Abstract:
The invention relates to compositions and methods comprising a new aluminum alloy system useful for aluminum bottle applications. In one aspect, the invention further relates to a method of producing highly shaped aluminum products, such as bottles or cans, comprising the aluminum alloy.
ALUMINUM ALLOY SUITABLE FOR THE HIGH SPEED PRODUCTION OF ALUMINUM BOTTLE AND THE PROCESS OF MANUFACTURING THEREOF

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Patent Application No. 62/094,358, filed December 19, 2014, which is incorporated by reference herein in its entirety.

FIELD OF THE INVENTION

The invention is related to a new aluminum alloy. In one aspect, the invention further relates to a method of producing highly shaped aluminum products, such as bottles or cans, using the aluminum alloy.

BACKGROUND

Many modern methods of aluminum can or bottle manufacture require highly shapeable aluminum alloys. For shaped bottles, the manufacturing process typically involves first producing a cylinder using a drawing and wall ironing (DWI) process. The resulting cylinder is then formed into a bottle shape using, for example, a sequence of full-body necking steps, blow molding, or other mechanical shaping, or a combination of these processes. The demands on any alloy used in such a process or combination of processes are complex.

There is a need for alloys that can sustain high levels of deformation during mechanical shaping or blow molding for the bottle shaping process and that function well in the DWI process used to make the starting cylindrical preform.

Further requirements of the alloy are that it must be possible to produce a bottle which meets the targets for mechanical performance (e.g., column strength, rigidity, and a minimum bottom dome reversal pressure in the final shaped product) with lower weight than the current generation of aluminum bottles. The only way to achieve lower weight without significant modification of the design is to reduce the wall thickness of the bottle. This makes meeting the mechanical performance requirement even more challenging.

A final requirement is the ability to form the bottles at a high speed. To achieve a high throughput (e.g., 1000 bottles per minute) in commercial production, the shaping of the bottle must be completed in a very short time. Thus, methods are needed for making
preforms from the alloy at high speeds and levels of runability, such as that demonstrated by the current can body alloy AA3 104. AA3 104 contains a high volume fraction of coarse intermetallic particles formed during casting and modified during homogenization and rolling. These particles play a major role in die cleaning during the DWI process, helping to remove any aluminum or aluminum oxide build-up on the dies, which improves both the metal surface appearance and also the runability of the sheet.

In meeting all the requirements as stated above, different embodiments of the alloys and methods of the current invention have the following specific chemical composition and properties (all elements are expressed in weight percent (wt. %)).

SUMMARY

Provided herein are novel alloys that display high strain rate formability at elevated temperatures. The alloys can be used for producing highly shaped aluminum products, including bottles and cans.

In one embodiment, the aluminum alloy described herein comprises about 0.15-0.50 % Si, 0.35-0.65 % Fe, 0.05-0.30 % Cu, 0.60-1.10 % Mn, 0.80-1.30 % Mg, 0.000-0.0080 % Cr, 0.000-0.500 % Zn, 0.000-0.080 % Ti, up to 0.15 % of impurities, with the remainder as Al (all in weight percentage (wt. %)). Also provided herein are products (e.g., bottles and cans) comprising an aluminum alloy as described herein.

Further provided herein are methods of producing the aluminum alloys described. In one embodiment, the methods include direct chill (DC) casting of an aluminum alloy as described herein to form a metal product, homogenizing the metal product, hot rolling the metal product to produce a metal sheet, cold rolling the metal sheet (e.g., with a 60 % to 90 % thickness rejection), optionally recrystallization annealing the rolled sheet, cold rolling the annealed sheet, and stabilization annealing the rolled sheet. Products (e.g., bottles or cans) obtained according to the methods are also provided herein.

Other objects and advantages of the invention will be apparent from the following detailed description of embodiments of the invention.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 is a scanning transmission electron microscopy (STEM) micrograph of an aluminum alloy according to an embodiment of the invention showing a substructure with average geometrically necessary boundary (GNB) spacing larger than 300 nm.
Figure 2 is a STEM micrograph of an aluminum alloy according to an embodiment of the invention showing a GNB-containing substructure with average GNB spacing larger than 2.5 μm.

Figure 3 is a STEM micrograph of an aluminum alloy according to an embodiment of the invention showing a GNB-containing substructure with average GNB spacing larger than 8 μm.

Figure 4 is a STEM micrograph of an aluminum alloy according to an embodiment of the invention showing a GNB-free substructure.

DETAILED DESCRIPTION OF THE INVENTION

Definitions and Descriptions

The terms "invention," "the invention," "this invention" and "the present invention" used herein are intended to refer broadly to all of the subject matter of this patent application and the claims below. Statements containing these terms should be understood not to limit the subject matter described herein or to limit the meaning or scope of the patent claims below.

