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(54) Title: CONTINUOUS CAST ALLOY FOR FOIL APPLICATIONS

(57) Abstract: Continuous casting methods and aluminum alloys suitable for continuous casting, and aluminum alloy products are provided. Methods include flowing a liquid metal to a casting cavity and continuously casting an aluminum alloy product. In methods, aluminum alloys, and aluminum alloy products, the aluminum alloy can include greater than 0.3 wt.% Si, greater than 0.45 wt.% Fe, greater than 0.05 wt.% Cu, less than 0.55 wt.% Mn, less than 0.85 wt.% Mg, and Al.

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CONTINUOUS CAST ALLOY FOR FOIL APPLICATIONS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of and priority to U.S. Provisional Patent Application No. 63/505,252, filed on May 31, 2023, the content of which is hereby incorporated by reference in its entirety.

FIELD

[0002] This present disclosure relates to the fields of material science, material chemistry, metallurgy, aluminum alloys, aluminum fabrication, and related fields. In particular, the present disclosure provides novel 3xxx series aluminum alloys suitable for continuous casting and that exhibit excellent formability. The disclosure also provides various continuous casting methods for producing and processing 3xxx series aluminum alloy products.

BACKGROUND

[0003] Direct chill (DC) and continuous casting are two methods of casting solid metal from liquid metal. In DC casting, liquid metal is poured into a mold having a retractable false bottom capable of withdrawing at the rate of solidification of the liquid metal in the mold, often resulting in a large and relatively thick ingot (e.g., 1500 mm x 500 mm x 5 m). The ingot can be processed, homogenized, hot rolled, cold rolled, annealed and/or heat treated, and otherwise finished before being coiled into a metal strip product distributable to a consumer of the metal strip product (e.g., an automotive manufacturing facility).

[0004] Continuous casting involves continuously injecting molten metal into a casting cavity defined between a pair of moving opposed casting surfaces and withdrawing a cast metal form (e.g., a metal strip) from the exit of the casting cavity. Continuous casting has been desirable in instances where the entire product can be prepared in a single, fully-coupled processing line or a decoupled processing line. Namely, continuous casting is capable of casting solid metal at faster rates, lower energy usage (e.g., more environmentally friendly), and at lower cost. In addition, continuous casting is capable of utilizing high levels of recycled materials when forming the solid metal, such as higher than about 40 wt.%, up to even 100 wt.%. However, continuously cast materials often exhibit poor formability as compared to DC formed solid metals, such as poor elongation and/or Olsen cup properties. These differences may be due at least in part to the differences in formation methods, such as

the fast freezing and lack of homogenization in continuous casting processes, to name a few. Such process differences may fail to fully disburse various alloy components, such as manganese, leading to precipitation and dispersoid problems, large grain size, and poor elongation, upon recrystallization.

BRIEF SUMMARY

[0005] The term embodiment and like terms are intended to refer broadly to all of the subject matter of this disclosure 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 claims below. Embodiments of the present disclosure covered herein are defined by the claims below, not this summary. This summary is a high-level overview of various aspects of the disclosure and introduces some of the concepts that are further described in the Detailed Description section below. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used in isolation to determine the scope of the claimed subject matter. The subject matter should be understood by reference to appropriate portions of the entire specification of this disclosure, any or all drawings and each claim.

[0006] The disclosure herein describes aluminum alloy products and methods of producing aluminum alloy products. Methods of producing aluminum alloy products include flowing liquid metal to a casting cavity, and continuously casting an aluminum alloy product. Methods include where the aluminum alloy contains greater than 0.30 wt.% silicon, greater than 0.45 wt.% iron, greater than 0.05 wt.% copper, less than 0.55 wt.% manganese, less than 0.85 wt.% magnesium, and aluminum.

[0007] In embodiments, methods include where the aluminum alloy product does not undergo homogenization after the continuous casting. In more embodiments, methods further include one or more hot rolling operations at an exit temperature of greater than or about 250 °C. In further embodiments, methods include where the hot rolling reduces a thickness of the aluminum alloy product by greater than or about 80% of a thickness of the aluminum alloy product after casting. In yet more embodiments, the aluminum alloy includes a thickness of less than or about 1 mm. Additionally or alternatively, in embodiments, methods further include one or more cold rolling operations at a temperature of greater than or about 300 °C. Moreover, in embodiments, cold rolling reduces a thickness of the aluminum alloy product by greater than or about 75% of a thickness of the aluminum alloy product after one or more hot rolling operations. In embodiments, the aluminum alloy has a thickness of less than or

about 0.5 mm. In yet more embodiments, the liquid metal includes at least about 40 wt.% recycled content. Furthermore, in embodiments, methods include where the continuous casting is continuous belt casting and/or where the continuously cast aluminum alloy product is thermally quenched at a rate of about 10 °C/second up to about 200 °C/second. The present disclosure also includes aluminum alloy products prepared according to any one or more of the embodiments discussed herein.

[0008] The present disclosure describes continuous cast aluminum foil products. Continuous cast aluminum foil products include greater than 0.30 wt.% silicon, greater than 0.45 wt.% iron, greater than 0.05 wt.% copper, less than 0.55 wt.% manganese, less than 0.85 wt.% magnesium, and aluminum. Continuous cast aluminum foil products include a ratio of iron to manganese of greater than 1:1 and exhibit an ultimate tensile strength of greater than or about 140 MPa.

[0009] In embodiments, continuous cast aluminum foil products include where the ratio of iron to manganese by weight is greater than 1.05:1. Furthermore, in embodiments, continuous cast aluminum foil products include where the ratio of magnesium to manganese is greater than 1.625:1. In more embodiments, continuous cast aluminum foil products include where a ratio of silicon to manganese by weight is greater than 0.30:1. In embodiments, the continuous cast aluminum foil products include from 0.30 to 0.50 wt.% silicon, from 0.45 to 0.60 wt.% iron, from 0.05 to 0.25 wt.% copper, from 0.01 to 0.55 wt.% manganese, from 0.01 to 0.85 wt.% magnesium, and aluminum. Additionally or alternatively, in embodiments, continuous cast aluminum foil products include from 0.35 to 0.45 wt.% silicon, from 0.45 wt.% to 0.55 wt.% iron, from 0.10 to 0.20 wt.% copper, from 0.30 to 0.55 wt.% manganese, from 0.50 to 0.80 wt.% magnesium, and aluminum. In embodiments, continuous cast aluminum foil products include less than 0.01 wt.% total of chromium and lead, from 0.15 to 0.35 wt.% zinc, up to 0.10 wt.% titanium, and up to 0.15 wt.% impurities. In more embodiments, the continuous cast aluminum foil products exhibit an Olsen Cup Height of greater than or about 0.20” (5.1 mm). In further embodiments, the continuous cast aluminum foil products have a thickness of less than or about 0.50 mm.

[0010] Other objects and advantages will be apparent from the following detailed description of non-limiting examples.

DETAILED DESCRIPTION

[0011] Certain aspects and features of the present disclosure related to novel 3xxx series aluminum alloys which are well suited for continuous casting. In addition, the novel 3xxx

series aluminum alloys discussed herein are capable of utilizing a high recycled content in the starting liquid metal while exhibiting such favorable properties. Namely, the novel 3xxx series aluminum alloys discussed herein can be utilized in continuous casting processes, and yield aluminum alloy products having excellent strength and formability. Amount other things, relatively low amounts of manganese and magnesium in conjunction with relatively high amounts of silicon and iron improve dispersoid problems generally exhibited when manganese precipitates from the alloy, such as when utilized in processes that do not include homogenization. Thus, surprisingly, alloys according to the present technology increase particle stimulated nucleation, reduce grain size, and improve elongation, even in the absence of a homogenization step. Without wishing to be bound by theory, it is believed that manganese amounts may be reduced in conjunction with lowered amounts of magnesium in order to reduce the manganese precipitation while counteracting an increase in hardness. Moreover, the relative increase in silicon and iron may remove additional manganese from the alloy matrix, without further reducing the overall levels of magnesium, improving formability and strength.

