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MAGNESIUM-BASE ALLOY

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The invention relates to magnesium-base alloys containing yttrium.

The magnesium-base alloys containing thorium have been known to offer the best high temperature properties of any of the magnesium alloys. However, thorium is radiocative and may be objectionable for some applications.

It has also been known to use a mixture of rare earth metals as alloying ingredients in magnesium to improve the high temperature properties of magnesium alloys. The addition of a mixture of rare earth metals, however, generally does not improve the magnesium alloys to the same extent as an addition of thorium.

It has long been considered desirable to provide magnesium alloys having mechanical properties comparable to the magnesium-thorium alloys but not offering the same disadvantages.

The magnesium alloys containing yttrium exhibit, in the cast form, properties comparable to the magnesium-thorium alloys. These alloys also exhibit excellent properties in the wrought form. It has now been discovered that these alloys are especially improved by the further addition of zinc or silver. Still further improvement is had by the addition of zirconium to the magnesium-yttrium-zinc or magnesium-yttrium-silver alloys in cast form and by the addition of zirconium and manganese to the magnesium-yttrium-zinc or magnesium-yttrium-silver alloys in wrought form.

The present improved alloy contains, by weight, from 0.2 to 10 percent of yttrium, from 0.1 to 6 percent of zinc, or from 0.5 to 2 percent of silver, and the balance substantially magnesium. The alloy is further improved by the addition of 0.1 to 1 percent of zirconium, or, alternatively, from 0.1 to 2.5 percent of manganese. If desired, low levels of both zirconium and manganese may be employed in amounts which are mutually compatible in a magnesium alloy system, for example, amounts of zirconium and of manganese in the range of from about 0.05 to 0.3 percent.

In more preferred ranges of compositions which are to be prepared in wrought form, the alloy comprises from 1 to 8 percent of yttrium, from 0.2 to 1 percent of zinc, from 0.5 to 1.5 percent of manganese, up to about 0.1 percent of zirconium and the balance substantially magnesium. An even more preferred range of yttrium content is from 2 to 5 percent.

In more preferred ranges of compositions for alloys which may be prepared either in cast or wrought form, the alloy comprises from 1 to 8 percent of yttrium, from 0.5 to 2.5 percent of zinc, from 0.2 to 0.7 percent of zirconium and the balance substantially magnesium. An even more preferred range of yttrium content is from 2 to 5 percent.

The present alloys with a high yttrium to zinc ratio, for example, a ratio of about 10 to 1, tend to exhibit optimum strength properties at elevated temperatures while those with a low yttrium to zinc ratio, for example, a ratio of about 0.3 to 1.0, tend to exhibit optimum properties

at lower temperatures. There appears to be a fairly uniform transition and alloys with intermediate yttrium to zinc ratios exhibit intermediate effects with regard to properties both at elevated temperature and at ambient room temperature.

The yttrium used in preparing the present alloy consists at least predominantly of yttrium and the balance not more than 25 percent by weight rare earth metals with other metals and nonmetals being present in not more than minor amounts, i.e., less than about 3 percent by weight. Preferably, the yttrium used consists of at least 95 percent of yttrium, not more than about 3 percent of other rare earth metals, not more than about 1.5 percent of other metals than rare earth metals and not more than about 0.5 percent of nonmetallic material. A dilution of yttrium with a natural blend of rare earth metals diminishes the excellent alloy properties obtained with relatively pure yttrium as a constituent of the alloy. The amount of rare earth metal in the magnesium-base alloy should be restricted to one percent by weight, and is preferably less than 0.5 percent by weight.

The alloy may be made in the desired proportions according to the invention by melting together the alloying ingredients in proper proportions or by using hardeners of magnesium alloys containing the alloying constituents. Protection from oxidation during alloying is effected by the use of a saline flux as in conventional alloying of magnesium. The molten alloy may be flux refined, if desired, by stirring the alloy with additional flux. The so-refined metal is allowed to settle and then is separated from the flux as by decanting into a suitable casting mold, e.g., a sand mold for cast products, a round mold for extrusion stock, and a rectangular mold for rolling slabs.

In rolling the cast metal, it is generally best to scalp the rolling slab and to reduce the thickness of the slab by rolling in the rolls of a mill at a temperature in the range of 800 to 950° F. The sheet is then generally annealed at 850 to 1050° F. for one hour, quenched and cold rolled and given a final heat treatment at about 500° F. for the hard temper and 850° F. for the soft temper condition. The sheet may also be heat treated at 850 to 1050° F. for about one hour, quenched and aged about 24 hours at about 450° F. to produce the T6 temper condition.

