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2,993,783
ALUMINUM BASE ALLOYS

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This invention relates to an aluminum base alloy of the type referred to in the trade as a sand cast alloy, and it relates more particularly to a sand cast alloy which is self-aging to enable the development of high strength in "as cast" condition and which develops outstanding properties in response to solution heat treatment and artificial aging.

It is an object of this invention to produce an aluminum base alloy for sand casting which may be used without heat treatment in applications requiring high strength but which also may be subjected to heat treatment for the further development of properties heretofore unavailable for aluminum base casting alloys.

Another object of this invention is to produce a sand cast aluminum base alloy of high strength in as cast condition and which is capable of self-aging in as cast condition for the development of strength properties heretofore unavailable without heat treatment.

In accordance with the practice of this invention, the aluminum base casting alloy is formulated to contain aluminum as the base material with zinc, magnesium, chromium and titanium as essential alloying elements, and boron and zirconium as additional alloying elements which can beneficially be included in the alloy. It has been found that the development of the properties desired in the casting alloy depends greatly upon the formulation of the alloy with less than 0.75% by weight of elements other than the described base metal and the foregoing alloying elements, with no one component of the residual metals or impurities making up said other elements being present in an amount greater than 0.25% by weight.

It has been found further, and it is an important concept of this invention, that the alloying elements be present in the composition in amounts which are critical to the development of the desired characteristics in the alloy, and that substantial deviation from the fairly narrow range of each of the alloying elements in the composition will be reflected by noticeable change in the physical and mechanical properties that are secured in the alloy. It is believed that the importance of each of the essential alloying elements and the amounts thereof in the base alloy can best be demonstrated by a series of evaluations of alloys wherein the amounts of the alloying elements have been varied.

For demonstration as to the importance of zinc and the amount thereof in the aluminum base alloy, a series of melts were prepared embodying the basic features of this invention but in which variation was made only in the amount of zinc in the alloy. The basic composition of the alloy, other than the zinc component, was as follows:

EXAMPLE 1

Percent by wgt.	
Magnesium	0.75
Chromium	0.10
Titanium	0.20
Boron	0.001
Iron	0.05
Silicon	0.07
Tin	10.001
Lead	10.001
Copper	10.25
Manganese	10.10

1 Max.

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The amount of zinc in the base alloy was varied from 5 to 10% by weight in increments of a whole percent. Test bars were sand cast of the alloy and were subjected to solution heat treatment for 12 hours at 960° F., followed by quenching in water maintained at a temperature of about 180° F. The quenched bars were artificially aged by heating for 5 hours at a temperature of 250° F. The results are set forth in the following Table I:

Table I

Amount of Zinc	Ult. Strength in p.s.i.	Yld. Strength in p.s.i.	Elongation in percent
5.0	29,000	19,330	9.8
6.0	42,980	37,120	6.0
8.0	51,660	46,910	4.8
9.0	51,670	48,140	2.5
10.0	53,250	50,080	3.0

From the results secured, it will be apparent that the strength rises sharply when zinc is present in an amount greater than 5%. While the strength properties continue to increase with increased amounts of zinc, it will be apparent that elongation falls suddenly to unacceptable levels when the amount of zinc is increased to as much as 9%. Best results are secured when the amount of zinc is limited to within the range of 5.5-8.5%, and preferably to within the range of 6-8%. It has been found that the amount of zinc within the range described above is applicable to all of the alloy systems within the confines of this invention.

In a similar manner, the amount of magnesium has been determined by variation of the amount of magnesium in an alloy system embodying the features of this invention. For this purpose, use was made of an alloy having the following basic composition other than magnesium:

EXAMPLE 2

Percent by wgt.	
Zinc	7.0
Chromium	0.10
Titanium	0.20
Boron	0.001
Iron	0.05
Silicon	0.07
Tin	10.001
Lead	10.001
Copper	10.15
Manganese	10.10

1 Max.

In this examination, the amount of magnesium was varied from 0.5 to 1.0% in increments of 0.1%.