Definitions and Descriptions:

[0012] 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.

[0013] In this description, reference is made to alloys identified by aluminum industry designations, such as "series" or "3xxx." For an understanding of the number designation system most commonly used in naming and identifying aluminum and its alloys, see "International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys" or "Registration Record of Aluminum Association Alloy Designations and Chemical Compositions Limits for Aluminum Alloys in the Form of Castings and Ingot," both published by The Aluminum Association.

[0014] The following aluminum alloys are described in terms of their elemental composition in weight percentage (wt. %, or %) based on the total weight of the alloy. In certain examples of each alloy, the remainder of the composition is aluminum, with a maximum wt. % of 0.15 % for the sum of the impurities. The wt.% of the aluminum alloys adds up to 100 wt.% total and may include Al in an amount to total to 100 wt.%.

[0015] As used herein, the meaning of "a," "an," or "the" includes singular and plural references unless the context clearly dictates otherwise.

[0016] As used herein, a plate generally has a thickness of greater than 15 mm up to 200 mm. For example, a plate may refer to an aluminum alloy product having a thickness of greater than 15 mm, greater than 20 mm, greater than 25 mm, greater than 30 mm, greater than 35 mm, greater than 40 mm, greater than 45 mm, greater than 50 mm, greater than 100 mm, or up to 200 mm.

[0017] As used herein, a shate (also referred to as a sheet plate) generally has a thickness of from 4 mm to 15 mm. For example, a shate may have a thickness of 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm, 11 mm, 12 mm, 13 mm, 14 mm, or 15 mm.

[0018] As used herein, a sheet or a foil generally refers to an aluminum product having a thickness of less than 4 mm (e.g., less than 3 mm, less than 2 mm, less than 1 mm, less than 0.5 mm, less than 0.3 mm, or less than 0.1 mm). For example, a sheet may have a thickness of 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm, 0.5, 0.6 mm 0.7 mm, 0.8 mm, 0.9 mm, 1 mm, 1.1 mm, 1.2 mm, 1.3 mm, 1.4 mm, 1.5 mm, 1.6 mm, 1.7 mm, 1.8 mm, 1.9 mm, 2 mm, 2.1 mm, 2.2 mm, 2.3 mm, 2.4 mm, 2.5 mm, 2.6 mm 2.7 mm, 2.8 mm, 2.9 mm, 3 mm, 3.1 mm, 3.2 mm, 3.3 mm, 3.4 mm, 3.5 mm, 3.6 mm, 3.7 mm, 3.8 mm, 3.9 mm, or 4 mm.

[0019] As used herein, formability refers to the ability of a material to undergo deformation into a desired shape without fracturing, tearing-off, necking, earing, or shaping errors such as wrinkling, spring-back, or galling occurring. In engineering, formability may be classified according to deformation modes. Examples of deformation modes include drawing, stretching, bending, and stretch-flanging.

[0020] Reference may be 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." An F condition or temper refers to an aluminum alloy as fabricated. An O condition or temper refers to an aluminum alloy after annealing. An Hxx condition or temper, also referred to herein as an H temper, refers to a non-heat treatable aluminum alloy after cold rolling with or without thermal treatment (e.g., annealing). Suitable H tempers include HX1, HX2, HX3 HX4, HX5, HX6, HX7, HX8, or HX9 tempers. A T1 condition or temper refers to an aluminum alloy cooled from hot working and naturally aged (e.g., at room temperature). A T2 condition or temper refers to an aluminum alloy cooled from hot working, cold worked and naturally aged. A T3 condition or temper refers to an aluminum alloy solution heat treated, cold worked, and naturally aged. A T4 condition or temper refers to an aluminum alloy solution

heat treated and naturally aged. A T5 condition or temper refers to an aluminum alloy cooled from hot working and artificially aged (at elevated temperatures). A T6 condition or temper refers to an aluminum alloy solution heat treated and artificially aged. A T7 condition or temper refers to an aluminum alloy solution heat treated and artificially overaged. A T8x condition or temper refers to an aluminum alloy solution heat treated, cold worked, and artificially aged. A T9 condition or temper refers to an aluminum alloy solution heat treated, artificially aged, and cold worked. A W condition or temper refers to an aluminum alloy after solution heat treatment.

[0021] As used herein, terms such as "cast metal product," "cast product," "cast aluminum alloy product," and the like are interchangeable and refer to a product produced by direct chill casting (including direct chill co-casting) or semi-continuous casting, continuous casting (including, for example, by use of a twin belt caster, a twin roll caster, a block caster, or any other continuous caster), electromagnetic casting, hot top casting, or any other casting method. However, as discussed above, in aspects, the aluminum alloy products discussed herein may be cast utilizing continuous casting methods.

[0022] As used herein, the meaning of "room temperature" can include a temperature of from 15 °C to 30 °C, for example 15 °C, 16 °C, 17 °C, 18 °C, 19 °C, 20 °C, 21 °C, 22 °C, 23 °C, 24 °C, 25 °C, 26 °C, 27 °C, 28 °C, 29 °C, or 30 °C.

[0023] All ranges disclosed herein are to be understood to encompass any endpoints, and any and all subranges subsumed therein. For example, a stated range of "1 to 10" should be considered to include any and all subranges between (and inclusive of) the minimum value of 1 and the maximum value of 10; that is, all subranges beginning with a minimum value of 1 or more, e.g., 1 to 6.1, and ending with a maximum value of 10 or less, e.g., 5.5 to 10.

Alloy Compositions

[0024] Aluminum alloy properties are partially determined by the composition of the aluminum alloys. In certain aspects, the alloy composition may influence or even determine whether the alloy will have properties adequate for a desired application.

[0025] The alloy and product described herein are novel aluminum compositions. The aluminum compositions exhibit desirable mechanical and physical properties, such as formability, strength, and a refined microstructure. The properties of the composition are achieved at least in part due to the elemental composition of the aluminum.

[0026] In some examples, an aluminum alloy as described herein may have the following elemental composition as provided in Table 1.

Table 1

Element	Weight Percentage (wt. %)
Si	greater than 0.30
Fe	greater than 0.45
Cu	greater than 0.05
Mn	0.00 – 0.55
Mg	0.00 – 0.85
Cr	0.00 – 0.10
Ti	0.00 – 0.10
Zn	0.00 – 0.50
Others	0 – 0.05 (each) 0 – 0.15 (total)
Al	

[0027] In some examples, the aluminum alloy as described herein may have the following elemental composition as provided in Table 2.

Table 2

Element	Weight Percentage (wt. %)
Si	0.30 – 0.90
Fe	0.45 – 0.1
Cu	0.05 – 0.25
Mn	0.01 – 0.55
Mg	0.01 – 0.85
Cr	0.00 – 0.10
Ti	0.00 – 0.10
Zn	0.00 – 0.50
Others	0 – 0.05 (each) 0 – 0.15 (total)
Al	

[0028] In some examples, the aluminum alloy as described herein may have the following elemental composition as provided in Table 3.

Table 3

Element	Weight Percentage (wt. %)
Si	0.35 – 0.75
Fe	0.45 – 0.85
Cu	0.1 – 0.2
Mn	0.30 – 0.55
Mg	0.50 – 0.80
Cr + Pb	0.00 – 0.01 (total)
Ti	0.00 – 0.10
Zn	0.15 – 0.35
Others	0 – 0.05 (each) 0 – 0.15 (total)
Al	

Silicon (Si)

[0029] In some examples, the aluminum alloy described herein includes Si in an amount of greater than 0.30 %, e.g., from 0.30 % to 0.90 %, from 0.30 % to 0.75 %, from 0.30 % to 0.50 %, from 0.35 % to 0.45 %, based on the total weight of the alloy. For example, the alloy can include 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 %, 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 %, 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%, or 0.90 %, Si. In some cases, Si is not present in the alloy (i.e., 0 %). All expressed in wt. %.