As used herein, the meaning of "a," "an," or "the" includes singular and plural references unless the context clearly dictates otherwise.

Reference is made in this application to alloy temper or condition. For an understanding of the alloy temper descriptions most commonly used, see "American National Standards (ANSI) H35 on Alloy and Temper Designation Systems."

The following aluminum alloys are described in terms of their elemental composition in weight percentage (wt. %) based on the total weight of the alloy. In certain embodiments of each alloy, the remainder is aluminum, with a maximum wt. % of 0.15 % for the sum of the impurities.

Aluminum Alloy Systems

In one aspect, the invention is related to a new aluminum alloy system for aluminum bottle applications. The alloy compositions exhibit good high strain rate formability at elevated temperatures. The high strain rate formability is achieved due to the elemental compositions of the alloys.

In one aspect, the invention provides highly formable alloys for use in manufacturing highly shaped cans and bottles. In one aspect, the invention provides chemistry and
manufacturing processes that are optimized for the high-speed production of aluminum bottles.

In one embodiment, the aluminum alloy comprises:

- 0.15-0.50 wt. % Si,
- 0.35-0.65 wt. % Fe,
- 0.05-0.30 wt. % Cu,
- 0.60-1.10 wt. % Mn,
- 0.80-1.30 wt. % Mg,
- 0.000-0.080 wt. % Cr,
- 0.000-0.500 wt. % Zn,
- 0.000-0.080 wt. % Ti,

up to about 0.15 wt. % impurities, with the remainder as Al.

In another embodiment, the aluminum alloy comprises:

- 0.20-0.40 wt. % Si,
- 0.40-0.60 wt. % Fe,
- 0.08-0.20 wt. % Cu,
- 0.70-1.00 wt. % Mn,
- 0.85-1.22 wt. % Mg,
- 0.000-0.070 wt. % Cr,
- 0.000-0.400 wt. % Zn,
- 0.000-0.070 wt. % Ti,

up to about 0.15 wt. % impurities, with the remainder as Al.

In yet another embodiment, the aluminum alloy comprises:

- 0.22-0.38 wt. % Si,
- 0.42-0.58 wt. % Fe,
- 0.10-0.18 wt. % Cu,
- 0.75-0.98 wt. % Mn,
- 0.90-1.15 wt. % Mg,
- 0.000-0.060 wt. % Cr,
- 0.000-0.300 wt. % Zn,
- 0.000-0.060 wt. % Ti,

up to about 0.15 wt. % impurities, with the remainder as Al.
In still another embodiment, the aluminum alloy comprises:

- 0.27-0.33 wt. % Si,
- 0.46-0.54 wt. % Fe,
- 0.11-0.15 wt. % Cu,
- 0.80-0.94 wt. % Mn,
- 0.93-1.07 wt. % Mg,
- 0.000-0.050 wt. % Cr,
- 0.000-0.250 wt. % Zn,
- 0.000-0.050 wt. % Ti,

up to about 0.15 wt. % impurities, with the remainder as Al.

In another embodiment, the aluminum alloy comprises:

- 0.25-0.35 wt. % Si,
- 0.44-0.56 wt. % Fe,
- 0.09-0.16 wt. % Cu,
- 0.78-0.94 wt. % Mn,
- 0.90-1.10 wt. % Mg,
- 0.000-0.050 wt. % Cr,
- 0.000-0.250 wt. % Zn,
- 0.000-0.050 wt. % Ti,

up to about 0.15 wt. % impurities, with the remainder as Al.

In still another embodiment, the aluminum alloy comprises:

- 0.12-0.28 wt. % Si,
- 0.32-0.52 wt. % Fe,
- 0.09-0.16 wt. % Cu,
- 0.78-0.96 wt. % Mn,
- 0.90-1.10 wt. % Mg,
- 0.000-0.050 wt. % Cr,
- 0.000-0.250 wt. % Zn,
- 0.000-0.050 wt. % Ti,

up to about 0.15 wt. % impurities, with the remainder as Al.

In another embodiment, the aluminum alloy comprises:

- 0.27-0.33 wt. % Si,
0.46-0.54 wt. % Fe,
0.1 1-0.15 wt. % Cu,
0.80-0.94 wt. % Mn,
0.93-1.07 wt. % Mg,
0.000-0.050 wt. % Cr,
0.000-0.250 wt. % Si,
0.000-0.250 wt. % Zn,
0.000-0.050 wt. % Ti,

up to about 0.15 wt. % impurities, with the remainder as Al. In one aspect, the aluminum alloy comprises about 0.296 wt. % Si, about 0.492 wt. % Fe, about 0.129 wt. % Cu, about 0.872 wt. % Mn, about 0.985 wt. % Mg, about 0.026 wt. % Cr, about 0.125 wt. % Zn, about 0.010 wt. Ti, up to about 0.15 wt. % impurities, with the remainder as Al.

