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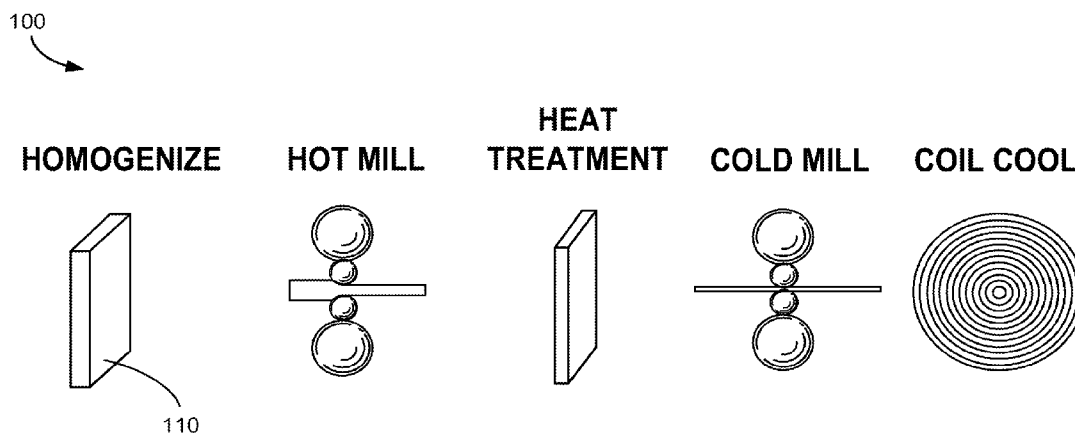


FIG. 1

(57) Abstract: Provided herein are highly-formable aluminum alloys and methods of making such alloys. The method of preparing aluminum alloys described herein can include a cold work thickness reduction subsequent to a solution heat treatment step to produce an aluminum alloy product exhibiting improved formability. The methods described herein result in the aluminum alloys having a relatively soft composition, enabling improved formability through reduced passes during hot mill rolling and cold mill rolling compared to conventional AA5182 aluminum alloys used to produce can end stock. Reducing the number of passes to produce an aluminum alloy product with a desirable gauge can reduce carbon emissions and energy consumption associated with producing the aluminum alloy product.

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METHODS OF PRODUCING 6XXX SERIES ALUMINUM ALLOYS AT THIN GAUGE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of and priority to U.S. Provisional Application No. 63/511,819 filed July 3, 2023, which is incorporated herein by reference in its entirety for all intents and purposes.

FIELD

[0002] This disclosure relates to the fields of material science, material chemistry, metallurgy, aluminum alloys, aluminum alloy products, aluminum fabrication, and related fields. More specifically, the present disclosure relates to 6xxx series aluminum alloys that exhibit high strength and formability at thin gauges. The 6xxx series aluminum alloys having thin gauges can be used to produce, for example, can tabs, can bodies, and can ends for beverage cans.

BACKGROUND

[0003] Can end stock is conventionally made from high-strength aluminum alloys that have good formability properties. The mechanical requirements for aluminum alloys used to produce can end stock are different than the mechanical requirements for can body stock. In general, aluminum alloys for producing can end stock require greater strength than can body stock. As a result, can end stock is often fabricated from an aluminum alloy comprising high amounts of magnesium (Mg). For instance, can end stock may be fabricated from a highly engineered AA5182 aluminum alloy that has a rigidly controlled composition and process for producing the alloy.

[0004] Many aluminum manufacturers use AA5182 aluminum alloy for can end stock. The AA5182 composition is strictly controlled to have a magnesium (Mg) content between 4.0 wt. % and 5.0 wt. %, a manganese (Mn) content between 0.2 wt. % and 0.5 wt. %, a maximum iron (Fe) content of 0.35 wt. %, a maximum silicon (Si) content of 0.2 wt. %, a maximum copper (Cu) content of 0.15 wt. %, and a maximum chromium (Cr) content of 0.1 wt. %. However, it is difficult to improve the performance of one property of a 5xxx series aluminum (e.g., strength) without decreasing the performance of another property (e.g., formability). If the Mg content of the AA5182 is increased above 5 wt. % to improve strength and/or formability, the aluminum alloy will be highly susceptible to cracking during the production

process. Additionally, a relatively high Mg content can hinder recovery of the aluminum alloy, causing decreased reusability and recyclability of the aluminum alloy products.

SUMMARY

[0005] Covered embodiments of the invention are defined by the claims, not this summary. This summary is a high-level overview of various aspects of the invention 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, any or all drawings, and each claim.