Iron (Fe)

[0030] In some examples, the aluminum alloy described herein also includes Fe in an amount of greater than 0.45%, e.g., from 0.45 % to 1.00 %, from 0.45 % to 0.85 %, from 0.45 % to 0.65 %, from 0.50 % to 0.60 %, based on the total weight of the alloy. For example, the

alloy can include 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 %, 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 %, or 1.00 % Fe. In some cases, Fe is not present in the alloy (i.e., 0 %). All expressed in wt. %.

Copper (Cu)

[0031] In some examples, the aluminum alloy described herein includes Cu in an amount of greater than 0.05 % up to 0.25 %, e.g., from 0.05 % to 0.25 %, from 0.01 % to 0.20 %, based on the total weight of the alloy. For example, the alloy 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 %, or 0.30 % Cu. In some cases, Cu is not present in the alloy (i.e., 0 %). All expressed in wt. %.

Manganese (Mn)

[0032] In some examples, the aluminum alloy described herein can include Mn in an amount of less than 0.55 %, e.g., from 0.00 % to 0.55 %, from 0.01 % to 0.55 %, or from 0.30 % to 0.55 %, based on the total weight of the alloy. For example, the alloy can include 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 %, 0.50 %, 0.51 %, 0.52 %, 0.53 %, 0.54 %, or 0.55 % Mn. In some cases, Mn is not present in the alloy (i.e., 0 %). All expressed in wt. %.

Magnesium (Mg)

[0033] In some examples, the aluminum alloy described herein can include Mg in an amount of less than 0.85 %, e.g., from 0.00 % to 0.85 %, from 0.01 % to 0.85 %, from 0.1 % to 0.80 %, or from 0.5 % to 0.80 %, based on the total weight of the alloy. For example, the alloy described herein can include Mg in an amount from 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 %, or 0.85 % Mg. In some cases, Mg is not present in the alloy (i.e., 0 %). All expressed in wt. %.

Chromium (Cr)

[0034] In some examples, the aluminum alloy described herein includes Cr in an amount of up to 0.10 %, e.g., from 0.01 % to 0.10 %, from 0.02 % to 0.8 %, from 0.03 % to 0.07 %, or from 0.04 % to 0.06 %, based on the total weight of the alloy. For example, the alloy can include 0.01 %, 0.02 %, 0.03 %, 0.04 %, 0.05 %, 0.06 %, 0.07 %, 0.08 %, 0.09 %, of 0.10 % Cr. In some cases, Cr is not present in the alloy (i.e., 0 %). All expressed in wt. %.

Zinc (Zn)

[0035] In some examples, the aluminum alloy described herein includes Zn in an amount of up to 0.30 %, e.g., from 0.00 % to 0.30 %, from 0.1 % to 0.29 %, from 0.15 % to 0.28 %, from 0.20 % to 0.27 %, or from 0.22 % to 0.26 %, based on the total weight of the alloy. For example, the alloy can include 0.01 %, 0.02 %, 0.03 %, 0.04 %, 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 %, 0.30 %, 0.31 %, 0.32 %, 0.33 %, 0.34 %, or 0.35 % Zn. In some cases, Zn is not present in the alloy (i.e., 0 %). All expressed in wt. %.

Ti (Titanium)

[0036] In some examples, the aluminum alloy described herein includes Ti in an amount of up to 0.10 %, e.g., from 0.00 % to 0.10 %, from 0.01 % to 0.10 %, or from 0.02 % to 0.08, based on the total weight of the alloy. For example, the alloy can include 0.01 %, 0.02 %, 0.03 %, 0.04 %, 0.05 %, 0.06 %, 0.07 %, 0.08 %, 0.09 %, or 0.10 % Ti. In some cases, Ti is not present in the alloy (i.e., 0 %). All expressed in wt. %.

[0037] In some non-limiting examples, Pb and Cd, in combination, may decrease formability properties of the aluminum alloy products. In some examples, the combined amount of Pb and Cd may be present in the composition in a total amount of less than 0.05 % e.g., from 0.00 wt. % to 0.04 wt. %, from 0.00 wt. % to 0.03 wt. %, or from 0.00 wt. % to 0.01 wt. %. For example, the combined amount of Pb and Cd can be 0.001 wt. %, 0.002 wt. %, 0.003 wt. %, 0.004 wt. %, 0.005 wt. %, 0.006 wt. %, 0.007 wt. %, 0.008 wt. %, 0.009 wt. %, 0.010 wt. %, 0.011 wt. %, 0.012 wt. %, 0.013 wt. %, 0.014 wt. %, 0.015 wt. %, 0.106 wt. %, 0.017 wt. %, 0.018 wt. %, 0.019 wt. %, 0.020 wt. %, or 0.025 wt. %.

[0038] The presence of Si in an amount of at least 0.30 wt. %, Fe in an amount of at least 0.45 wt. %, Mn in an amount less than 0.55 wt.%, and Mg in an amount less than 0.85 wt.%, may result in an alloy well suited for a continuous cast process, forming an aluminum alloy

product having exceptional strength and formability. Moreover, as discussed above, by utilizing Fe, Si, Mn, and/or Mg in any one or more of the above discussed ranges and/or according to the following ratios, a finer grain size may be achieved, such as by increasing particle stimulated nucleation. Namely, in embodiments the relative amounts of Mg to Mn, Si to Mn, and/or Fe to Mn may further contribute to the exceptional strength and formability of the aluminum alloy.

[0039] Thus, in some non-limiting examples, a ratio of Fe to Mn is greater than 1.00:1, e.g., greater than 1.01:1, 1.02:1, 1.03:1, 1.04:1, 1.05:1, 1.06:1, 1.07:1, 1.08:1, 1.09:1, 1.10:1, 1.11:1, 1.12:1, 1.13:1, 1.14:1, 1.15:1, 1.16:1, 1.17:1, 1.18:1, 1.19:1, 1.20:1, 1.21:1, 1.22:1, 1.23:1, 1.24:1, 1.25:1, 1.26:1, 1.27:1, 1.28:1, 1.29:1, 1.30:1, 1.31:1, 1.32:1, 1.33:1, 1.34:1, 1.35:1, 1.36:1, 1.37:1, 1.38:1, 1.39:1, 1.40:1, 1.41:1, 1.42:1, 1.43:1, 1.44:1, 1.45:1, 1.46:1, 1.47:1, 1.48:1, 1.49:1, or greater than 1.50:1.

[0040] In some non-limiting examples, a ratio of Mg to Mn may be greater than 1.60:1, e.g., greater than 1.61:1, 1.62:1, 1.63:1, 1.64:1, 1.65:1, 1.66:1, 1.67:1, 1.68:1, 1.69:1, 1.70:1, 1.71:1, 1.72:1, 1.73:1, 1.74:1, 1.75:1, 1.76:1, 1.77:1, 1.78:1, 1.79:1, 1.80:1, 1.81:1, 1.82:1, 1.83:1, 1.84:1, 1.85:1, 1.86:1, 1.87:1, 1.88:1, 1.89:1, 1.90:1, 1.91:1, 1.92:1, 1.93:1, 1.94:1, 1.95:1, 1.96:1, 1.97:1, 1.98:1, 1.99:1, or greater than 2:1.

[0041] In some non-limiting examples, a ratio of Si to Mn may be greater than 0.30:1, e.g., greater than 0.31:1, 0.32:1, 0.33:1, 0.34:1, 0.35:1, 0.36:1, 0.37:1, 0.38:1, 0.39:1, 0.40:1, 0.41:1, 0.42:1, 0.43:1, 0.44:1, 0.45:1, 0.46:1, 0.47:1, 0.48:1, 0.49:1, 0.50:1, 0.51:1, 0.52:1, 0.53:1, 0.54:1, 0.55:1, 0.56:1, 0.57:1, 0.58:1, 0.59:1, 0.60:1, 0.61:1, or greater than 0.62:1.