In certain aspects, the disclosed alloy includes silicon (Si) in an amount from about 0.12 % to 0.50 % (e.g., from 0.20 % to 0.40 %, from 0.22 % to 0.38 %, from 0.25 % to 0.35 %, from 0.27 % to 0.33 %, or from 0.12 % to 0.28 %) based on the total weight of the alloy. For example, the alloys can include 0.12 %, 0.13 %, 0.14 %, 0.15 %, 0.16 %, 0.17 %, 0.18 %, 0.19 %, 0.20 %, 0.21 %, 0.22 %, 0.23 %, 0.24 %, 0.25 %, 0.26 %, 0.27 %, 0.28 %, 0.29 %, 0.30 %, 0.31 %, 0.32 %, 0.33 %, 0.34 %, 0.35 %, 0.36 %, 0.37 %, 0.38 %, 0.39 %, 0.40 %, 0.41 %, 0.42 %, 0.43 %, 0.44 %, 0.45 %, 0.46 %, 0.47 %, 0.48 %, 0.49 %, or 0.50 % Si. All expressed in wt. %.

In certain aspects, the alloy also includes iron (Fe) in an amount from about 0.35 % to about 0.65 % (e.g., 0.40 % to 0.60 %, from 0.42 % to 0.58 %, from 0.44 % to 0.56 %, from 0.46 % to 0.54 %, or from 0.32 % to 0.52 %) based on the total weight of the alloy. For example, the alloys can include 0.35 %, 0.36 %, 0.37 %, 0.38 %, 0.39 %, 0.40 %, 0.41 %, 0.42 %, 0.43 %, 0.44 %, 0.45 %, 0.46 %, 0.47 %, 0.48 %, 0.49 %, 0.50 %, 0.51 %, 0.52 %, 0.53 %, 0.54 %, 0.55 %, 0.56 %, 0.57 %, 0.58 %, 0.59 %, 0.60 %, 0.61 %, 0.62 %, 0.63 %, 0.64 %, or 0.65 % Fe. All expressed in wt. %.

In certain aspects, the disclosed alloy includes copper (Cu) in an amount from about 0.05 % to about 0.30 % (e.g., from 0.08 % to 0.20 %, from 0.10 % to 0.18 %, from 0.09 % to 0.16 %, from 0.10% to 0.16%, from 0.109 % to 0.16 %, or from 0.11 % to 0.15 %) based on the total weight of the alloy. For example, the alloys can include 0.05 %, 0.06 %, 0.07 %, 0.08 %, 0.09 %, 0.10 %, 0.11 %, 0.12 %, 0.13 %, 0.14 %, 0.15 %, 0.16 %, 0.17 %, 0.18 %, 0.19 %, 0.20 %, 0.21 %, 0.22 %, 0.23 %, 0.24 %, 0.25 %, 0.26 %, 0.27 %, 0.28 %, 0.29 %, or 0.30 % Cu. All expressed in wt. %.
In certain embodiments, the disclosed alloy includes manganese (Mn) in an amount from about 0.60 % to about 1.10 % (e.g., about 0.70 % to 1.00 %, from 0.75 % to 0.98 %, from 0.78 % to 0.94 %, from 0.78 % to 0.96 %, or from 0.80 % to 0.94 %,) based on the total weight of the alloy. For example, the alloy can include 0.60 %, 0.61 %, 0.62 %, 0.63 %, 0.64 %, 0.65 %, 0.66 %, 0.67 %, 0.68 %, 0.69 %, 0.70 %, 0.71 %, 0.72 %, 0.73 %, 0.74 %, 0.75 %, 0.76 %, 0.77 %, 0.78 %, 0.79 %, 0.80 %, 0.81 %, 0.82 %, 0.83 %, 0.84 %, 0.85 %, 0.86 %, 0.87 %, 0.88 %, 0.89 %, 0.90 %, 0.91 %, 0.92 %, 0.93 %, 0.94 %, 0.95 %, 0.96 %, 0.97 %, 0.98 %, 0.99 %, 1.00 %, 1.01 %, 1.02 %, 1.03 %, 1.04 %, 1.05 %, 1.06 %, 1.07 %, 1.08 %, 1.09 %, or 1.10 % Mn. All expressed in wt. %.

