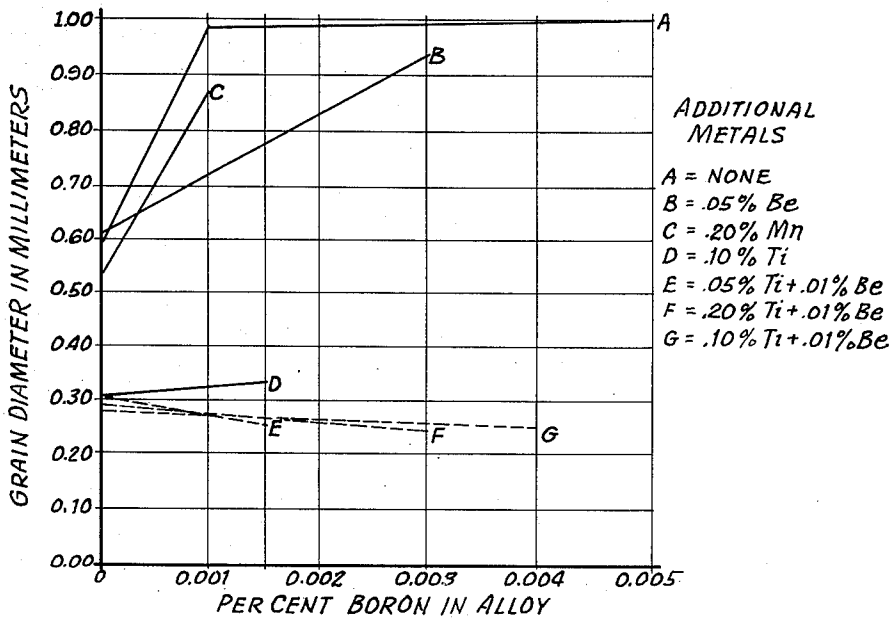


Fig. 1

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ALUMINUM-MAGNESIUM CASTING ALLOYS

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CHART 2: SHOWING EFFECT OF TITANIUM ON THE PHYSICAL PROPERTIES OF ALUMINUM ALLOYED WITH 6.5 PER CENT MAGNESIUM

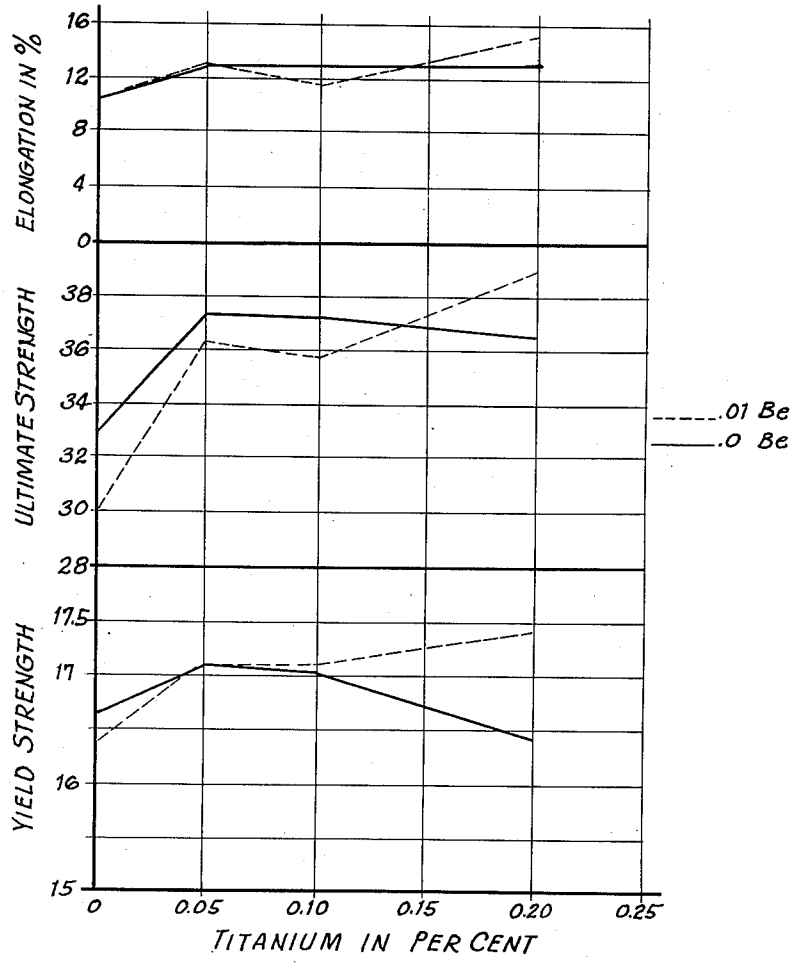


Fig. 2

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ALUMINUM-MAGNESIUM CASTING ALLOYS

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Application August 24, 1950, Serial No. 181,261

2 Claims. (Cl. 75—147)

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, and entitled Aluminum-Magnesium Casting Alloys, now Patent No. 2,564,044 issued on August 14, 1951.