Test bars sand cast of the alloy systems were solution heat treated for 12 hours at 960° F., followed by quenching in water maintained at about 180° F. The quenched bars were artificially aged by heating for 5 hours at a temperature of about 250° F. The results are set forth in the following Table II:

Table II

Amount of Magnesium	Ult. Strength in p.s.i.	Yld. Strength in p.s.i.	Elongation in percent
0.50	38,610	31,120	9.8
0.60	43,140	36,460	9.5
0.70	45,970	39,960	7.0
0.80	46,190	43,080	6.5
0.90	53,850	49,280	4.5
1.00	53,890	50,560	2.0

From the results secured, it will be apparent that the strength rises quite rapidly when the amount of magnesium exceeds 0.5% until the amount of magnesium reached 0.9%. Thereafter, no substantial increase in strength properties is secured by further increase in the amount of magnesium. The upper limitation in the amount of magnesium is defined by the marked reduction which is experienced in the elongation when the amount of magnesium exceeds 0.9%. Thus, in the practice of this invention, it is important to maintain the amount of magnesium in the sand cast alloy within the broad range of 0.55-0.95%, and preferably to within the range of 0.6-0.8%.

Similar investigations have established that limitations also exist with respect to others of the alloying elements present in the aluminum base alloy of this invention. The amount of chromium should be limited to within the range of 0.025-0.25% by weight of the alloy, and preferably to within the range of 0.05-0.15% by weight.

The amount of titanium should be in excess of 0.05% by weight. While more than 0.4% by weight titanium can be used, no corresponding improvements are secured by reason of such additional amounts of titanium. It is preferred to limit the amount of titanium to within the range of 0.10-0.25% by weight of the alloy composition.

When boron is present in the alloy, the amount of boron should be less than 0.002%, but best practice limits the amount of boron to within the range of 0.0005-0.001% by weight. Zirconium, when present, should be limited to an amount less than 0.35% by weight, and preferably to an amount within the range of 0.05-0.25% by weight.

Iron and silicon represent residual metals which have been found to have a most undesirable effect upon the properties of the alloy when either is present in an amount greater than 0.15% by weight. This can be illustrated by the examples which will hereinafter be set forth. In an alloy of Examples 1 and 2, wherein the magnesium is present in the optimum amount of 0.75% and the zinc is present in the optimum amount of 7%, test bars were cast from melts in which, in one instance, the iron content was varied from 0.12% to 0.25% by weight and, in another instance, the silicon was varied from 0.10% to 0.25% by weight. The cast test bars were evaluated in as cast condition and after the test bars were subjected to solution heat treatment and artificial aging. The following tables set forth the values that were secured:

Table III

COMPARISON OF STEEL BARS IN AS CAST CONDITION IN WHICH IRON CONTENT IS VARIED

Amount of Iron	Ult. Strength in p.s.i.	Yld. Strength in p.s.i.	Elongation in percent
.12-----	37,350	23,250	9.2
.16-----	37,610	22,480	9.2
.21-----	37,610	22,100	10.5
.25-----	37,980	22,810	8.5

Table IV

COMPARISON OF STEEL BARS OF TABLE III AFTER SOLUTION HEAT TREATMENT

Amount of Iron	Ult. Strength in p.s.i.	Yld. Strength in p.s.i.	Elongation in percent
.12-----	51,430	47,020	4.5
.16-----	51,120	46,930	3.0
.21-----	51,740	48,140	3.0
.25-----	49,830	45,910	2.5

Table V

COMPARISON OF STEEL BARS IN AS CAST CONDITION VARIATION IN SILICON

Amount of Silicon	Ult. Strength in p.s.i.	Yld. Strength in p.s.i.	Elongation in percent
.10-----	38,280	24,240	10.5
.15-----	35,090	22,950	7.8
.20-----	30,230	17,620	8.5
.25-----	26,460	14,160	9.2

Table VI

COMPARISON OF STEEL BARS OF TABLE V AFTER SOLUTION HEAT TREATMENT

Amount of Silicon	Ult. Strength in p.s.i.	Yld. Strength in p.s.i.	Elongation in percent
.10-----	50,520	45,120	5.0
.15-----	48,810	43,910	4.0
.20-----	45,840	40,320	5.0
.25-----	43,570	34,620	8.2

While no material differences were observed in the strength properties or elongation in as cast condition for variation in the amount of iron, the elongation falls off undesirably when the iron content is as high as 0.16% after the bars have been subjected to solution heat treatment and artificial aging. Thus the amount of iron should be held to less than 0.16% and it is believed that the upper limitation can properly be placed at 0.15% by weight of iron.