In extruding the cast metal, it is desirable first to scalp the cast metal so as to present a smooth, clean surface to the extrusion die. The clean extrusion stock is heated to a suitable temperature, e.g., about 700 to 1000° F. The metal is then extruded in a conventional metal extrusion press. The resulting extrusion may be heat treated in the manner described above for sheet metal to produce the T6 temper condition or it may simply be aged to produce the T5 temper condition.

EXAMPLES

Alloys according to the invention as well as comparative alloys outside the scope of the invention were conventionally prepared and cast into sand test bar molds, 2" x 4" x 8" rolling slabs and 3-inch diameter ertrusion billets.

The cast bars were heat treated to the T5 or T6 temper condition as noted above and the mechanical properties were determined without machining the bars. The compositions employed, the conditions of heat treatment and tensile properties, elongation and percent creep are listed in Table I.

TABLE I.—PROPERTIES OF CAST METAL

Test Number	Composition, percent by Weight*					Mechanical Properties										
						Metal in T5 Condition				Metal in T6 Condition						
	Y	Zn	Zr	Mn	Ag	Test Temp. 75° F.			600° F.	Test Temp. 75° F.			Test Temp. 700° F.			600° F.
						%E	TYS	TS	%C	%E	TYS	TS	%E	TYS	TS	%C
1	4.8					7	13	23	0.57	5	13	21	39	7	10	0.03
2	3.1		0.9			16	14	28	8.75	15	12	27	56	6	8	0.82
3	1.9	2.1	0.9			8	16	31	0.28	9	19	37	23	9	13	0.32
4	2.6	6.1	1.0			1	22	32	**0.03	3	20	33	63	5	7	**0.01
5	3.8		.05	0.9		8	11	25	0.15	5	12	23	42	7	9	0.08
6	2.7	0.4		0.9		7	11	24	0.02	8	12	26	12	8	13	0.06
7	5.3	1.0	0.6			10	16	30	.11	10	18	32	25	10	16	.97
8	4.8	2.1	0.7			11	16	32	.11	4	15	26	29	9	16	.14
9	4.5		0.7		1.6	6	16	29	3.16	11	21	37	99	6	9	1.4
10	5.0	0.3	.06	1.0		10	13	27	.11	1	11	12			7	.19
11	.85	5.7	0.9			4	20	33	**.10	1	18	19	43	4	6	**.17

*=Balance magnesium.
%E=Percent elongation.
TYS=Tensile yield strength given in thousands of pounds per square inch.
**=Test carried out at 400° F. and 5,000 pounds per square inch.

TS=Ultimate tensile strength given in thousands of pounds per square inch.
%C=Percent creep in 100 hours at test temperature under a load of 3,000 pounds per square inch.

By way of comparison, magnesium-base alloys containing thorium and having the ASTM designation HK31A were similarly cast in a sand test bar mold. In the T6 condition, the test bar exhibited a tensile yield strength of 17,000 pounds per square inch and an ultimate tensile strength of 32,000 pounds per square inch when tested at 75° F. A bar of the same alloy exhibited a tensile yield strength of 8,000 pounds per square inch and an ultimate tensile strength of 14,000 pounds per square inch when tested at 700° F. Bars of the same thorium alloy exhibited a 0.2 percent total extension (about 0.15 percent creep) in 100 hours at 600° F. under a load of 2,500 pounds per square inch.

By way of comparison, a thorium-containing magnesium-base alloy having the ASTM designation HZ32A was similarly cast in a sand test bar mold. A bar of this also exhibited 0.2 percent total extension (about 0.15 percent creep) under a load of 1,000 pounds per square inch at 600° F. for 100 hours. A bar of the same alloy in the T6 condition exhibited a tensile yield strength of 6,000 pounds per square inch and an ultimate tensile strength of 8,000 pounds per square inch when tested at 700° F.

The rolling slabs were scalped and reduced to a thickness of about 1/10" by rolling in the rolls of a mill at 850 to 950° F., reheating as necessary to prevent cracking. The so-formed sheet was then annealed at 850 to 1050° F., quenched, cold rolled 10 to 40 percent (1 to 2 percent per pass through steam heated rolls), and given a final heat treatment at a temperature of about 500° F. The alloy composition, the mechanical properties of the sheet and the conditions of heat treatment are given in Table II.