[0006] Provided herein are highly-formable 6xxx series aluminum alloys and methods of producing the aluminum alloys at thin gauge. The aluminum alloys described herein comprise 0.20 – 1.40 wt. % Si, 0.20 – 0.80 wt. % Fe, 0.05 – 1.00 wt. % Cu, 0.05 – 0.80 wt. % Mn, 0.50 – 1.60 wt. % Mg, up to 0.25 wt. % Zn, up to 0.30 wt. % Cr, up to 0.60 wt. % Bi, up to 0.60 wt. % Pb, up to 0.15 wt. % impurities, and the remainder Al. In some embodiments, the aluminum alloys comprise 0.60 – 1.10 wt. % Si, up to 0.40 wt. % Fe, 0.50 – 0.90 wt. % Cu, 0.10 – 0.45 wt. % Mn, 0.50 – 1.00 wt. % Mg, up to 0.15 wt. % Zn, up to 0.10 wt. % Cr, up to 0.05 wt. % Bi, up to 0.05 wt. % Pb, up to 0.15 wt. % impurities, and the remainder Al.

[0007] In some embodiments, a method of producing an aluminum alloy product is provided. The method includes: casting an aluminum alloy to produce a cast aluminum alloy product, wherein the aluminum alloy comprises a 6xxx series aluminum alloy; homogenizing the cast aluminum alloy product to produce a homogenized cast aluminum alloy product; hot rolling the homogenized cast aluminum alloy product to produce a hot rolled product; optionally, i) solution heat treating the hot rolled product at a solution heat treatment temperature of about 450 °C to 600 °C; or ii) coiling the hot rolled product at a hot rolling exit temperature; cold rolling the hot rolled product to produce a cold rolled product, wherein the cold rolled product is rolled to a final gauge thickness from 0.180 mm to 0.250 mm, wherein an exit temperature of the cold rolled product is 150 °C or greater; and optionally, solution heat treating the cold rolled product at a solution heat treatment temperature of about 450 °C to 580 °C.

[0008] In some embodiments, the method further comprises coiling the cold rolled product to produce a coiled aluminum alloy product, wherein the cold rolled product is configured to undergo precipitation hardening during coil cooling. In some embodiments, the method further comprises aging the coiled aluminum alloy product at a temperature from 150 °C to 250 °C for

1 hour to 10 hours. In some embodiments, the cast step comprises direct chill casting. In some embodiments, the homogenizing step is performed at a homogenization temperature from about 540 °C to 600 °C. In some embodiments, the hot rolled product is cooled to about ambient temperature prior to the solution heat treating step. In some embodiments, the solution heat treating step comprises heating the hot rolled product at the solution heat treatment temperature for up to 50 seconds prior to the cold rolling step. In some embodiments, the line speed of the solution heat treating step is at least 20 meters/min.

[0009] In some embodiments, an entry temperature of the hot rolled product to the cold rolling step is from 20 °C to 80 °C. In some embodiments, the cold rolling step comprises 6 or fewer cold rolling passes to produce the cold rolled product. Additionally, in some embodiments, the method further comprises solution heat treating the cold rolled product in between at least two cold rolling passes. In some embodiments, the method does not include artificial aging after the cold rolling step. In some embodiments, the cold rolling step is performed in a cold rolling mill comprising at least two stands arranged in series. In some embodiments, the cold rolling step comprises a single pass to produce the cold rolled product. In some embodiments, the exit temperature of the cold rolled product is from about 150 °C to 220 °C. In some embodiments, the cold rolling step produces at least 80% cold work thickness reduction from the hot rolled product to the cold rolled product. In some embodiments, the cold rolling step produces a cold work thickness reduction from about 85% to 95%. In some embodiments, the method further comprises solution heat treating the cold rolled product.

[0010] In some embodiments, the hot rolling step is configured to produce the hot rolled product having a hot band gauge of from about 0.5 mm to 3.5 mm. In some embodiments, the hot rolling step is characterized by using 21 or fewer passes to produce the hot rolled product. In some embodiments, the precipitation hardening is configured to occur using residual heat corresponding to the exit temperature of the cold rolled product. In some embodiments, the method further comprises coating the coiled aluminum alloy product. In some embodiments, the aluminum alloy product has a yield strength of about 150 MPa to 425 MPa. In some embodiments, the aluminum alloy product has an elongation from 1% to 20%.

[0011] Also provided herein are aluminum alloy products (e.g., aluminum alloy can end stock, aluminum alloy can tab stock, or aluminum alloy can body stock) comprising the aluminum alloys described herein. In some embodiments, the aluminum alloy products comprise at least 20 wt. % of recycled aluminum materials. In some embodiments, the recycled aluminum materials comprise used beverage can scrap.

[0012] Further aspects, objects, and advantages will become apparent upon consideration of the detailed description of non-limiting examples that follow.

BRIEF DESCRIPTION OF THE FIGURES

[0013] The disclosure will be readily understood by the following detailed description in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements, and in which:

[0014] **FIG. 1** is a schematic depicting a processing method as described herein having a cold rolling step subsequent to a solution heat treatment step.