With respect to silicon, the strength properties of the as cast alloy falls off materially when the amount of silicon exceeds 0.15% by weight. A similar drop in strength is experienced also in the alloy subjected to solution heat treatment, but the values secured are so unexpectedly high in the first instance that the drop in strength is still acceptable.

The foregoing Tables III-VI will also illustrate the exceptionally high strength properties that are secured with the alloy of this invention upon solution heat treatment and artificial aging. One of the outstanding characteristics of the alloys embodying the features of this invention is the ability of the alloy to self age in the as cast condition to provide strength properties which have not heretofore been available in sand cast alloys. This makes available an alloy which can be put to a number of uses that were not heretofore open to aluminum or its alloys. The alloys having these unexpected self-aging properties and high strength in as cast condition are also subject to solution heat treatment to provide alloys of exceptionally high strengths, as previously pointed out. The foregoing can be illustrated by the following examples.

EXAMPLE 3

Alloy composition:	
Elements—	Percent by wgt.
Zinc -----	7.33
Magnesium -----	0.80
Titanium -----	0.22
Chromium -----	0.10
Boron -----	0.001
Zirconium -----	0.005
Silicon -----	0.07
Iron -----	0.05
Aluminum—remainder (with less than 0.75% residual metals and impurities).	

As cast, the alloy had an ultimate strength of 38,220 p.s.i. After one week, it increased to 40,830. After two weeks, it increased to 43,010. After three weeks, it increased to 43,320, and after three months the ultimate strength reached a value of 44,000 or slightly better. The yield strengths were similarly increased from 21,980 as cast, to 28,920 after one week, to 31,880 after two weeks,

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to 33,170 after three weeks, and to better than 36,000 after three months aging. The elongation varied from 10.8% as cast to 5.5% after three weeks, and a minimum of 5% after three months aging.

EXAMPLE 4

Alloy composition:

Elements—	Percent by wgt.
Zinc	7.0
Magnesium	0.75
Chromium	0.05-0.15
Titanium	0.10-0.25
Boron	0.0005-0.001
Iron	10.15
Silicon	10.15
Tin	10.001
Lead	10.001
Copper	10.25
Manganese	10.10
Aluminum—remainder (with less than 0.75% residual metals and impurities).	

¹ Max.

The following are the results secured of the alloy of Example 4 after aging for one day, one week, one month, and three months:

Time of Aging	U.S., p.s.i.	Y.S., p.s.i.	Elong., Percent	Hardness, BHN
1 day	38,000	25,000	11	70
1 week	39,000	27,000	8	80
1 month	41,000	34,000	5	90
3 months	43,000	35,000	4	91

EXAMPLE 5

Alloy composition:

Elements—	Percent by wgt.
Zinc	6.5
Magnesium	0.65
Chromium	0.05-0.15
Titanium	0.10-0.25
Boron	0.0005-0.001
Iron	¹ 0.15
Silicon	¹ 0.15
Tin	¹ 0.001
Lead	¹ 0.001
Copper	¹ 0.25
Manganese	¹ 0.10
Aluminum—remainder (with less than 0.75% residual metals and impurities).	

¹ Max.

The following are the results which are secured after self aging for one day, one week, two weeks, three weeks, and four weeks:

Time of Aging	U.S., p.s.i.	Y.S., p.s.i.	Elong., Percent	Hardness, BHN
1 day	36,000	20,000	14	55
1 week	37,000	24,000	12	65
2 weeks	38,000	27,000	10	70
3 weeks	39,000	30,000	9	80
4 weeks	40,000	32,000	8	85

The following are further illustrations of formulations of aluminum base alloys embodying the features of this invention:

EXAMPLE 6

Alloy composition:

Elements—	Percent by wgt.
Zinc	5.5-8.5
Magnesium	0.55-0.9
Chromium	0.025-0.25
Titanium	0.05-0.4
Aluminum—remainder (with less than 0.75% residual metals and impurities).	

