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[54] PROCESS FOR PREPARING ALUMINUM BASE ALLOYS

[72] Inventors: **Philip R. Sperry**, North Haven; **Damian V. Gullotti**, West Haven, both of Conn.

[73] Assignee: **Olin Corporation**

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[58] **Field of Search** 75/146, 147, 141, 142; 148/11.5, 12.7, 159, 32, 32.5, 2

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Primary Examiner—Richard O. Dean
Attorney—Robert H. Bachman and Gordon G. Menzies

[57] **ABSTRACT**

A process for preparing aluminum base alloys containing silicon and magnesium comprising the steps of hot working, quenching and aging and to improved hot-worked aluminum-based alloys having high-strength and high-impact properties.

11 Claims, No Drawings

PROCESS FOR PREPARING ALUMINUM BASE ALLOYS

The present invention relates to a process for obtaining an aluminum base alloy containing silicon and magnesium. The present invention also relates to an improved aluminum base alloy containing silicon and magnesium, wherein said alloy is a hot-worked alloy and has high-strength and high-impact properties.

Hot-worked aluminum base alloys containing magnesium and silicon find wide application in a wide variety of uses, for example, they may be readily used as extrusions, forgings or rolled products.

There are many applications where it is highly desirable to develop a hot-worked product having a combination of high-strength and high-impact properties. For example, there are certain applications for aluminum alloy extrusions where high impact strength is one of the major requirements. A highway bridge railing or median barrier of extruded aluminum must absorb a considerable amount of energy from a vehicle crashing into it before it fails.

Accordingly, it is a principal object of the present invention to provide new and improved hot-worked aluminum base alloys.

It is a further object of the present invention to provide a process for obtaining improved hot-worked aluminum base alloys.

It is a still further object of the present invention to provide improved hot-worked aluminum base alloys having a combination of high-strength and high-impact properties.

Further objects and advantages of the present invention will appear hereinafter.

In accordance with the present invention it has now been found that the foregoing objects and advantages may be readily obtained.

The improved hot-worked alloy of the present invention consists essentially of silicon from 0.3 to 1.3 percent, magnesium from 0.3 to 1.5 percent, chromium from 0.03 to 0.40 percent and zirconium from 0.03 to 0.20 percent. Preferably, the alloy of the present invention also contains manganese in an amount from 0.03 to 0.4 percent.

The improved alloy of the present invention is a hot-worked product and has a surprising combination of high-strength and high-impact properties. The microstructure of the alloy of the present invention is characterized by a substantially unrecrystallized grain structure. It is surprising that the combination of ingredients of the alloy of the present invention achieves such excellent properties and it is further surprising that the substantially unrecrystallized grain structure results in improved impact properties.

The process of the present invention comprises: hot working the alloys at a finishing temperature in excess of 850° F.; water quenching the alloys down to a temperature of 350° F. or below at a cooling rate of from 1,000° to 10,000° F. per minute; and thermally artificially aging the alloys at a temperature from 200° to 410° F. for from 15 minutes to 24 hours.

As stated hereinabove, the alloys of the present invention are characterized by a surprising combination of high-strength and high-impact toughness. For example, generally the minimum properties obtained in accordance with the foregoing process are as follows: tensile strength at least 38,000 p.s.i.; yield strength at 0.2 percent offset at least 35,000 p.s.i. and elongation at least 8 percent.

The minimum impact toughness of the alloys of the present invention is for a ⅛-inch-thick specimen, the Charpy Notch impact test yields at least 15 foot-pounds. One would obtain at least 20 foot-pounds for a 0.394-inch-thick specimen, and typically 30 to 40 foot-pounds.

In addition to the foregoing the alloy of the present invention has numerous other highly desirable characteristics, for example, it is easily extruded and has good corrosion resistance.

The alloy of the present invention contains from 0.3 to 1.3 percent silicon and preferably from 0.4 to 0.9 percent silicon.

Silicon in the preferred range has been found to give particularly advantageous results. The alloy of the present invention contains magnesium in an amount from 0.3 to 1.5 percent and preferably from 0.4 to 1.0 percent. The chromium content may vary from 0.03 to 0.40 percent and preferably from 0.05 to 0.35 percent. The zirconium may vary from 0.03 to 0.20 percent and preferably from 0.05 to 0.15 percent.