In some embodiments, the disclosed alloy includes magnesium (Mg) in an amount from about 0.80 % to about 1.30 % (e.g., from 0.85 % to 1.22 %, from 0.90 % to 1.15 %, from 0.93 % to 1.07 %) based on the total weight of the alloy. For example, the alloy can include 0.80 %, 0.81 %, 0.82 %, 0.83 %, 0.84 %, 0.85 %, 0.86 %, 0.87 %, 0.88 %, 0.89 %, 0.90 %, 0.91 %, 0.92 %, 0.93 %, 0.94 %, 0.95 %, 0.96 %, 0.97 %, 0.98 %, 0.99 %, 1.00 %, 1.01 %, 1.02 %, 1.03 %, 1.04 %, 1.05 %, 1.06 %, 1.07 %, 1.08 %, 1.09 %, 1.10 %, 1.11 %, 1.12 %, 1.13 %, 1.14 %, 1.15 %, 1.16 %, 1.17 %, 1.18 %, 1.19 %, 1.20 %, 1.21 %, 1.22 %, 1.23 %, 1.24 %, 1.25 %, 1.26 %, 1.27 %, 1.28 %, 1.29 % or 1.30 Mg. All expressed in wt. %.

In certain aspects, the alloy includes chromium (Cr) in an amount up to about 0.80 % (e.g., from 0 % to 0.05 %, 0 % to 0.06 %, from 0 % to 0.07 %, from 0 % to 0.08 %, from 0.03 to 0.06 %, from 0.005 % to 0.05 %, or from 0.001 % to 0.06 %) based on the total weight of the alloy. For example, the alloy can include 0.001 %, 0.002 %, 0.003 %, 0.004 %, 0.005 %, 0.006 %, 0.007 %, 0.008 %, 0.009 %, 0.010 %, 0.011 %, 0.012 %, 0.013 %, 0.014 %, 0.015 %, 0.016 %, 0.017 %, 0.018 %, 0.019 %, 0.020 %, 0.021 %, 0.022 %, 0.023 %, 0.024 %, 0.025 %, 0.026 %, 0.027 %, 0.028 %, 0.029 %, 0.030 %, 0.031 %, 0.032 %, 0.033 %, 0.034 %, 0.035 %, 0.036 %, 0.037 %, 0.038 %, 0.039 %, 0.040 %, 0.05 %, 0.051 %, 0.052 %, 0.053 %, 0.054 %, 0.055 %, 0.056 %, 0.057 %, 0.058 %, 0.059 %, 0.060 %, 0.065 %, 0.070 %, 0.075 %, or 0.08 % Cr. In certain aspects, Cr is not present in the alloy (i.e., 0 %). All expressed in wt. %.

In certain aspects, the alloy described herein includes zinc (Zn) in an amount up to about 0.5 % (e.g., from 0 % to 0.25 %, from 0 % to 0.2 %, from 0 % to 0.30 %, from 0 % to 0.40 %, from 0.01 % to 0.35 %, or from 0.01 % to 0.25 %) based on the total weight of the alloy. For example, the alloy can include 0.001 %, 0.002 %, 0.003 %, 0.004 %, 0.005 %, 0.006 %, 0.007 %, 0.008 %, 0.009 %, 0.01 %, 0.02 %, 0.03 %, 0.04 %, 0.05 %, 0.06 %, 0.07
In certain cases, Zn is not present in the alloy (i.e., 0%). All expressed in wt. %.

In certain aspects, the alloy includes titanium (Ti) in an amount up to about 0.08 % (e.g., from 0 % to 0.05 %, 0 % to 0.06 %, from 0 % to 0.07 %, from 0.03 to 0.06 %, from 0.005 to 0.05 %, or from 0.001 to 0.06 %) based on the total weight of the alloy. For example, the alloy can include 0.001 %, 0.002 %, 0.003 %, 0.004 %, 0.005 %, 0.006 %, 0.007 %, 0.008 %, 0.009 %, 0.01 %, 0.011 %, 0.012 %, 0.013 %, 0.014 %, 0.015 %, 0.016 %, 0.017 %, 0.018 %, 0.019 %, 0.02 %, 0.021 %, 0.022 %, 0.023 %, 0.024 %, 0.025 %, 0.026 %, 0.027 %, 0.028 %, 0.029 %, 0.03 %, 0.031 %, 0.032 %, 0.033 %, 0.034 %, 0.035 %, 0.036 %, 0.037 %, 0.038 %, 0.039 %, 0.04 %, 0.05 %, 0.051 %, 0.052 %, 0.053 %, 0.054 %, 0.055 %, 0.056 %, 0.057 %, 0.058 %, 0.059 %, 0.06 %, 0.065 %, 0.07 %, 0.075 %, or 0.08 % Ti. In certain aspects, Ti is not present in the alloy (i.e., 0%). All expressed in wt. %.