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EXAMPLE 7

Alloy composition:

Elements—	Percent by wgt.
Zinc	6-8
Magnesium	0.6-0.8
Chromium	0.05-0.15
Titanium	0.10-0.25
Aluminum—remainder (with less than 0.75% residual metals and impurities).	

EXAMPLE 8

Alloy Composition—Elements	Percent by Wgt.	
	Broad Range	Narrow Range
Zinc	5.5-8.5	6-8
Magnesium	0.55-0.9	0.6-0.8
Chromium	0.025-0.25	0.05-0.15
Titanium	0.05-0.40	0.10-0.25
Boron	0.0002-0.002	0.0005-0.001
Aluminum	(¹)	(¹)

¹ Remainder (with less than 0.75% residual metals and impurities).

EXAMPLE 9

Alloy Composition—Elements	Percent by Wgt.	
	Broad Range	Narrow Range
Zinc	5.5-8.5	6-8
Magnesium	0.55-0.9	0.6-0.8
Chromium	0.025-0.25	0.05-0.15
Titanium	0.05-0.40	0.10-0.25
Boron	0.0002-0.001	0.0005-0.001
Zirconium	Less than 0.35	0.05-0.25
Aluminum	(¹)	(¹)

¹ Remainder (with less than 0.75% residual metals and impurities).

When the total impurities and residual metals, including the iron, silicon, copper, manganese and sodium, exceeds 0.75% by weight of the alloys, an undesirable drop in the physical and mechanical properties is experienced both in the as cast and in the heat treated condition. Thus it is undesirable to permit the silicon and iron to exceed 0.15% each or to permit the amount of copper to exceed 0.25% or to permit the amount of manganese to exceed 0.10%, or to permit the silicon, iron, copper, tin, sodium and lead to exceed a total of 0.75%. The amount of such other residual metals should not exceed the maximum set forth in Examples 4 and 5.

It will be apparent from the foregoing that I have provided an aluminum base alloy capable of self aging to produce what is believed to be fantastically high yield strengths in the as cast condition. A value in the order of 44,000 p.s.i. for ultimate strength in as cast aluminum alloy has, to my knowledge, never previously been available. Similarly, ultimate strengths in the order of 50,000 p.s.i. and yield strengths of 42,000 p.s.i., with elongations as high as 6-8% as secured by heat treatment of the alloys of this invention, are also believed to be unexpectedly secured with an aluminum base alloy.

It will be understood that changes may be made in the details of formulation and preparation without departing from the spirit of the invention, especially as defined in the following claims.

I claim:

1. A self-aging aluminum base casting alloy consisting essentially of zinc present in an amount within the range of 6-8% by weight, magnesium present in an amount within the range of 0.6-0.8% by weight, chromium present in an amount within the range of 0.05-0.15% by weight, and titanium present in an amount within the range of 0.1-0.25% by weight, the remainder being aluminum plus minor amounts of impurities.

2. A self-aging aluminum base casting alloy consisting essentially of zinc present in an amount within the range of 6-8% by weight, magnesium present in an amount

within the range of 0.6–0.8% by weight, chromium present in an amount within the range of 0.05–0.15% by weight, titanium present in an amount within the range of 0.1–0.25% by weight, and less than 0.75% by weight of impurities, the balance being aluminum.

3. A self-aging aluminum base casting alloy consisting essentially of zinc present in an amount within the range of 6–8% by weight, magnesium present in an amount within the range of 0.6–0.8% by weight, chromium present in an amount within the range of 0.05–0.15% by weight, and titanium present in an amount within the range of 0.1–0.25% by weight, and less than 0.75% by weight of impurities including a maximum of 0.15% by weight of any of the metals selected from the group consisting of silicon and iron, the balance being aluminum.

4. A self-aging aluminum base casting alloy consisting essentially of zinc present in an amount within the range of 6–8% by weight, magnesium present in an amount within the range of 0.6–0.8% by weight, chromium present in an amount within the range of 0.05–0.15% by weight, titanium present in an amount within the range of 0.1–0.25% by weight, and boron present in an amount within the range of 0.0005–0.001% by weight, the remainder being aluminum plus minor amounts of impurities.