As stated hereinabove, it has been found to be particularly advantageous to include manganese in an amount from 0.03 to 0.4 percent and preferably in an amount from 0.05 to 0.3 percent.

Other especially advantageous additives are titanium up to 0.10 percent and vanadium up to 0.15 percent.

Naturally, the present invention contemplates conventional impurities common for alloys of this type. This is important since it indicates that the improved properties of the alloys of the present invention are obtainable with normal commercial purity materials. For example, normal impurities include 0.60 percent maximum iron; 0.30 percent maximum copper; 0.50 percent maximum zinc; up to 0.008 percent boron; 0.10 percent maximum each of other elements the total of which is a maximum of 0.50 percent.

The manner of melting and casting the alloy is not especially critical and conventional methods of melting and casting may be conveniently employed. It is desirable to uniformly distribute the silicon and magnesium throughout the matrix of the alloy before the process of the present invention is performed, such as by a homogenization heat treatment subsequent to the casting operation. Before or during hot working some high temperature precipitate should be formed due to Cr, Zr and Mn, as this is the mechanism by which recrystallization is inhibited. However, this can be accomplished by reheating for hot working as well as by homogenization.

After casting the alloy is hot worked at a finishing temperature in excess of 850° F. and preferably in excess of 900° F., for example, forging, rolling or extruding. By "finishing temperature" it is meant the final temperature at which significant deformation is obtained in the hot-working operation. When the alloy is extruded, the die exit temperature should be in excess of 850° F. It is preferable that the actual temperature be high enough to dissolve substantially all Mg and Si which is available for maximum strengthening.

Following the hot working operation it is important to rapidly quench the material to a temperature of at least 350° F. at a cooling rate of 1,000° to 10,000° F. per minute. The rapid quenching is normally obtained by plunging the material in water or by passing the material through a water spray quench.

Optionally, the material may then be cold worked up to 5 percent, e.g., rolling, stretching, etc.

The material should be then artificially aged at a temperature of 200° to 410° F. for 15 minutes to 24 hours.

The alloys of the present invention are quench sensitive. It is a particularly surprising finding of the present invention that this quench sensitivity can be controlled with respect to a particularly preferred composition. This is accomplished by a critical adjustment of the quantities of chromium, zirconium and manganese present in the alloy so that each of these materials are present in an amount of 0.03 to 0.2 percent, and the total chromium plus zirconium plus manganese content is from 0.2 to 0.35 percent. It has been found that when the composition has been controlled in this manner, the alloy can be air cooled at a cooling rate from 100° to 1,000° F. per minute; otherwise, the alloy must be water quenched at the more rapid rate specified hereinabove.

The air cooling is normally achieved by using appropriately placed fans.

In this particularly preferred composition, the hot working step should be performed at a finishing temperature in excess of 900° F. and preferably in excess of 950° F.

As stated hereinabove, the alloy of the present invention is a hot-worked product with a surprising combination of high-strength and high-impact properties and with a microstructure characterized by a substantially unrecrystallized grain structure.

The process of the present invention and improvements resulting therefrom will be more readily apparent from a consideration of the following illustrative examples.

EXAMPLE I

Ingots were prepared by direct chill (DC) casting in a conventional manner summarized as follows. Melting and alloying was carried out in a gas-fired, open hearth furnace. After alloying the melt was degassed by gaseous chlorine fluxing for 20 minutes. The average pouring temperature was 1,370° F. The average casting speed was 4½ inches per minute and the metal head was maintained between 2½ and 3 inches. The composition of the alloys prepared are given in Table I below.

TABLE I

Alloy A		
	silicon	0.78
	magnesium	0.47
	iron	0.14
	titanium	0.01
	chromium	0.050
	zirconium	0.056
	manganese	0.054
	copper	0.00
	zinc	0.04
	aluminum	Balance
Alloy B		
	silicon	0.81
	magnesium	0.53
	iron	0.14
	titanium	0.01
	chromium	0.107
	zirconium	0.108
	manganese	0.108
	copper	0.00
	zinc	0.03
	aluminum	Balance