Optionally, the alloy compositions can further include other minor elements, sometimes referred to as impurities, in amounts of about 0.15 % or below, 0.14 % or below, 0.13 % or below, 0.12 % or below, 0.11 % or below, 0.10 % or below, 0.09 % or below, 0.08 % or below, 0.07 % or below, 0.06 % or below, 0.05 % or below, 0.04 % or below, 0.03 % or below, 0.02 % or below, or 0.01 % or below. These impurities may include, but are not limited to, V, Ga, Ni, Sc, Zr, Ca, Hf, Sr, or combinations thereof. In certain aspects, the alloy composition comprises only unavoidable impurities. In certain aspects, the remaining percentage of the alloy is aluminum. All expressed in wt. %.

Alloy Properties

In certain embodiments, the aluminum alloys of the present invention display one or more of the following properties: very low earing (maximum mean earing level of 3 %); high recycled content (e.g., at least 60 %, 65 %, 70 %, 75 %, 80 %, 82 % or 85 %); yield strength 25-36 ksi; excellent die cleaning performance which allows the application of very low die striping pressure; excellent formability which allows extensive neck shaping progression without fracture; excellent surface finished in the final bottles with no visible markings; excellent coating adhesion; high strength to meet the typical axial load (>300 lbs) and dome reversal pressure (>90 psi); overall scrap rate of the bottle making process can be as low as less than 1 %.
In certain embodiments, the substructure of the aluminum alloy coil made by this method has a geometrically necessary boundary (GNB)-free substructure. In certain embodiments, the substructure has a GNB-containing substructure with an average GNB spacing larger than 10 microns. In certain embodiments, the substructure aluminum alloy coil made by this method has a GNB-containing substructure with average GNB spacing larger than 300 nm (e.g., FIG. 1), average GNB spacing larger than 2.5 μm (FIG. 2), average GNB spacing larger than 8 μm (e.g., FIG. 3), or a GNB-free substructure (e.g., FIG. 4).

In certain embodiments, the alloy sheet has very low earing. In certain embodiments, the earing balance from the edge, sides, and center (over the coil width) is less than 1.5 % (e.g., less than 1.25 %, less than 1 %). In certain embodiments, the mean earing is less than 4 %. For example, the mean earing is less than 3.75 %, less than 3.5 %, less than 3.25 %, less than 3 %, less than 2.75 %, or less than 2.5 %.

In certain embodiments, the alloy sheet has high recycled content.

**Methods of Making the Alloy**

In certain aspects, the disclosed alloy composition is a product of a disclosed method. Without intending to limit the invention, aluminum alloy properties are partially determined by the formation of microstructures during the alloy's preparation. In certain aspects, the method of preparation for an alloy composition may influence or even determine whether the alloy will have properties adequate for a desired application.

In one aspect, the invention sets forth a method of making an aluminum alloy described herein. Typically, can body stocks are provided to the customer in the H19 temper. For aluminum bottle application, the typical H19 temper does not work well as H19 alloys are too brittle. In one aspect, to meet the high formability requirement for the shaping of aluminum bottles, an inventive alloy must be processed in a different way, by direct chill (DC) casting, homogenizing, hot rolling, cold rolling, recrystallization annealing, cold rolling, and stabilization annealing.

In one embodiment, the method of making an aluminum alloy as described herein comprises the sequential steps of:

- DC casting;
- Homogenizing;
- Hot rolling;
- Cold rolling (60-90 % thickness reduction);
- Optionally recrystallization annealing (290-500 °C/0.5-4 hrs);
Cold rolling (15-30 % reduction);
Stabilization annealing (100-300 °C/0.5-4 hrs).

In another embodiment, the method of making the aluminum alloy as described herein comprises the sequential steps of:

DC casting;
Homogenizing;
Hot rolling;
Cold rolling (60-90 % thickness reduction);
Optionally recrystallization annealing (300-450 °C/1-2 hrs);
Cold rolling (15-30 % reduction); and,
Stabilization annealing (120-250 °C/1-2 hrs).

In another embodiment, the method of making an aluminum alloy as described herein comprises direct chill casting an aluminum ingot; homogenizing the ingot; hot rolling the homogenized ingot to form a hot rolled product; cold rolling the hot rolled product in a first cold rolling step to produce a first cold rolled product, wherein the first cold rolling step produces an about 60-90 % thickness reduction. In certain embodiments the method further comprises cold rolling the first cold rolled product in a second cold rolling step to produce a second cold rolled product, wherein the second cold rolling step produces an about 15-30 % thickness reduction.

In certain embodiments having two cold rolling steps, the method further comprises recrystallization annealing the first cold rolled product, wherein the recrystallization annealing is at a metal temperature from about 290-500 °C for about 0.5-4 hrs. In certain embodiments, the recrystallization annealing is at a metal temperature from about 300-450 °C. In certain embodiments, the recrystallization annealing is for about 1-2 hrs.