Minor Elements

[0042] Optionally, the aluminum alloys described herein can further include other minor elements, sometimes referred to as impurities, in amounts of 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, Ni, Hf, Zr, Sn, Ga, Ca, Bi, Na, or combinations thereof. Accordingly, V, Ni, Hf, Zr, Sn, Ga, Ca, Bi, Na, or Pb, may be present in alloys in amounts of 0.05 % or below, 0.04 % or below, 0.03 % or below, 0.02 % or below, or 0.01 % or below. The sum of all impurities does not exceed 0.15 % (e.g., 0.1 %). All expressed in wt. %. The remaining percentage of each alloy can be aluminum. In some aspects, each of the above impurities may not be present (e.g., 0.00 %).

[0043] The aluminum alloys described herein can contain at least 40 wt. % recycled content. For example, the aluminum alloys can contain at least 45 wt. %, at least 50 wt. %, at

least 60 wt. %, at least 70 wt. %, at least 75 wt.%, at least 80 wt. %, at least 85 wt.%, at least 90 wt. %, at least 95 wt. %, at least 99 wt. % recycled content, or even up to 100 wt.%.

Processing Methods

[0044] Optionally, suitable aluminum alloy products for use in the methods described herein include 3xxx series aluminum alloys. In some cases, a 3xxx series aluminum alloy for use in the methods described herein can be a 3xxx series aluminum alloy as registered with the Aluminum Association, and can optionally be modified to include an amount of Si, Mg, Mn, Fe, and/or any other element as described above. Non-limiting exemplary 3xxx series aluminum alloys for use in the methods described herein can include AA3002, AA3102, AA3003, AA3103, AA3103A, AA3103B, AA3203, AA3403, AA3004, AA3004A, AA3104, AA3204, AA3304, AA3005, A A3005 A, AA3105, AA3105A, AA3105B, AA3007, AA3107, AA3207, AA3207A, AA3307, AA3009, AA3010, AA3110, AA3011, AA3012, AA3012A, AA3013, AA3014, AA3015, AA3016, AA3017, AA3019, AA3020, AA3021, AA3025, AA3026, AA3030, AA3130, or AA3065.

Casting

[0045] The alloys can be cast using any suitable casting process. For example, a molten aluminum alloy composition including an aluminum alloy as described herein may be cast using a continuous casting (CC) process that may include, but is not limited to, the use of twin belt casters, twin roll casters, or block casters. In some examples, the casting process is performed by a CC process to form a cast product such as a billet, slab, strip, or the like. In aspects, the process includes continuous belt casting.

[0046] In some cases, the resulting cast aluminum alloy product can exit the caster at a temperature (e.g., a caster exit temperature) of from 370 °C to 450 °C. For example, the cast aluminum alloy product can have a caster exit temperature of 370 °C, 380 °C, 390 °C, 400 °C, 410 °C, 420 °C, 430 °C, 440 °C, 450 °C, or anywhere in between.

[0047] The resulting cast aluminum alloy product can have a thickness of 5 mm to 50 mm (e.g., from 10 mm to 45 mm, from 15 mm to 40 mm, or from 20 mm to 35 mm), such as 10 mm. For example, the cast aluminum alloy product can be 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm, 11 mm, 12 mm, 13 mm, 14 mm, 15 mm, 16 mm, 17 mm, 18 mm, 19 mm, 20 mm, 21 mm, 22 mm, 23 mm, 24 mm, 25 mm, 26 mm, 27 mm, 28 mm, 29 mm, 30 mm, 31 mm, 32 mm, 33 mm, 34 mm, 35 mm, 36 mm, 37 mm, 38 mm, 39 mm, 40 mm, 41 mm, 42 mm, 43 mm, 44 mm, 45 mm, 46 mm, 47 mm, 48 mm, 49 mm, or 50 mm thick.

[0048] The cast aluminum alloy product can then be subjected to further processing steps. In some non-limiting examples, the processing method includes hot rolling, coiling, coil cooling, further processing, solutionizing, and/or aging. In some cases, the further processing can include hot rolling and/or cold rolling to a final gauge. In other cases, the further processing steps can include homogenizing, cooling, and cold rolling to a final gauge. In still other cases, the further processing steps can include cold rolling to a final gauge.

Quenching

[0049] The resulting slabs can optionally be thermally quenched upon exit from the continuous caster. In some examples, the quench is performed with water. Optionally, the quenching step, which may be water quenching, can be performed at a rate of up to about 200° C./s (for example, from 10° C./s to 190° C./s, from 25° C./s to 175° C./s, from 50° C./s to 150° C./s, from 75° C./s to 125° C./s, or from 10° C./s to 50° C./s, or any ranges or values therebetween). The water temperature can be from about 20° C. to about 75° C. (e.g., about 25° C., about 30° C., about 35° C., about 40° C., about 45° C., about 50° C., about 55° C., about 60° C., about 65° C., about 70° C., or about 75° C.). Optionally, the resulting slabs can be coiled upon exit from the continuous caster. The resulting intermediate coil can be cooled in air. The air cooling step can be performed at a rate of about 1° C./s to about 300° C./day. The quenching steps utilized in continuous casting result in an extremely fast "freezing" of the cast aluminum alloy. Such processes contribute to manganese dispersoid and precipitation problems, often resulting in poor formability in conventional alloys. However, as noted above, the alloys of the present technology overcome these deficiencies without removing quenching or requiring homogenization steps not normally present in continuous casting.

Hot Rolling

[0050] Following the casting step, a hot rolling step can be performed. In some cases, the hot rolling step can be performed immediately after the casting. The hot rolling step can include a hot reversing mill operation and/or a hot tandem mill operation. The hot rolling step can be performed at a temperature ranging from 200 °C to 500 °C (e.g., from 225 °C to 400 °C or from 250 °C to 350 °C). For example, the hot rolling step can be performed at a temperature of 250 °C, 260 °C, 270 °C, 280 °C, 290 °C, 300 °C, 310 °C, 320 °C, 330 °C, 340 °C, 350 °C, 360 °C, 370 °C, 380 °C, 390 °C, 400 °C, or anywhere in between.

[0051] In the hot rolling step, the cast aluminum alloy product can be hot rolled to a thickness of 15 mm or less (e.g., from 0.5 mm to 10 mm), providing an aluminum alloy hot

band. For example, the cast aluminum alloy product can be hot rolled to a 15 mm gauge or less, a 14 mm gauge or less, a 13 mm gauge or less, a 12 mm gauge or less, an 11 mm gauge or less, a 10 mm gauge or less, a 9 mm gauge or less, an 8 mm gauge or less, a 7 mm gauge or less, a 6 mm gauge or less, a 5 mm gauge or less, a 4 mm gauge or less, a 3 mm gauge or less, a 2 mm gauge or less, or a 1 mm gauge or less. In some cases, the percentage reduction in thickness resulting from the hot rolling step can be at least 40 % (e.g., from 40 % to 95 %). For example, the thickness of the cast aluminum alloy product can be reduced by 40 %, 45 %, 50 %, 55 %, 60 %, 65 %, 70 %, 75 %, 80 %, 85 %, 90 %, or 95%. In some cases, the aluminum alloy hot band can exit the hot reversing mill and/or the hot tandem mill (i.e., hot mill) at a temperature of from 200 °C to 400 °C. For example, the aluminum alloy hot band can have a hot mill exit temperature of 200 °C, 210 °C, 220 °C, 230 °C, 240 °C, 250 °C, 260 °C, 270 °C, 280 °C, 290 °C, 300 °C, 310 °C, 320 °C, 330 °C, 340 °C, 350 °C, 360 °C, 370 °C, 380 °C, 390 °C, 400 °C, or anywhere in between.