EXAMPLE II

The alloys prepared in Example I were processed in the following manner. The ingots were given a homogenization heat treatment of about 1,025° F. for about 10 hours followed by cooling in air. The billets were sawed to length and reheated for extrusion in a gas-fired, control temperature set at 1,000° F. Measured surface temperatures ranged between 975° and 1,025° F. before entering the press. Three extrusion dies were used to produce section thicknesses of one-eighth, one-fourth, and one-half inch. Exit temperatures ranged from 980° to 1,000° F. One extrusion of each thickness was fan cooled as it exited from the press at a cooling rate in the range of the process of the present invention; another was water quenched by passing it through an open ended trough fed by an upward flow of water at both ends at a cooling rate in the range of the process of the present invention. All extrusions were aged at room temperature for about 24 hours, followed by artificial aging at 350° F. for 5 hours. Tensile test specimens and Charpy impact specimens were taken from the extrusions. The ⅛- and ¼-inch-thick extrusions were tested with reduced width from the standard 0.394 inch and the impact test value was corrected for reduced area.

The results are shown in Table II below and clearly show a combination of high strength and high impact properties.

The excellent improved impact toughness was due to the retention of an unrecrystallized grain structure in the alloys. There were shallow layers of recrystallized grains at the extrusion surfaces. These shallow layers were shallower for Alloy B than for Alloy A.

TABLE II

Section thickness (inches)	Alloy	Quench method	UTS (K s.i.)	Y.S. (K s.i.) at 0.2%	Elongation (percent in 2 in.)	Charpy impact strength (ft.-lbs.)
⅛	A	Fan cool	43.5	41.0	10	20.5
		Water	46.1	43.4	11	25.2
⅛	B	Fan cool	43.5	39.3	9.5	26.8
		Water	45.5	42.4	10	26.8
¼	A	Fan cool	43.0	39.3	8	24.0
		Water	46.0	43.1	9.5	27.8
¼	B	Fan cool	41.3	36.5	9.5	35.2
		Water	45.8	43.0	9.5	37.8
½	A	Fan cool	41.4	37.0	10.5	30.3
		Water	44.0	41.0	11.5	58.0
½	B	Fan cool	38.5	33.3	12	69.5
		Water	48.6	46.0	12.5	43.5

EXAMPLE III

Ingots were prepared in a conventional manner from two kilogram melts cast by the tilt mold (Durville) process. The resultant compositions are indicated in Table III below.

TABLE III

Alloy C		
	silicon	0.71%
	magnesium	0.56%
	iron	0.16%
	copper	<0.01%
	titanium	0.02%
	zirconium	0.16%
	aluminum	Balance
Alloy D		
	silicon	0.83%
	magnesium	0.58%
	iron	0.20%
	copper	<0.01%
	titanium	0.01%
	chromium	0.31%
	aluminum	Balance
Alloy E		
	silicon	0.71%
	magnesium	0.57%
	iron	0.16%
	copper	<0.01%
	titanium	0.02%
	chromium	0.22%
	zirconium	0.10%
	aluminum	Balance
Alloy F		
	silicon	0.78%
	magnesium	0.58%
	iron	0.17%
	copper	<0.01%
	titanium	0.02%
	chromium	0.10%
	manganese	0.09%
	zirconium	0.11%
	aluminum	Balance

EXAMPLE IV

The alloys prepared in Example III were processed in the following manner. The ingots were homogenized at 1,025° F. for 12 hours. The ingots were hot rolled from 1,000° F., 80 percent in one pass. The materials were quenched by plunging into water at room temperature, thus providing a cooling rate in the range of the process of the present invention. The materials were age hardened 5 hours at 350° F. The materials were then tested for tensile properties and Charpy impact properties using ⅛-inch specimens. The results are shown in Table IV below. The results clearly show that the alloy of the present invention namely Alloys E and F gave surprising improved properties over comparative Alloys C and D. It is noted that Alloy C does not contain the chromium addition and Alloy D does not contain the zirconium addition.

TABLE IV

Alloy	Tensile properties: Ultimate (K s.i.)	Yield (K s.i.)	Elongation (percent)	Charpy impact (ft.-lbs.): Individual	Average
C	43.7	38.6	14	10.4, 11.8	11.1
	44.1	38.4	13	12.6, 14.3	13.5
D	43.3	38.2	11	9.90, 10.7	10.3
	44.3	39.7	11	14.1, 14.7	14.4
E	43.5	38.4	13.5	20.5, 22.4	21.5
	45.2	39.3	12.5	18.6, 17.3	18.0
F	45.2	39.9	12.5	18.0, 17.8	17.9
	47.2	42.3	11.5	19.4, 18.9	19.2

EXAMPLE V

Ingots were prepared in a manner after Example I to have the composition indicated in Table V below.