In certain embodiments having one or two cold rolling steps, the method further comprises stabilization annealing of the first cold rolled product if one cold rolling step is used or stabilization annealing of the second cold rolled product if two cold rolling steps are used, wherein the stabilization annealing is at a metal temperature from about 100-300 °C for about 0.5-4 hrs. In certain embodiments, the stabilization annealing is at a metal temperature of from about 120-250 °C. In certain embodiments, the stabilization annealing is for about 1-2 hrs.
In certain embodiments where the alloy has a composition including about 0.25-0.35 wt. % Si, about 0.44-0.56 wt. % Fe, about 0.09-0.16 wt. % Cu, about 0.78-0.94 wt. % Mn, about 0.90-1.1 wt. % Mg, about 0.000-0.050 wt. % Cr, about 0.000-0.250 wt. % Zn, about 0.000-0.050 wt. % Ti, and up to 0.15 wt. % impurities, with the remainder Al, the method of making an aluminum alloy as described herein comprises direct chill casting an aluminum ingot; homogenizing the ingot; hot rolling the ingot to form a hot rolled product; cold rolling the hot rolled product to form a cold rolled product, wherein the cold rolling produces an about 60-90 % thickness reduction; and stabilization annealing of the cold rolled product, wherein the stabilization annealing is at a metal temperature from about 100-300 °C for about 0.5-4 hrs. In certain embodiments the stabilization annealing is at a metal temperature of 120-250 °C. In certain embodiments the stabilization annealing is for about 1-2 hrs.

In certain other embodiments where the alloy has a composition including about 0.12-0.28 wt. % Si, about 0.32-0.52 wt. % Fe, about 0.09-0.16 wt. % Cu, about 0.78-0.96 wt. % Mn, about 0.90-1.10 wt. % Mg, about 0.000-0.050 wt. % Cr, about 0.000-0.250 wt. % Zn, about 0.000-0.050 wt. % Ti, and up to 0.15 wt. % impurities, with the remainder Al, the method of making an aluminum alloy as described herein comprises direct chill casting an aluminum ingot; homogenizing the ingot; hot rolling the ingot to form a hot rolled product; cold rolling the hot rolled product in a first cold rolling step, wherein the cold rolling produces an about 60-90 % thickness reduction in the hot rolled product; recrystallization annealing of the cold rolled product, wherein the recrystallization annealing is at a metal temperature from about 290-500 °C for about 0.5-4 hrs; cold rolling the annealed product in a second cold rolling step to produce a second cold rolled product, wherein the second cold rolling step produces an about 15-30 % thickness reduction in the annealed product; and stabilization annealing of the cold rolled product, wherein the stabilization annealing is at a metal temperature from about 100-300 °C for about 0.5-4 hrs. In certain embodiments, the recrystallization annealing is at a metal temperature from about 300 to 450 °C. In certain embodiments, the recrystallization annealing is for about 1-2 hrs. In certain embodiments the stabilization annealing is at a metal temperature of 120-250 °C. In certain embodiments the stabilization annealing is for about 1-2 hrs.

In other embodiments where the alloy has a composition including 0.12-0.28 wt. % Si, about 0.32-0.52 wt. % Fe, about 0.09-0.16 wt. % Cu, about 0.78-0.96 wt. % Mn, about 0.90-1.10 wt. % Mg, about 0.000-0.050 wt. % Cr, about 0.000-0.250 wt. % Zn, about 0.000-0.050 wt. % Ti, and up to 0.15 wt. % impurities, with the remainder Al, the method of
making an aluminum alloy as described herein comprises direct chill casting an aluminum ingot; homogenizing the ingot; hot rolling the ingot to form a hot rolled product; cold rolling the hot rolled product in a first cold rolling step to form a first cold rolled product, wherein the first cold rolling step produces an about 60-90 % thickness reduction in the hot rolled product; cold rolling the first cold rolled product in a second cold rolling step, wherein the second cold rolling step produces an about 15-30 % thickness reduction in the product; and stabilization annealing of the second cold rolled product, wherein the stabilization annealing is at a metal temperature from about 100-300 °C for about 0.5-4 hrs. In certain embodiments, the stabilization annealing is at a metal temperature from about 120-250 °C. In certain embodiments, the stabilization annealing is for about 1-2 hrs.

The final temper of the alloys could be either H2x (without interannealing) or H3x or Hlx (with interannealing). The combination of rolling reduction gives optimized earing and excellent performance in the bodemaker. The stabilization annealing cycle was designed to induce specific working hardening characteristics and formability in the alloys allowing extensive neck shaping without fracture.

Casting

The alloys described herein can be cast into ingots using a direct chill (DC) process. The DC casting process is performed according to standards commonly used in the aluminum industry as known to one of skill in the art. Optionally, the casting process can include a continuous casting process. The continuous casting may include, but are not limited to, twin roll casters, twin belt casters, and block casters. In some embodiments, to achieve the desired microstructure, mechanical properties, and physical properties of the products, the alloys are not processed using continuous casting methods.