Coiling and Coil Cooling

[0052] Optionally, the aluminum alloy hot band can be coiled into a hot band coil upon exit from the hot mill. In some further examples, the hot band coil is cooled in air (referred to as a coil cooling). The coil cooling step can be performed at a rate of 12.5 °C/hour (°C/h) to 3600 °C/h. For example, the coil cooling step can be performed at a rate of 12.5 °C/h, 25 °C/h, 50 °C/h, 100 °C/h, 200 °C/h, 400 °C/h, 800 °C/h, 1600 °C/h, 3200 °C/h, 3600 °C/h, or anywhere in between. The hot band coil can be cooled to a temperature of from 200 °C to 400 °C. For example, the hot band coil can be cooled to a temperature of 200 °C, 210 °C, 220 °C, 230 °C, 240 °C, 250 °C, 260 °C, 270 °C, 280 °C, 290 °C, or 300 °C.

[0053] In some examples, the air cooled coil can be stored for a period of time. For example, the coil can be maintained at a temperature of 300 °C to 400 °C for 1 hour or more (e.g., 2 hours or more, 5 hours or more, 10 hours or more, 1 day or more, 2 days or more, or 1 week or more).

Homogenization, Hot Rolling to Final Gauge, Coil Cooling, and Cold Rolling to Final Gauge

[0054] Optionally, a homogenization step can be performed after hot rolling, coiling, and coil cooling. The homogenization step can include heating the hot band coil to attain a peak metal temperature (PMT) of, or at least, 450 °C (e.g., at least 460 °C, at least 470 °C, at least 480 °C, at least 490 °C, at least 500 °C, at least 510 °C, at least 520 °C, at least 530 °C, at

least 540 °C, at least 550 °C, at least 560 °C, at least 570 °C, at least 580 °C, or at least 590 °C). For example, the hot band coil can be heated to a temperature of from 450 °C to 580 °C, from 460 °C to 590 °C, from 465 °C to 570 °C, from 470 °C to 565 °C, from 475 °C to 555 °C, or from 480 °C to 550 °C, or any ranges or values therebetween . In some cases, the heating rate to the PMT can be 100 °C/hour or less, 75 °C/hour or less, 50 °C/hour or less, 40 °C/hour or less, 30 °C/hour or less, 25 °C/hour or less, 20 °C/hour or less, or 15 °C/hour or less. In other cases, the heating rate to the PMT can be from 10 °C/min to 100 °C/min (e.g., from 10 °C/min to 90 °C/min, from 15 °C/min to 70 °C/min, from 20 °C/min to 60 °C/min, from 20 °C/min to 50 °C/min, or from 30 °C/min to 40 °C/min).

[0055] The hot band coil is then allowed to soak (i.e., held at the indicated temperature) for a period of time. According to one non-limiting example, the hot band coil is allowed to soak for up to 36 hours (e.g., for 30 minutes, for 2 hours, or for 36 hours). For example, the hot band coil can be soaked at the indicated temperature for 30 minutes, 60 minutes (i.e., 1 hour), 90 minutes, 120 minutes (i.e., 2 hours), 150 minutes, 3 hours, 4 hours, 5 hours, 6 hours, 7 hours, 8 hours, 9 hours, 10 hours, 11 hours, 12 hours, 13 hours, 14 hours, 15 hours, 16 hours, 17 hours, 18 hours, 19 hours, 20 hours, 21 hours, 22 hours, 23 hours, 24 hours, 25 hours, 26 hours, 27 hours, 28 hours, 29 hours, 30 hours, 31 hours, 32 hours, 33 hours, 34 hours, 35 hours, 36 hours, or anywhere in between.

[0056] In embodiments, the hot band coil may be soaked in a nitrogen atmosphere.

[0057] For instance, in embodiments, homogenization of hot band coils may allow recrystallization of the microstructure, reducing any elongated microstructures present. Such recrystallization may result in improved further improved bendability and elongation, as examples. Namely, in embodiments, aluminum alloy product that include a hot band coil homogenization may exhibit a percent elongation after processing of greater than or about 12 %. The elongation can be at least 13 % or greater, 14 % or greater, 15 % or greater, 16 % or greater, 17 % or greater, 18 % or greater, 19 % or greater 20 % or greater, or 20.5 % or greater, after processing according to the methods described herein.

[0058] However, as noted above, in some non-limiting aspects, a homogenization step is not performed as excellent properties are obtained utilizing alloys according to the present technology.

[0059] Optionally, the homogenized hot band coil can be hot rolled to provide a final gauge aluminum alloy product. However, in aspects, an additional hot rolling processing may not be necessary. The hot rolling to final gauge step can be performed after the homogenization step employing, for example, a finishing mill. The hot rolling step can be performed at a

temperature ranging from 250 °C to 500 °C (e.g., from 300 °C to 400 °C or from 350 °C to 430 °C). For example, the hot rolling step can be performed at a temperature of 250 °C, 260 °C, 270 °C, 280 °C, 290 °C, 300 °C, 310 °C, 320 °C, 330 °C, 340 °C, 350 °C, 360 °C, 370 °C, 380 °C, 390 °C, 400 °C, 410 °C, 420 °C, 430 °C, 440 °C, 450 °C, 460 °C, 470 °C, 480 °C, 490 °C, 500 °C, or anywhere in between.

[0060] The hot rolling to final gauge step can further reduce the thickness of the hot band to a final gauge of from 0.5 mm to 6 mm. For example, the hot rolling to final gauge step can provide an aluminum alloy product having a gauge of 6 mm or less, 5.5 mm or less, 5 mm or less, 4.5 mm or less, 4 mm or less, 3.5 mm or less, 3 mm or less, 2.5 mm or less, 2 mm or less, 1.5 mm or less, 1 mm or less, 0.5 mm, or anywhere in between.

[0061] Optionally, after homogenization, the homogenized hot band coil can undergo coil cooling and cold rolling. The homogenized hot band coil can be cooled in air at a rate of 12.5 °C/hour (°C/h) to 3600 °C/h. For example, the coil cooling step can be performed at a rate of 12.5 °C/h, 25 °C/h, 50 °C/h, 100 °C/h, 200 °C/h, 400 °C/h, 800 °C/h, 1600 °C/h, 3200 °C/h, 3600 °C/h, or anywhere in between.

[0062] Following the coil cooling, a cold rolling step can optionally be performed at a temperature of 250 °C, 260 °C, 270 °C, 280 °C, 290 °C, 300 °C, 310 °C, 320 °C, 330 °C, 340 °C, 350 °C, 360 °C, 370 °C, 380 °C, 390 °C, 400 °C, 410 °C, 420 °C, 430 °C, 440 °C, 450 °C, 460 °C, 470 °C, 480 °C, 490 °C, 500 °C, or anywhere in between. In some cases, the percentage reduction in thickness resulting from the cold rolling step (e.g., further reduction from a thickness subsequent hot rolling discussed above) can be at least 40 % (e.g., from 40 % to 95 %). For example, the thickness of the cast aluminum alloy product can be reduced by 40 %, 45 %, 50 %, 55 %, 60 %, 65 %, 70 %, 75 %, 80 %, 85 %, 90 %, or 95%.

[0063] During the cold rolling step, the aluminum alloy product can be cold rolled to a thickness of from 0.1 mm to 5 mm (e.g., from 0.2 mm to 3 mm, or from 0.3 mm to 1 mm, or from 0.4 mm to 0.6 mm). For example, the homogenized hot band coil can be cold rolled to a thickness of less than 4 mm to provide a final gauge aluminum alloy product. For example, the final gauge aluminum alloy product can have a thickness of 5 mm or less, 4.5 mm or less, 4 mm or less, 3.5 mm or less, 3 mm or less, 2.5 mm or less, 2 mm or less, 1.5 mm or less, 1 mm, 0.5 mm or less, 0.4 mm or less, 0. 3 mm or less, 0.2 mm or less, 0.1 mm or less, or anywhere in between. Optionally, the cold rolling step can be performed without a homogenization step and/or a hot rolling step.