TABLE II.—PROPERTIES OF ROLLED SHEET

Test Number	Composition, Percent by Weight*					Mechanical Properties							
	Y	Zn	Zr	Mn	Ag	YS at 75° F., Percent of Cold Rolling			YS at 700° F., Percent of Cold Rolling			Creep, 600° F., 100 hours, 10% of Cold Rolling	
						0	10	40	0	10	40	Stress, p.s.i.	Percent of Creep
12	4.8					11	22	26	6	4	2	2,000	0.26
13	3.1		0.9			11	22	30	5	3	1	2,000	2.92
14	2.0	1.1	0.8			13	28	**36(30)	8	7	4	2,000	1.24
15	2.6	6.1	1.0			17	27	36	4	2	1	***5,000	0.18
16	3.8		.05	0.9		10	23	32	6	6	3	2,000	0.28
17	2.7	0.4		0.9		10	22	28(30)	7	9	6	2,000	0.12
						Lower of Tensile and Compression Yield Strengths Measured in Longitudinal Direction Only							
18	5.1	1.0	0.6			18	33	39(19)	11	12	10(19)	2,000	.31
19	4.8	2.1	0.7			23	41	47(24)	10	9	5	2,000	.78
20	4.4		0.7		1.6	16	31	43	7	5	2	2,000	.99
21	5.0	0.3	.06	0.9		13	25	38	9	11	7	3,000	1.19
22	0.8	5.7	0.9			Not Rollable—Hot Short							

YS=Lowest yield strength, tension or compression, measured in longitudinal or transverse direction except as noted, the strength being expressed in thousands of pounds per square inch.
*=Balance magnesium.

**=Parenthetical values following yield strength indicates percent of cold rolling when different from column heading.
***=Test carried out at 400° F. instead of 600° F.

alloy in the T5 condition exhibited a tensile yield strength of 14,000 pounds per square inch and an ultimate tensile strength of 28,000 pounds per square inch when tested at 75° F. The alloy in the T5 condition exhibited 0.2 percent total extension (about 0.15 percent creep) when placed under a load of 35,000 pounds per square inch at 600° F. for 100 hours. A bar of this alloy in the T6 condition exhibited tensile yield strength of 7,000 pounds per square inch and an ultimate tensile strength of 10,000 pounds per square inch when tested at 700° F.

In a further comparison test, a rare earth metal-containing magnesium-base alloy having the ASTM designation EZ33A was similarly prepared and cast into sand test bar molds. A bar of this metal in the T5 condition exhibited a tensile yield strength of 16,000 pounds per square inch and an ultimate tensile strength of 22,000 pounds per square inch. The metal in the T5 condition

In a comparison test, a thorium-containing magnesium-base alloy having the ASTM designation HM21A was similarly cast in a rolling slab, scalped and rolled and brought to the T8 condition. The so-rolled sheet was subjected to mechanical testing. Sheet which had been cold rolled 10 percent exhibited a minimum yield strength in the longitudinal direction of 26,000 pounds per square inch at 75° F. Samples of the same sheet when tested at 700° F. exhibited a minimum yield strength of 9,000 pounds per square inch. Further samples of the same sheet, on being subjected to 6,000 pounds per square inch load at 500° F. for 1 hour, showed a total extension of 0.2 percent.

The extrusion billets were scalped and heated to a temperature of 750 to 850° F. and extruded into 1/16" x 1¼" strip from the 3-inch diameter contianer of a ram extrusion press. During the extrusion, the container was maintained at a temperature in the range of 700 to 800° F. and the strip was expressed at a speed of 5 feet per minute. The strip was then heat treated and mechanical properties were determined. The compositions of the alloy, the mechanical properties and the heat treatment are indicated in Table III.