The cast ingot can then be subjected to further processing steps to form a metal sheet. In some embodiments, the further processing steps include subjecting a metal ingot to a homogenization cycle, a hot rolling step, a cold rolling step, an optional recrystallization annealing step, a second cold rolling step, and a stabilization annealing step.

Homogenization

The homogenization step can involve a one-step homogenization or a two-step homogenization. In some embodiments of the homogenization step, a one-step homogenization is performed in which an ingot prepared from the alloy compositions described herein is heated to attain a peak metal temperature (PMT). The ingot is then...
allowed to soak (i.e., held at the indicated temperature) for a period of time during the first stage.

In some embodiments of the homogenization step, a two-step homogenization is performed where an ingot prepared from an alloy composition described herein is heated to attain a first temperature and then allowed to soak for a period of time. In the second stage, the ingot can be cooled to a temperature lower than the temperature used in the first stage and then allowed to soak for a period of time during the second stage.

**Hot Rolling**

Following the homogenization, a hot rolling process can be performed. In some embodiments, the ingots can be hot rolled to an 5 mm thick gauge or less. For example, the ingots can be hot rolled to a 4 mm thick gauge or less, 3 mm thick gauge or less, 2 mm thick gauge or less, or 1 mm thick gauge or less.

In some embodiments, to obtain an appropriate balance of texture in the final materials, the hot rolling speed and temperature can be controlled such that full recrystallization of the hot rolled materials is achieved during coiling at the exit of the tandem mill.

**Cold Rolling**

In some embodiments, the hot rolled products can then be cold rolled to a final gauge thickness. In some embodiments, a first cold rolling step produces a reduction in thickness of from about 60-90 % (e.g. about 50-80 %, about 60-70 %, about 50-90 %, or about 60-80 %). For example, the first cold rolling step produces a reduction in thickness of about 65 %, about 70 %, about 75 %, about 80 %, about 85 %, or about 90 %. In some embodiments, a second cold rolling step produces a further reduction in thickness of from about 15-30 % (e.g., from about 20-25%, about 15-25%, about 15-20%, about 20-30%, or about 25-30 %). For example, the second cold rolling step produces a further reduction in thickness of about 15 %, 20 %, 25 %, or 30 %.

**Annealing**

In some embodiments, an annealing step is a recrystallization annealing (e.g., after the initial cold rolling). In one embodiment, the recrystallization annealing is at a metal temperature from about 290-500 °C for about 0.5-4 hrs. In one embodiment, the recrystallization annealing is at a metal temperature from about 300-450 °C. In one embodiment, the recrystallization is for about 1-2 hrs.
The recrystallization annealing step can include heating the alloy from room temperature to a temperature from about 290 °C to about 500 °C (e.g., from about 300 °C to about 450 °C, from about 325 °C to about 425 °C, from about 300 °C to about 400 °C, from about 400 °C to about 500 °C, from about 330 °C to about 470 °C, from about 375 °C to about 450 °C, or from about 450 °C to about 500 °C).

In certain aspects, an annealing step is stabilization annealing (e.g., after the final cold rolling). In one embodiment, the stabilization annealing is at a metal temperature from about 100-300 °C for about 0.5-4 hrs. In one embodiment, the stabilization annealing is at a metal temperature from about 120-250 °C for about 1-2 hrs.

The stabilization annealing step can include heating the alloy from room temperature to a temperature from about 100°C to about 300 °C (e.g., from about 120 °C to about 250 °C, from about 125 °C to about 200 °C, from about 200 °C to about 300 °C, from about 150 °C to about 275 °C, from about 225 °C to about 300 °C, or from about 100 °C to about 175 °C).

Methods of Preparing Highly Shaped Metal Objects

The methods described herein can be used to prepare highly shaped metal objects, such as aluminum cans or bottles. The cold rolled sheets described above can be subjected to a series of conventional can and bottle making processes to produce preforms. The preforms can then be annealed to form annealed preforms. Optionally, the preforms are prepared from the aluminum alloys using a drawing and wall ironing (DWI) process and the cans and bottles are made according to other shaping processes as known to those of ordinary skill in the art.

The shaped aluminum bottle of the present invention may be used for beverages including but not limited to soft drinks, water, beer, energy drinks and other beverages.
WHAT I S CLAIMED IS:

1. An aluminum alloy comprising:
   about 0.15-0.50 wt. % Si,
   about 0.35-0.65 wt. % Fe,
   about 0.05-0.30 wt. % Cu,
   about 0.60-1.10 wt. % Mn,
   about 0.80-1.30 wt. % Mg,
   about 0.000-0.080 wt. % Cr,
   about 0.000-0.500 wt. % Zn,
   about 0.000-0.080 wt. % Ti,
   up to 0.15 wt. % impurities, with the remainder Al.