[0064] In some cases, an exemplary sequence of steps for use in further processing the hot band coil to provide a final gauge aluminum alloy product includes homogenizing the hot

band coil to provide a homogenized hot band coil and hot rolling the homogenized hot band coil to provide the final gauge aluminum alloy product. In other cases, an exemplary sequence of steps for use in further processing the hot band coil to provide a final gauge aluminum alloy product includes homogenizing the hot band coil to provide a homogenized hot band coil, cooling the homogenized hot band coil, and cold rolling the homogenized hot band coil to provide a final gauge aluminum alloy product. In still other cases, further processing the hot band coil to provide a final gauge aluminum alloy product includes cold rolling the hot band coil to provide a final gauge aluminum alloy product. In yet other aspects, the processing includes an intermediate anneal operation.

Solutionizing

[0065] The methods described herein further include a step of solutionizing the final gauge aluminum alloy product. The solutionizing step can include heating or cooling, as necessary, the final gauge aluminum alloy product to a solutionizing temperature of 450 °C or greater (e.g., from 460 °C to 600 °C, from 465 °C to 575 °C, from 470 °C to 550 °C, from 475 °C to 525 °C, or from 480 °C to 500 °C). The final gauge aluminum alloy product can soak at the solutionizing temperature for a period of time. In certain aspects, the final gauge aluminum alloy product is allowed to soak for at least 30 seconds (e.g., from 60 seconds to 120 minutes, inclusively). For example, the final gauge aluminum alloy product can be soaked at the temperature of 450 °C or greater for 30 seconds, 35 seconds, 40 seconds, 45 seconds, 50 seconds, 55 seconds, 60 seconds, 65 seconds, 70 seconds, 75 seconds, 80 seconds, 85 seconds, 90 seconds, 95 seconds, 100 seconds, 105 seconds, 110 seconds, 115 seconds, 120 seconds, 125 seconds, 130 seconds, 135 seconds, 140 seconds, 145 seconds, 150 seconds, 5 minutes, 10 minutes, 15 minutes, 20 minutes, 25 minutes, 30 minutes, 35 minutes, 40 minutes, 45 minutes, 50 minutes, 55 minutes, 60 minutes, 65 minutes, 70 minutes, 75 minutes, 80 minutes, 85 minutes, 90 minutes, 95 minutes, 100 minutes, 105 minutes, 110 minutes, 115 minutes, or 120 minutes, or anywhere in between. In certain aspects, the solutionizing is performed immediately after a hot rolling step or a cold rolling step.

Quenching

[0066] The methods described herein can include a quenching step, and/or an additional quenching step than discussed above. The term "quenching," as used herein, can include rapidly reducing a temperature of a final gauge aluminum alloy product that has been solutionized as described above. In the quenching step, the product can be quenched with a

liquid (e.g., water), gas (air), any other suitable quench medium, or any combination thereof. In certain aspects, the product can be quenched using water having a water temperature of between 40 °C and 75 °C. In certain aspects, the product is quenched using forced air.

[0067] In certain aspects, the product can be cooled to a temperature of 25 °C to 65 °C at a quench speed that can vary between 10 °C/s to 400 °C/s in a quenching step that is based on the selected gauge. For example, the quench rate can be from 10 °C/s to 375 °C/s, from 15 °C/s to 350 °C/s, from 20 °C/s to 300 °C/s, from 25 °C/s to 275 °C/s, from 30 °C/s to 250 °C/s, from 40 °C/s to 225 °C/s, from 50 °C/s to 200 °C/s, from 60 °C/s to 175 °C/s, or from 70 °C/s to 150 °C/s.

Pre-Aging

[0068] In some cases, a pre-aging step can be performed. Not to be bound by theory, the pre-aging step can at least partially arrest the mechanical property changes caused by natural aging of the aluminum alloy product. Optionally, the pre-aging step can be performed before the solutionizing step or after the solutionizing step. The pre-aging step can include heating the final gauge aluminum alloy product to a pre-aging temperature of from 50 °C to 300 °C (e.g., from 75 °C to 250 °C, from 100 °C to 300 °C, from 100 °C to 275 °C, or from 100 °C to 250 °C). For example, the pre-aging step can include heating the final gauge aluminum alloy product to a temperature of 50 °C, 55 °C, 60 °C, 65 °C, 70 °C, 75 °C, 80 °C, 85 °C, 90 °C, 95 °C, 100 °C, 105 °C, 110 °C, 115 °C, 120 °C, 125 °C, 130 °C, 135 °C, 140 °C, 145 °C, 150 °C, 155 °C, 160 °C, 165 °C, 170 °C, 175 °C, 180 °C, 185 °C, 190 °C, 195 °C, 200 °C, 205 °C, 210 °C, 215 °C, 220 °C, 225 °C, 230 °C, 235 °C, 240 °C, 245 °C, 250 °C, 255 °C, 260 °C, 265 °C, 270 °C, 275 °C, 280 °C, 285 °C, 290 °C, 295 °C, 300 °C. The final gauge aluminum alloy product can be maintained at the pre-aging temperature for a period of up to 72 hours (e.g., from 1 hour to 72 hours). For example, the final gauge aluminum alloy product can be maintained for 72 hours or less, 60 hours or less, 48 hours or less, 36 hours or less, 24 hours or less, 12 hours or less, 6 hours or less, 5 hours or less, 4 hours or less, 3 hours or less, 2 hours or less, 1 hour or less, or anywhere in between.

Aging

[0069] After the solutionizing, quenching and/or pre-aging steps, one or more aging steps can be performed. The aging can include one or more of natural aging, artificial aging, paint baking, and post-forming heat treating.

[0070] Optionally, the aging can include a natural aging step. The natural aging can include a step of maintaining the final gauge aluminum alloy product at room temperature for a period of time. For example, the final gauge aluminum alloy product can be maintained at room temperature for up to 12 weeks (e.g., 1 day, 2 days, 3 days, 4 days, 5 days, 6 days, 1 week, 2 weeks, 3 weeks, 4 weeks, 5 weeks, 6 weeks, 7 weeks, 8 weeks, 9 weeks, 10 weeks, 11 weeks, or 12 weeks).

[0071] Aluminum alloy products prepared according to the methods described herein can be delivered after being subjected to the optional pre-aging and natural aging. The aluminum alloy products can achieve high yield strengths after processing by an end user, for example, by deforming (e.g., stamping, pressing, forming, or any suitable deforming process) and/or by aging or thermal treatment (e.g., coating and paint baking, artificial aging, post-forming heat treatment, or any suitable end user thermal treatment). Optionally, after the optional pre-aging and/or natural aging step, the aluminum alloy products described herein are subjected to, for example, a forming process, a coating process, an artificial aging step, and/or a paint baking process.

[0072] Optionally, the aging can include an artificial aging step. The artificial aging can include heating the final gauge aluminum alloy product to an artificial aging temperature of from 80 °C to 250 °C (e.g., from 80 °C to 225 °C, from 100 °C to 225 °C, from 100 °C to 225 °C, from 110 °C to 220 °C, from 115 °C to 210 °C, or from 120 °C to 210 °C, from 125 °C to 225 °C, from 140 °C to 225 °C, from 160 °C to 225 °C, from 180 °C to 225 °C, from 200 °C to 225°C, and all combinations of endpoints). The artificial aging step can include maintaining the artificial aging temperature for a period of from 30 minutes hours to 72 hours (e.g., 1 hour, 2 hours, 4 hours, 8 hours, 10 hours, 12 hours, 15 hours, 20 hours, 24 hours, 30 hours 48 hours, 60 hours, or 72 hours, including combinations of all endpoints).