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. Ordinarily, these characteristics in a metal or alloy lead to improved physical properties, but the reverse effects are obtained with aluminum-magnesium alloys. There is no satisfactory explanation for the distinguishing deficiency in behavior of aluminum-magnesium alloys to develop superior properties responsive to finer grain size and increased amount of magnesium in solid solution. Perhaps it is the domination of the coring effect. 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 casing the same alloy in sand. An object of this invention is to produce an aluminum-magnesium base alloy in which the usual loss of physical properties resulting from the coring effect in rapid freezing is not encountered.

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 from an aluminum-magnesium alloy of corresponding magnesium content 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 lustre; 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 differing from those heretofore followed to provide for improved characteristics in the alloy and which has a decidedly added advantage in that it has less adhesion to the mold surface in which it is cast and can more readily be removed from the mold.

Briefly described, invention resides in alloying with aluminum and magnesium, minor but important quantities of titanium, beryllium and boron to provide 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 prepared by sand or permanent mold casting and having 6 to 8.5 per cent magnesium, have a tensile strength of 32,000 pounds per square inch and elongation in order of 10 percent; 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 com-

bination 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.

To develop improved physical properties in metal alloys, effort is made to reduce the grain size by means which are not deleterious to others of the more important physical characteristics. Boron, as well as titanium, molybdenum, and vanadium, has the reputation of grain refining aluminum base alloys, but this reputation is predicated primarily on its effect with aluminum alloyed with copper and the like. By itself, boron is not a grain refiner in aluminum-magnesium alloys. This can best be illustrated with reference to Chart I showing that by the addition of 0.001 percent boron, the grain diameter of the resulting aluminum-magnesium alloy is increased from 0.59 to 0.99 millimeter in diameter, and by the addition of 0.005 per cent boron, the grain diameter is increased still further to 1.00 millimeter.

Chart 1 shows the effect of boron and beryllium as intensifiers for the grain refining of titanium in the aluminum-magnesium alloys having 6.5 percent magnesium, and Chart 2 shows the effect of titanium on the physical properties of aluminum alloyed with 6.5 percent magnesium.

I have found that boron, which is not a grain refiner when added by itself to aluminum-magnesium alloys, nevertheless, acts as desired on an aluminum-magnesium alloy, which has been grain refined as far as possible with titanium, to refine the grain still further provided that beryllium is also present; that is, boron and beryllium serve to intensify the grain refining effect of titanium although neither boron nor beryllium alone has this intensifying effect on titanium. This is also illustrated by Chart I drawn from the results secured from a large number of experiments. In the chart, lines B and D indicate that the grain size increases with the addition of boron to an alloy in which either beryllium or titanium alone is present. On the other hand, lines E, F and G show that the grain size decreases from a relatively low value as the amount of boron is increased when in the presence of both titanium and beryllium in the aluminum-magnesium alloy.

In formulating with boron to secure the desired results, I prefer to limit the use of boron to less than 0.01 percent by weight because it appears that aluminum-magnesium alloys are incapable of retaining more in solution and that excess boron is precipitated out as an intermetallic compound of boron, which does not appear to add to the physical properties of the alloy but instead becomes detrimental, especially if the amount of precipitation is excessive. 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 0.005 to 0.02 percent. For chill casting, beryllium content as high as 0.20 is useful, but it is most economical to hold the beryllium content to less than 0.07 percent. In any event, more than 0.001 percent beryllium should be used.

It appears that maximum benefit of titanium is derived when it is present in amounts ranging from 0.10 to 0.2

percent. Larger quantities, up to, at least 0.40 percent titanium, may be used; however, it is probable that amounts in excess of 0.25 percent do not remain dissolved in the alloy throughout its freezing range and, therefore, can be of little additional benefit. Furthermore, it appears that as the liquid alloy passes through its freezing range, the excess titanium tends to form precipitates of intermetallic compounds with other metals, making the liquid metal more sluggish to the extent that excess titanium may be deterimental to the mechanical properties of the casting. In view of the above, I prefer to use less than 0.25 percent titanium, with best results being secured with amounts ranging from 0.05 to 0.25 per cent titanium.