2. The alloy of claim 1 comprising:
   about 0.20-0.40 wt. % Si,
   about 0.40-0.60 wt. % Fe,
   about 0.08-0.20 wt. % Cu,
   about 0.70-1.00 wt. % Mn,
   about 0.85-1.22 wt. % Mg,
   about 0.000-0.070 wt. % Cr,
   about 0.000-0.400 wt. % Zn,
   about 0.000-0.070 wt. % Ti,
   up to 0.15 wt. % impurities, with the remainder Al.

3. The alloy of claim 2 comprising:
   about 0.22-0.38 wt. % Si,
   about 0.42-0.58 wt. % Fe,
   about 0.10-0.18 wt. % Cu,
   about 0.75-0.98 wt. % Mn,
   about 0.90-1.15 wt. % Mg,
   about 0.000-0.060 wt. % Cr,
   about 0.000-0.300 wt. % Zn,
   about 0.000-0.060 wt. % Ti,
   up to 0.15 wt. % impurities, with the remainder Al.
4. The alloy of claim 3 comprising:
   about 0.27-0.33 wt. % Si,
   about 0.46-0.54 wt. % Fe,
   about 0.11-0.15 wt. % Cu,
   about 0.80-0.94 wt. % Mn,
   about 0.93-1.07 wt. % Mg,
   about 0.000-0.050 wt. % Cr,
   about 0.000-0.250 wt. % Zn,
   about 0.000-0.050 wt. % Ti,
   up to about 0.15 wt. % impurities, with the remainder as Al.

5. The alloy of claim 3 comprising:
   about 0.25-0.35 wt. % Si,
   about 0.44-0.56 wt. % Fe,
   about 0.09-0.160 wt. % Cu,
   about 0.78-0.94 wt. % Mn,
   about 0.90-1.1 wt. % Mg,
   about 0.000-0.050 wt. % Cr,
   about 0.000-0.250 wt. % Zn,
   about 0.000-0.050 wt. % Ti,
   up to 0.15 wt. % impurities, with the remainder Al.

6. An aluminum alloy comprising:
   about 0.12-0.28 wt. % Si,
   about 0.32-0.52 wt. % Fe,
   about 0.09-0.16 wt. % Cu,
   about 0.78-0.96 wt. % Mn,
   about 0.90-1.10 wt. % Mg,
   about 0.000-0.050 wt. % Cr,
   about 0.000-0.250 wt. % Zn,
   about 0.000-0.050 wt. % Ti,
   up to 0.15 wt. % impurities, with the remainder Al.

7. A shaped aluminum bottle comprising the composition of any of claims 1–6.
8. A method of making the aluminum alloy of any of claims 1-6 comprising:
   direct chill casting an aluminum ingot;
   homogenizing the ingot;
   hot rolling the homogenized ingot to form a hot rolled product;
   cold rolling the hot rolled product in a first cold rolling step to form a first cold rolled product, wherein the first cold rolling step produces an about 60-90 % thickness reduction; and
   stabilization annealing of the second cold rolling product, wherein the stabilization annealing is at a metal temperature from about 100-300 °C for about 0.5-4 hrs.

9. The method of claim 8, wherein the stabilization annealing is at a metal temperature from about 120-250 °C for about 1-2 hrs.

10. The method of claim 8 or 9, wherein the cold rolling step is a first cold rolling step, the method further comprising cold rolling the first cold rolled product in a second cold rolling step to form a second cold rolled product, wherein the second cold rolling produces an about 15-30 % thickness reduction.

11. The method of claim 10, further comprising:
   prior to the second cold rolling step, recrystallization annealing the first cold rolled product, wherein the recrystallization annealing is at a metal temperature from about 290-500 °C for about 0.5-4 hrs.

12. The method of claim 11, wherein the recrystallization annealing is at a metal temperature from about 300-450 °C for about 1-2 hrs.

13. The aluminum alloy of any of claims 1-6 comprising a recycled content of at least 60 wt. %

14. The aluminum alloy of claim 13 comprising a recycled content of at least 75 wt. %.

15. The aluminum alloy of claim 14 comprising a recycled content of at least 85 wt. %.
16. An aluminum alloy made by the method of any of claims 8-12.

17. An aluminum alloy made by the method of claim 16.
INTERNATIONAL SEARCH REPORT

PCT/US2015/066638

A. CLASSIFICATION OF SUBJECT MATTER

INV. C22C21/00 C22C21/08 C22F1/04 C22F1/047

According to International Patent Classification (IPC) or both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C C22F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of Box C. See patent family annex.

Date of the actual completion of the international search
4 March 2016

Date of mailing of the international search report
16/03/2016

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Gonzal ez Junquera, J
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