[0073] In some aspects, an optional coating procedure can be performed (e.g., painting, electrocoating, or zinc-phosphating, to name a few). After coating, the final gauge aluminum alloy product can be subjected to further thermal treatment including paint baking, post-forming heat treatment, any suitable OEM thermal treatment process, or any combination thereof. The paint bake can further strengthen the aluminum alloy product providing a high strength aluminum alloy product having an optionally complex formed shape. In some cases, a paint baking procedure can include heating the aluminum alloy product to a paint baking temperature of from 75 °C to 250 °C and maintaining the aluminum alloy product at the paint baking temperature for a period of up to 3 hours (e.g., from 15 minutes to 2 hours, from 15 minutes to 45 minutes, or from 30 minutes to 1 hour). In some aspects, the at least one paint

baking step may be is conducted at a temperature from 75 to 250 ˚C for a period of from 15 minutes to 3 hours, at a temperature from 100 to 200 ˚C for a period of from 15 minutes to 2 hours, or at a temperature from 150 to 180 ˚C for a period of from 15 minutes to 45 minutes.

[0074] In some further cases, a post-forming heat treatment can be performed. The post-forming heat treatment procedure can include heating the final gauge aluminum alloy product to a post-forming heat treating temperature of from 100 °C to 250 °C and maintaining this temperature for 1 hour to 24 hours (e.g., from 2 hours to 12 hours), or any anneal temperatures and time as known in the art. In some embodiments, the method of forming the aluminum alloy described herein may comprise at least one paint bake treatment. In some embodiments, the method of making the aluminum alloy described herein may comprise at least 2 paint bake treatments. The method of making the aluminum alloy described herein may comprise from 1 to 5 paint bake treatments. For example, the method of making the aluminum alloy described herein may include 1 paint bake treatment, 2 paint bake treatments, 3 paint bake treatments, 4 paint bake treatments, 5 paint bake treatments, or greater than 5 paint bake treatments.

Alloy Product Properties

[0075] The aluminum alloy products described herein can have high strength and formability properties, before and after aging as described herein. In some aspects, the aluminum alloy product is formable at a temperature below room temperature, e.g., from 0 to up to 15 ˚C. In some aspects, the aluminum alloy product is formable at ambient (room) temperature and may be formable at temperatures up to 40 ˚C.

[0076] In some cases, the aluminum alloy product exhibits a percent elongation after processing of greater than or about 11%. The elongation can be at least 12 % or greater, 12.5 % or greater, 13 % or greater, 13.5 % or greater, 14 % or greater, 14.5 % or greater, 15 % or greater 15.5 % or greater, or 16 % or greater, after processing according to the methods described herein.

[0077] In some examples, the aluminum alloy products have an ultimate tensile strength of greater than 125 MPa after processing according to the methods described herein. For example, the aluminum alloy products can have an ultimate tensile strength of 130 MPa or greater, 135 MPa or greater, 140 MPa or greater, 145 MPa or greater, 150 MPa or greater, 155 MPa or greater, 160 MPa or greater, 165 MPa or greater, 170 MPa or greater, or 175 MPa or greater, after processing according to the methods described herein.

[0078] In some examples, the aluminum alloy products have a yield strength of greater than 50 MPa after processing according to the methods described herein. For example, the aluminum alloy products can have a yield strength of 55 MPa or greater, 60 MPa or greater, 65 MPa or greater, 70 MPa or greater, or 75 MPa or greater, after processing according to the methods described herein.

[0079] In some aspects, the aluminum alloy products have an Olsen Cup Height of greater than or about 0.18" (4.6 mm), after processing according to the methods described herein. For example, the aluminum alloy products can have an Olsen Cup Height of 0.19" (4.8 mm) or greater, 0.20" (5.1 mm) or greater, 0.21" (5.3) or greater, 0.22" (5.6 mm) or greater, 0.23" (5.8 mm) or greater, 0.24" (6.1 mm) or greater, or 0.25" (6.4 mm) or greater, after processing according to the methods described herein.

Methods of Using

[0080] The alloy products and methods described herein can be used, but are not limited to, components of an automobile, truck, trailer, train, railroad car, airplane, such as a body panel or other part for any of the foregoing, a bridge, a pipeline, a pipe, a tubing, a boat, a ship, a storage container, a storage tank, an article of furniture, a window, a door, a railing, a functional or decorative architectural piece, a pipe railing, an electrical component, a conduit, a beverage container, a food container, or a foil. In some embodiments, the articles of manufacture are automotive or transportation body parts, including motor vehicle body parts (e.g., bumpers, side beams, roof beams, cross beams, pillar reinforcements, inner panels, outer panels, side panels, hood inners, hood outers, and trunk lid panels). The articles of manufacture can also include aerospace products and electronic device housings.

[0081] The products and methods described herein can also be used in electronics applications, to prepare, for example, external and internal encasements. For example, the products and methods described herein can also be used to prepare housings for electronic devices, including mobile phones and tablet computers. In some examples, the products can be used to prepare housings for the outer casing of mobile phones (e.g., smart phones) and tablet bottom chassis.

[0082] In certain aspects, the products and methods can be used to prepare a smooth walled container, a drug container, or a combination thereof.

[0083] The products and methods can be used in any other desired application.

ILLUSTRATIVE ASPECTS

[0084] As used below, any reference to a series of aspects (e.g., "Aspects 1-4") or non-enumerated group of aspects (e.g., "any previous or subsequent aspect") is to be understood as a reference to each of those aspects disjunctively (e.g., "Aspects 1-4" is to be understood as "Aspects 1, 2, 3, or 4").

[0085] Aspect 1: A method of producing an aluminum alloy product, comprising: flowing liquid metal to a casting cavity, and continuously casting an aluminum alloy product, wherein the aluminum alloy comprises greater than 0.30 wt.% Si, greater than 0.45 wt.% Fe, greater than 0.05 wt.% Cu, less than 0.55 wt.% Mn, less than 0.85 wt.% Mg, and Al.

[0086] Aspect 2: The method of aspect 1, wherein the aluminum alloy product does not undergo homogenization after the continuous casting.

[0087] Aspect 3: The method of aspect 1 or 2, further comprising one or more hot rolling operations at an exit temperature of greater than or about 250 °C.

[0088] Aspect 4: The method of aspect 3, wherein the hot rolling reduces a thickness of the aluminum alloy product by greater than or about 80% of a thickness of the aluminum alloy product after casting.

[0089] Aspect 5: The method of aspect 3, wherein the aluminum alloy comprises a thickness of less than or about 1 mm.

[0090] Aspect 6: The method of aspect 3, further comprising one or more cold rolling operations at a temperature of greater than or about 300 °C.

[0091] Aspect 7: The method of aspect 6, wherein the cold rolling reduces a thickness of the aluminum alloy product by greater than or about 75% of a thickness of the aluminum alloy product after one or more hot rolling operations.

[0092] Aspect 8: The method of aspect 7, wherein the aluminum alloy comprises a thickness of less than or about 0.5 mm.

[0093] Aspect 9: The method of any one of aspects 1 to 8, wherein the liquid metal comprises at least about 40 wt.% recycled content.

[0094] Aspect 10, The method of any one of aspects 1 to 9, wherein the continuous casting comprises continuous belt casting and/or wherein the continuously cast aluminum alloy product is thermally quenched at a rate of about 10 °C/second up to about 200 °C/second.

[0095] Aspect 11: An aluminum alloy product prepared according to any one of aspects 1 to 10.

[0096] Aspect 12: A continuous cast aluminum alloy foil, comprising: greater than 0.30 wt.% Si, greater than 0.45 wt.% Fe, greater than 0.05 wt.% Cu, less than 0.55 wt.% Mn, less

than 0.85 wt.% Mg, and Al; and wherein a ratio of Fe to Mn by weight is greater than 1:1 and the continuous cast aluminum alloy foil comprises an Ultimate Tensile Strength of greater than or about 140 MPa.