[0015] **FIG. 2** is a graph showing the influence of processing steps on the electrical conductivity of the example aluminum alloy in Table 2 as measured according to the international annealed copper standard (IACS).

[0016] **FIG. 3** is a bar graph showing the yield strength, spread, and percent elongation of aluminum alloys as described herein subjected to a solution heat treatment step at about 560 °C.

[0017] **FIG. 4** is a bar graph showing the yield strength and spread of aluminum alloys as described herein subjected to a solution heat treatment step at about 540 °C.

[0018] **FIG. 5** shows a graph of the whiteness index values of Example Alloy 2 and Comparative Alloy 1 (AA5182 alloy) as measured by a spectrophotometer.

[0019] **FIG. 6** shows a graph of the gloss values taken at 60° of Example Alloy 2 and Comparative Alloy 1 as measured by a spectrophotometer.

[0020] **FIG. 7** shows a graph of the yield strength (MPa), ultimate tensile strength (MPa), and elongation properties (%) of Example Alloy 2 after different processing conditions.

[0021] **FIG. 8** shows a graph of the propagation energy (KJ/m²) of Example Alloy 2 and Comparative Alloy 1 as measured by the Kahn Tear test.

[0022] **FIG. 9** shows a graph of the shell buckle strength (psi) of Example Alloy 2 and Comparative Alloy 1.

[0023] **FIG. 10** shows a graph of the fresh buckle strength (psi) of Example Alloy 2 and Comparative Alloy 1.

[0024] **FIG. 11** shows a graph of the turbo-aged buckle strength (psi) of Example Alloy 2 and Comparative Alloy 1.

[0025] **FIG. 12** shows a graph of the shell clamping pressure formability results for Example Alloy 2 and Comparative Example 1.

DETAILED DESCRIPTION

[0026] Described herein are 6xxx series aluminum alloys and methods of preparing 6xxx series aluminum alloys (e.g., for can end stock, can tab stock, or can body stock). The 6xxx series aluminum alloys described herein provide a cost-effective alternative to the use of AA5182 aluminum alloys for can end stock. The 6xxx series aluminum alloys exhibit high strength and formability at thin gauge (e.g., less than 10 mm) while having a lower Mg content than conventional AA5182 aluminum alloys. The lower Mg content of the 6xxx series aluminum alloys described herein can reduce the amount and cost of Mg addition for can ends. Specifically, the 6xxx series aluminum alloys described herein can be produced from higher amounts of recycled aluminum materials than AA5182 aluminum alloys due to the lower Mg content. Additionally, the methods of preparing the 6xxx series aluminum alloys described herein reduce the total number of hot rolling passes needed to achieve a predetermined gauge (e.g., can end stock gauge) compared to AA5182 aluminum alloys thereby providing process efficiencies and reducing the amount of resources and time for hot rolling, which is a time and resource-intensive step in aluminum alloy production. In some non-limiting examples, the methods of preparing the highly-formable aluminum alloy sheets include a cold rolling step with six or fewer passes to produce a cold rolled product.

[0027] Conventionally, AA5182 aluminum alloys are used for producing can end stock. 6xxx series aluminum alloys were not used for producing can end stock because their mechanical properties (e.g., formability) were not suitable for can end stock at thin gauges (e.g., less than 10 mm). AA5182 aluminum alloys for producing can end stock require a strictly controlled composition to meet the minimum strength requirements for can end stock while still maintaining formability to produce complex geometries. In general, greater strength is required for aluminum alloys used to produce can end stock compared to can body stock, which has dictated that such can end stock be fabricated from an aluminum alloy including high amounts of Mg, such as AA5182 aluminum alloy. This limits the amount of recycled aluminum material that can be used to produce AA5182 aluminum alloy. The high amounts of Mg in conventional AA5182 aluminum alloys for producing can end stock can limit the recyclability of the AA5182 aluminum alloys due to poor recovery resulting from the relatively high Mg content. Aluminum alloy products formed using AA5182 aluminum alloy also experience a loss of end buckle strength after forming due to the AA5182 aluminum alloy exhibiting an age-softening effect due to high Mg content.