5. A self-aging aluminum base casting alloy consisting essentially of zinc present in an amount within the range of 6–8% by weight, magnesium present in an amount within the range of 0.6–0.8% by weight, chromium present in an amount within the range of 0.05–0.15% by weight, titanium present in an amount within the range of 0.1–0.25% by weight, and boron present in an amount within the range of 0.0005–0.001% by weight, and less than 0.75% by weight of impurities, the balance being aluminum.

6. A self-aging aluminum base casting alloy consisting essentially of zinc present in an amount within the range of 5.5–8.5% by weight, magnesium present in an amount within the range of 0.55–0.95% by weight, chromium present in an amount within the range of 0.025–0.25% by weight, titanium present in an amount up to 0.4% by weight, and boron present in an amount up to 0.002% by weight, and less than 0.75% by weight of impurities including a maximum of 0.15% by weight of any of the metals selected from the group consisting of silicon and iron, the balance being aluminum.

7. A self-aging aluminum base casting alloy consisting essentially of zinc present in an amount within the range of 6–8% by weight, magnesium present in an amount within the range of 0.6–0.8% by weight, chromium present in an amount within the range of 0.05–0.15% by weight, titanium present in an amount within the range of 0.1–0.25% by weight, and boron present in an amount within the range of 0.0005–0.001% by weight, and less than 0.75% by weight of impurities including a maximum of 0.15% by weight of any of the metals selected from the group consisting of silicon and iron, the balance being aluminum.

8. A self-aging aluminum base casting alloy consisting essentially of zinc present in an amount within the range of 6–8% by weight, magnesium present in an amount within the range of 0.6–0.8% by weight, chromium pres-

ent in an amount within the range of 0.05–0.15% by weight, titanium present in an amount within the range of 0.1–0.25% by weight, and boron present in an amount within the range of 0.0005–0.001% by weight, and zirconium present in an amount within the range of 0.05–0.25% by weight, the remainder being aluminum plus minor amounts of impurities.

9. A self-aging aluminum base casting alloy consisting essentially of zinc present in an amount within the range of 6–8% by weight, magnesium present in an amount within the range of 0.6–0.8% by weight, chromium present in an amount within the range of 0.05–0.15% by weight, titanium present in an amount within the range of 0.1–0.25% by weight, and boron present in an amount within the range of 0.0005–0.001% by weight, and zirconium present in an amount within the range of 0.05–0.25% by weight, and less than 0.75% by weight of impurities, the balance being aluminum.

10. A self-aging aluminum base casting alloy consisting essentially of zinc present in an amount within the range of 6–8% by weight, magnesium present in an amount within the range of 0.6–0.8% by weight, chromium present in an amount within the range of 0.05–0.15% by weight, titanium present in an amount within the range of 0.1–0.25% by weight, and boron present in an amount within the range of 0.0005–0.001% by weight, and zirconium present in an amount within the range of 0.05–0.25% by weight, and less than 0.75% by weight of impurities including a maximum of 0.15% by weight of any of the metals selected from the group consisting of silicon and iron, the balance being aluminum.

11. A self-aging aluminum base casting alloy consisting essentially of zinc present in an amount within the range of 5.5–8.5% by weight, magnesium present in an amount within the range of 0.55–0.95% by weight, chromium present in an amount within the range of 0.025–0.25% by weight, titanium present in an amount up to 0.4% by weight, zirconium present in an amount up to 0.35% by weight, and less than 0.75% by weight of impurities including a maximum of 0.15% by weight of any of the metals selected from the group consisting of iron and silicon, the balance being aluminum.

12. A self-aging aluminum base casting alloy consisting essentially of zinc present in an amount within the range of 6–8% by weight, magnesium present in an amount within the range of 0.6–0.8% by weight, chromium present in an amount within the range of 0.05–0.15% by weight, titanium present in an amount within the range of 0.1–0.25% by weight, zirconium present in an amount within the range of 0.05–0.25% by weight, and less than 0.75% by weight of impurities including a maximum of 0.15% by weight of any of the metals selected from the group consisting of iron and silicon, the balance being aluminum.

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