TABLE III.—PROPERTIES OF EXTRUDED METAL

Test No.	Composition, Percent by Weight*					Mechanical Properties											
						Metal in T5 Condition						Metal in T6 Condition					
	Y	Zn	Zr	Mn	Ag	Test Temp. 15 75° F.				700° F.		Test Temp. at 75° F.				700° F.	600° F.
						%E	TYS	CYS	TS	TYS	TS	%E	TYS	CYS	TS	TYS	TS	%C
23	4.8					30	16	16	30	4	6	19	9	8	22	6	10	.23
24	3.1		0.9			32	22	21	30	2	5	26	8	8	23	5	7	6.75
25	2.0	1.1	0.8			26	23	24	36	3	10	28	17	18	34	7	12	**RA(10)
26	2.6	6.1	1.0			14	43	36	50	1	2	12	36	22	45	5	7	***0.00
27	3.8		.05	0.9		30	15	16	29	4	6	21	10	9	24	6	9	0.42
28	2.7	0.4		0.9		28	16	17	31	5	10	16	11	11	26	8	12	0.10
29	5.3	1.0	0.6			25	24	26	37	5	11	25	18	19	36	9	14	1.3
30	4.8	2.1	0.7			24	24	27	40	4	11	24	22	24	39	7	14	**RA(1)
31	4.4		0.7		1.6	20	28	28	39	3	8	16	20	22	36	6	10	1.53
32	5.0	0.3	.06	0.9		26	17	18	32	8	11	20	11	11	28	8	13	.56
33	0.8	5.7	0.9			14	43	37	51	1	2	10	38	20	45	5	6	5.35

*=Balance magnesium.
**RA=Ran away, extension too large to measure, ran off scale in the number of hours shown in parentheses.
%E=Percent elongation.
TYS=Tensile yield strength given in thousands of pounds per square inch.
TS=Ultimate tensile strength given in thousands of pounds per square inch.
%C=Percent creep in 100 hours at test temperature under a load of 3,000 pounds per square inch.
***=Test carried out at 400° F. with a load of 5,000 pounds per square inch.

In a comparison test, a thorium-containing magnesium-base alloy having the designation HM31A–F was similarly cast and extruded. An extruded strip of the metal while in the T5 condition exhibited a tensile yield strength of 33,000 pounds per square inch and ultimate tensile strength of 40,000 pounds per square inch when tested at 75° F. The strip in the T5 condition exhibited tensile yield strength of 11,000 pounds per square inch and an ultimate tensile strength of 13,000 pounds per square inch when tested at 700° F. The strip in the T5 condition also showed 0.2 percent total extension on being subjected to a load of 6,000 pounds per square inch at 600° F. for 100 hours.

The alloy of the invention having been thus fully described, various modifications thereof will at once be apparent to those skilled in the art, and the scope of the invention is to be considered limiting only by the appended claims.

We claim:

1. The magnesium-base alloy which comprises by weight from 0.2 to 10 percent of yttrium, an alloying constituent selected from the group consisting of from 0.1 to 6 percent of zinc and from 0.5 to 2 percent of silver and the balance substantially magnesium.

2. The alloy as in claim **1** which contains at least 0.05 percent of zirconium and at least 0.05 percent of manganese, the zirconium and manganese being present in mutually compatible amounts and alloyed with the magnesium.

3. The magnesium-base alloy which comprises by weight from 0.2 to 10 percent of yttrium, from 0.1 to 6 percent of zinc and the balance substantially magnesium.

4. The alloy as in claim **3** which contains from 0.1 to 1 percent of zirconium.

5. The alloy as in claim **3** which contains from 0.1 to 2.5 percent of manganese.

6. The magnesium-base alloy which comprises by weight from 1 to 8 percent of yttrium, from 0.2 to 1 percent of zinc, from 0.5 to 1.5 percent of manganese and the balance substantially magnesium.

7. The alloy as in claim **6** which contains from 2 to 5 percent of yttrium.

8. The alloy as in claim **6** which contains up to about 0.1 percent of zirconium.

9. The magnesium-base alloy which comprises by weight from 1 to 8 percent of yttrium, from 0.5 to 2.5 percent of zinc, from 0.2 to 0.7 percent of zirconium and the balance substantially magnesium.

10. The alloy as in claim **9** which contains from 2 to 5 percent of yttrium.

11. The magnesium-base alloy which comprises by weight from 0.2 to 10 percent of yttrium, from 0.5 to 2 percent of silver and the balance substantially magnesium.

12. The alloy as in claim **11** which contains in addition an alloying constituent selected from the group consisting of from 0.1 to 1 percent of zirconium, from 0.1 to 2.5 percent of manganese, and a combination of at least 0.05 percent of zirconium and at least 0.05 percent of manganese, the zirconium and manganese being mutually compatible in the alloy and both the zirconium and the manganese being alloyed with the magnesium.

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