Grain size is an important factor in the determination of the physical characteristics of an aluminum-magnesium alloy. Grain refinement leads to improvement in tensile strength, yield strength, and elongation or ductility, properties which spell the acceptability and commercial success of the alloy in various applications. Grain refinement, therefore, is an important characteristic and the discovery of means whereby it may be effected to control or improve other physical properties constitutes an important advance in metallurgical compositions, and the means by which it is secured suggests new alloying principles. This I have accomplished with a new and improved five-component system of aluminum-magnesium, boron, titanium, beryllium within the limitations described.

From a practical standpoint, the five-component system embodying features of my invention has the added advantage that the 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 crystallization whereby finer grain size and the retention of excess metals as solid solutions are characteristic of chill casting. For most aluminum alloys, physical properties developed by chill casting are superior to those obtained by sand casting, but for aluminum-magnesium alloys, the reverse is more often true. This is best illustrated by Table I which shows the physical properties determined after sand and chill casting. To the best of my knowledge, no one heretofore has developed an aluminum-magnesium alloy which gives physical properties by chill casting which are comparable to the same alloy cast in green sand.

TABLE I

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

A further illustration of the advantages of this invention and the ability to reverse the usual trend between sand and chill casting is as follows:

TABLE II

Exp. No.	Mg	Ti	Be	B	Sand Casting			Chill Casting		
					Ult. Str., p. s. i.	Yield Str., p. s. i.	Elong., Percent	Ult. Str., p. s. i.	Yield Str., p. s. i.	Elong., Percent
A	6.5	.15	.00	.000	38,300	18,100	13.4	36,900	17,700	11.4
B	6.5	.20	.01	.005	40,500	18,700	13.6	39,700	18,400	12.1
C	7.5	.20	.05	.005	32,500	20,100	5.0	42,200	20,200	11.8

Formula A illustrates the usual trend in aluminum-magnesium alloys—the physical properties in chill casting falling off from the properties secured by the same alloy in sand casting. Formula B, which embodies concepts of this invention, begins to reverse the trend in that the properties in sand or in chill casting are comparable. Formula C shows what can be done for the properties in permanent mold or chill casting by bringing the beryllium and boron content within preferred ranges.

By other slight variations of percentages of these same elements within the limitations prescribed, it is possible to achieve an alloy wherein the properties developed by chill casting, especially in molds heated to 600–900° F., are still higher in many respects compared to those secured by the best sand cast alloys. In many instances, the same alloy may be used for sand casting and for chill casting interchangeably and still develop excellent physical properties. A common formulation for use in such two dissimilar casting processes is an achievement which has been the subject of concentrated research.

For chill casting, the boron content should be less than 0.01 percent but more than 0.001 percent to be effective. Beryllium, in amounts up to 0.05 percent, is very effective, and excellent physical properties have been developed with as much as 0.2 percent, but because of its high cost, use beyond 0.07 percent may not be economical. Reasons previously pointed out for keeping the titanium content below 0.40 percent and, preferably, below 0.25 but above 0.10 percent still hold true.

In production, the alloy may be compounded by the addition of the metallic component 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 desired amounts and free of harmful impurities. In some instances, it is better to alloy with pure metals, while in other instances, additions may best be made as master alloys or as inorganic salts from which the metal may be made available and from which benefit may be had of certain released gases and compositions which tend to remove impurities and gases from the melt. For example, beryllium may be incorporated as a master alloy with aluminum, and titanium and boron may be added to advantage as inorganic salts.

Example

	Percent
Magnesium	6.5
Titanium	0.20
Manganese	----
Beryllium	0.010
Boron	0.003
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 as my invention:

1. An aluminum base alloy for sand casting consisting essentially of 3–9 percent by weight magnesium, 0.001–0.2 percent by weight beryllium, 0.001—less than 0.01 percent by weight boron, and 0.05–0.25 percent by weight titanium, the balance being aluminum.

2. An aluminum base alloy for chill casting consisting essentially of 3–9 percent by weight magnesium, 0.001–02 percent by weight beryllium, 0.001—less than 0.01 percent by weight boron, and 0.05–0.25 percent by weight titanium, the balance being aluminum.

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