[0097] Aspect 13: The continuous cast aluminum alloy foil of aspect 12, wherein the ratio of Fe to Mn by weight is greater than 1.05:1.

[0098] Aspect 14: The continuous cast aluminum alloy foil of aspect 12 or 13, wherein a ratio of Mg to Mn is greater than 1.625:1.

[0099] Aspect 15: The continuous cast aluminum alloy foil of any one of aspects 12 to 14, wherein a ratio of Si to Mn is greater than 0.30:1.

[0100] Aspect 16: The continuous cast aluminum alloy foil of any one of aspects 12 to 15, wherein the continuous cast aluminum alloy foil comprises: from 0.30 to 0.50 wt.% Si, from 0.45 to 0.60 wt.% Fe, from 0.05 to 0.25 wt.% Cu, from 0.01 to 0.55 wt.% Mn, from 0.01 to 0.85 wt.% Mg, and Al.

[0101] Aspect 17: The continuous cast aluminum alloy foil of any one of aspects 12 to 16, wherein the continuous cast aluminum alloy foil comprises: from 0.35 to 0.45 wt.% Si, from 0.45 to 0.55 wt.% Fe, from 0.10 to 0.20 wt.% Cu, from 0.30 to 0.55 wt.% Mn, from 0.50 to 0.80 wt.% Mg, and Al.

[0102] Aspect 18: The continuous cast aluminum alloy foil of any one of aspects 12 to 17, further comprising: less than 0.01 wt.% total of Cr and Pb, from 0.15 to 0.35 wt.% Zn, up to 0.10 wt.% Ti, up to 0.15 wt.% impurities.

[0103] Aspect 19: The continuous cast aluminum alloy foil of any one of aspects 12 to 18, wherein the continuous cast aluminum foil comprises an Olsen Cup Height of greater than or about 0.20” (5.1 mm).

[0104] Aspect 20: The continuous cast aluminum alloy foil of any one of aspects 12 to 19, wherein the continuous cast aluminum foil comprises a thickness of less than or about 0.50 mm.

[0105] All patents and publications cited herein are incorporated by reference in their entirety. The foregoing description of the embodiments, including illustrated embodiments, has been presented only for the purpose of illustration and description and is not intended to be exhaustive or limiting to the precise forms disclosed. Numerous modifications, adaptations, and uses thereof will be apparent to those skilled in the art.

WHAT IS CLAIMED IS:

1. A method of producing an aluminum alloy product, comprising:
flowing liquid metal to a casting cavity; and
continuously casting an aluminum alloy product;
wherein the aluminum alloy comprises,
greater than 0.30 wt.% Si,
greater than 0.45 wt.% Fe,
greater than 0.05 wt.% Cu,
less than 0.55 wt.% Mn,
less than 0.85 wt.% Mg, and
Al.

2. The method of claim 1, wherein the aluminum alloy product does not undergo homogenization after the continuous casting.

3. The method of claim 1, further comprising one or more hot rolling operations at an exit temperature of greater than or about 250 °C.

4. The method of claim 3, wherein the hot rolling reduces a thickness of the aluminum alloy product by greater than or about 80% of a thickness of the aluminum alloy product after casting.

5. The method of claim 3, wherein the aluminum alloy comprises a thickness of less than or about 1 mm.

6. The method of claim 3, further comprising one or more cold rolling operations at a temperature of greater than or about 300 °C.

7. The method of claim 6, wherein the cold rolling reduces a thickness of the aluminum alloy product by greater than or about 75% of a thickness of the aluminum alloy product after one or more hot rolling operations.

8. The method of claim 7, wherein the aluminum alloy comprises a thickness of less than or about 0.5 mm.

9. The method of claim 1, wherein the liquid metal comprises at least about 40 wt.% recycled content.

10. The method of claim 1, wherein the continuous casting comprises continuous belt casting and/or wherein the continuously cast aluminum alloy product is thermally quenched at a rate of about 10 °C/second up to about 200 °C/second.

11. An aluminum alloy product prepared according to the method of claim 1.

12. A continuous cast aluminum alloy foil, comprising:
greater than 0.30 wt.% Si,
greater than 0.45 wt.% Fe,
greater than 0.05 wt.% Cu,
less than 0.55 wt.% Mn,
less than 0.85 wt.% Mg, and
Al; and
wherein a ratio of Fe to Mn by weight is greater than 1:1 and the continuous cast aluminum alloy foil comprises an Ultimate Tensile Strength of greater than or about 140 MPa.

13. The continuous cast aluminum alloy foil of claim 12, wherein the ratio of Fe to Mn by weight is greater than 1.05:1.

14. The continuous cast aluminum alloy foil of claim 12, wherein a ratio of Mg to Mn by weight is greater than 1.625:1.

15. The continuous cast aluminum alloy foil of claim 12, wherein a ratio of Si to Mn by weight is greater than 0.30:1.

16. The continuous cast aluminum alloy foil of claim 12, wherein the continuous cast aluminum alloy foil comprises:
from 0.30 to 0.50 wt.% Si,
from 0.45 to 0.60 wt.% Fe,
from 0.05 to 0.25 wt.% Cu,
from 0.01 to 0.55 wt.% Mn,
from 0.01 to 0.85 wt.% Mg, and

Al.

17. The continuous cast aluminum alloy foil of claim 12, wherein the continuous cast aluminum alloy foil comprises:
from 0.35 to 0.45 wt.% Si,
from 0.45 to 0.55 wt.% Fe,
from 0.10 to 0.20 wt.% Cu,
from 0.30 to 0.55 wt.% Mn,
from 0.50 to 0.80 wt.% Mg, and
Al.

18. The continuous cast aluminum alloy foil of claim 12, further comprising:
less than 0.01 wt.% total of Cr and Pb,
from 0.15 to 0.35 wt.% Zn,
up to 0.10 wt.% Ti, and
up to 0.15 wt.% impurities.

19. The continuous cast aluminum foil of claim 12, wherein the continuous cast aluminum foil comprises an Olsen Cup Height of greater than or about 0.20" (5.1 mm).

20. The continuous cast aluminum foil of claim 12, wherein the continuous cast aluminum foil comprises a thickness of less than or about 0.50 mm.

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2024/030197

A. CLASSIFICATION OF SUBJECT MATTER

INV. C22C21/00 B22D11/00 C22C21/06 C22C21/08 C22F1/04
C22F1/047
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C B22D 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, CHEM ABS Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2005 290431 A (FURUKAWA SKY KK) 20 October 2005 (2005-10-20) paragraphs [0005], [0006], [0017], [0022] - [0024]; tables 1-4	1,2, 9-15,19, 20
X	JP H08 209312 A (FURUKAWA ELECTRIC CO LTD; FUJI PHOTO FILM CO LTD) 13 August 1996 (1996-08-13) paragraphs [0018] - [0020]; tables 1,2	1,2, 9-16,18, 19
X	JP H11 71623 A (NIPPON STEEL CORP) 16 March 1999 (1999-03-16) paragraphs [0013], [0021], [0025]; tables 1,5	1,3-12, 16,17, 19,20

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[x] Further documents are listed in the continuation of Box C.

[x] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 August 2024	10/09/2024

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2024/030197

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
T	ANONYMOUS: "International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys", THE ALUMINUM ASSOCIATION, 1 August 2018 (2018-08-01), pages 1-45, XP093136682, ISSN: 2377-6692 page 1	
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T	Anonymous: "ENVIRONMENTAL PRODUCT DECLARATION COLD-ROLLED ALUMINUM", , 16 October 2014 (2014-10-16), XP093198799, Retrieved from the Internet: URL:https://www.aluminum.org/sites/default/files/2021-11/101.1_Aluminum_EPD_ColdRolledAluminum.pdf Manufacture; page 5	

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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JP H08209312 A	13-08-1996	JP 3107191 B2	06-11-2000
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