TABLE V

Alloy G		
	silicon	0.84%
	magnesium	0.50%
	iron	0.20%
	copper	0.003%
	titanium	0.023%
	boron	0.004%
Alloy H		
	silicon	0.81%
	magnesium	0.58%
	iron	0.19%
	copper	0.004%
	titanium	0.023%
	chromium	0.25%
	zirconium	0.082%
	boron	0.004%
Alloy I (Commercial Alloy AA 6351)		
	silicon	1.08%
	magnesium	0.65%
	iron	0.19%
	copper	0.004%
	titanium	0.024%
	manganese	0.66%
	boron	0.004%
Alloy J (Commercial Alloy 6061)		
	silicon	0.64%
	magnesium	1.10%
	iron	0.25%
	copper	0.25%
	titanium	0.017%
	chromium	0.18%
	manganese	0.053%

EXAMPLE VI

The materials from Example V were processed in a manner after Example IV except that the materials were hot rolled 50 percent in one pass rather than 80 percent and Alloys I and J were aged for 8 hours at 350° F. The results are given in Table VI below and clearly show the surprising properties of Alloy H which represents the alloy of the present invention. It should be noted that the Charpy impact test utilized standard 0.394 inch specimens.

TABLE VI

Alloy	Tensile properties: Ultimate (K s.i.)	Yield (K s.i.)	Elongation (percent)	Standard charpy impact (ft.-lbs.)
G	43.5	38.8	12.0	8.10
	43.5	39.3	11.4	7.85
H	45.9	41.7	15.0	37.20
	46.1	42.0	15.0	37.75
I	49.5	46.4	12.1	11.85
	49.4	46.3	12.0	11.90
J	47.3	42.2	12.8	9.75
	47.5	42.3	13.0	9.60

This invention may be embodied in other forms or carried out in other ways without departing from the spirit or essential characteristics thereof. The present embodiment is therefore to be considered as in all respects illustrative and not restrictive, the scope of the invention being indicated by the appended claims. and all changes which come within the meaning and range of equivalency are intended to be embraced therein.

What is claimed is:

1. The process for preparing a material having a combination of high-strength and high-impact properties which comprises: providing an aluminum base alloy consisting essentially of from 0.3 to 1.3 percent silicon, 0.3 to 1.5 percent magnesium, 0.03 to 0.4 percent chromium, 0.03 to 0.2 percent zirconium, balance essentially aluminum; hot working said alloy at a finishing temperature in excess of 850° F.; water quenching said alloy to a temperature of at least 350° F. at a cooling rate of from 1,000° to 10,000° F. per minute; and thermally artificially aging said alloy at a temperature of from 200° to 410° F. for 15 minutes to 24 hours.

2. A process according to claim 1 wherein said alloy contains manganese in an amount from 0.03 to 0.4 percent.

3. A process according to claim 1 wherein said hot working is extruding at a die exit temperature in excess of 900° F.

4. A process according to claim 1 wherein said hot working is rolling at a finishing temperature in excess of 900° F.

5. A process according to claim 1 wherein the alloy is homogenized prior to hot working.

6. A process according to claim 1 wherein after said water quenching step said alloy is cold worked up to 5 percent.

7. The process for preparing a material having a combination of high-strength and high-impact properties which comprises: providing an aluminum base alloy consisting essentially of silicon from 0.3 to 1.3 percent, magnesium from 0.3 to 1.5 percent, chromium from 0.03 to 0.2 percent, zirconium from 0.03 to 0.2 percent, manganese from 0.03 to 0.2 percent, balance essentially aluminum, wherein the total chromium plus zirconium plus manganese content is from 0.2 to 0.35 percent; hot working said alloy at a finishing temperature in excess of 900° F.; air cooling said alloy to a temperature of at least 350° F. at a cooling rate of from 100° to 1,000° F. per minute; and thermally artificially aging said alloy at a temperature of from 200° to 410° F. for 15 minutes to 24 hours.

8. A process according to claim 7 wherein said hot working is extruding at a die exit temperature in excess of 950° F.

9. A process according to claim 7 wherein said hot working is rolling at a finishing temperature in excess of 950° F.

10. A process according to claim 7 wherein the alloy is homogenized prior to hot working.

11. A process according to claim 7 wherein after said air cooling step the alloy is cold worked up to 5 percent.

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