[0028] The 6xxx series aluminum alloys described herein can effectively replace AA5182 aluminum alloy for producing can end stock. The 6xxx series aluminum alloys described herein

beneficially mitigates back-end performance during down gauging (end buckle strength), eliminates end-age softening, and prevents/reduces loss of end buckle strength over time. Additionally, the 6xxx series aluminum alloys described herein improve production recycle content in can end stock, and improve control of recycled alloy when using UBC integrated with 6xxx series aluminum alloys. The methods described herein produces a 6xxx series aluminum alloy that can be down-gauged to thicknesses suitable for can end stock used to produce can ends. Although the 6xxx series aluminum alloys are generally described herein with respect to can end stock, the 6xxx series aluminum alloys can be used in other beverage can applications, such as tab stock used to produce tabs or can body stock to produce can bodies. In some embodiments, the method includes post-solutionizing cold rolling (e.g., cold rolling an aluminum alloy product after solution heat treatment). The method includes solution heat treating a hot rolled product (produced from a 6xxx series aluminum alloy) to produce a solution-heat treated hot rolled product, cold rolling the solution-heat treated hot rolled product to produce a cold rolled product, and aging the cold rolled product. In some embodiments, the hot rolled product can be subjected to solution heat treatment and then cold rolled to reduce the thickness of the hot rolled product by greater than 80 % to a final gauge.

[0029] The 6xxx series aluminum alloy has processing advantages due to having a softer condition (lower strength) compared to conventional AA5182 aluminum alloys. The softer condition of the 6xxx series aluminum alloy can correspond to a yield strength of the 6xxx series aluminum alloy being 20% to 30% lower compared to conventional AA5182 aluminum alloys. For instance, conventional AA5182 aluminum alloys in an F temper may exhibit a yield strength of about 200 MPa due to the high Mg content. In contrast, AA6111 aluminum alloys that have been naturally aged to a T4 temper exhibit a yield strength of 135 MPa. As a result, the rolling process takes much longer for a AA5182 aluminum alloy compared to a 6xxx series aluminum alloy. In certain cases, the softer condition of the 6xxx series aluminum alloy enables energy reduction associated with producing the aluminum alloy, such as through fewer passes during hot mill rolling and cold mill rolling compared to conventional AA5182 aluminum alloys. High-strength aluminum alloys (e.g., AA5182 aluminum alloys) typically require relatively high mill power to reduce the thickness of the high-strength aluminum alloys to a desirable thickness, such as for use in can end stock. Thus, the softer condition of the 6xxx series aluminum alloy described herein can lower the carbon footprint and energy consumption associated with producing the aluminum alloy, while reducing manufacturing or processing costs.

[0030] Additionally, the 6xxx series aluminum alloy described herein exhibit similar mechanical properties to conventional AA5182 aluminum alloys, allowing can manufacturers to use the 6xxx series aluminum alloy with little to no changes to their existing methods. In some embodiments, higher amounts of used beverage cans may be used to produce the 6xxx series aluminum alloy described herein, thereby reducing the amount of primary aluminum needed, reducing the total cost, and maintaining equivalent or better rolling productivity. In some embodiments, the 6xxx series aluminum alloy described herein can be used to produce can end stock for can ends, can tab stock for tabs, or can body stock for can bodies.

[0031] *Definitions and Descriptions*

[0032] As used herein, the terms “invention,” “the invention,” “this invention” and “the present invention” 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.

[0033] In this description, reference is made to alloys identified by aluminum industry designations, such as “series” or “6xxx.” 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.

[0034] As used herein, the meaning of “a,” “an,” or “the” includes singular and plural references unless the context clearly dictates otherwise.

[0035] As used herein, a plate generally has a thickness of greater than about 15 mm. For example, a plate may refer to an aluminum product having a thickness of greater than about 15 mm, greater than about 20 mm, greater than about 25 mm, greater than about 30 mm, greater than about 35 mm, greater than about 40 mm, greater than about 45 mm, greater than about 50 mm, or greater than about 100 mm.

[0036] As used herein, a shate (also referred to as a sheet plate) generally has a thickness of from about 4 mm to about 15 mm. For example, a shate may have a thickness of about 4 mm, about 5 mm, about 6 mm, about 7 mm, about 8 mm, about 9 mm, about 10 mm, about 11 mm, about 12 mm, about 13 mm, about 14 mm, or about 15 mm.

[0037] As used herein, a sheet generally refers to an aluminum product having a thickness of less than about 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 about 0.1 mm, about 0.2 mm, about 0.3 mm, about 0.4 mm, about 0.5, about 0.6 mm about 0.7 mm, about 0.8 mm, about 0.9 mm, about 1 mm, about 1.1 mm, about 1.2 mm, about 1.3 mm, about 1.4 mm, about 1.5 mm, about 1.6 mm, about 1.7 mm, about 1.8 mm, about 1.9 mm, about 2 mm, about 2.1 mm, about 2.2 mm, about 2.3 mm, about 2.4 mm, about 2.5 mm, about 2.6 mm about 2.7 mm, about 2.8 mm, about 2.9 mm, about 3 mm, about 3.1 mm, about 3.2 mm, about 3.3 mm, about 3.4 mm, about 3.5 mm, about 3.6 mm, about 3.7 mm, about 3.8 mm, or about 3.9 mm.

[0038] 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.

[0039] 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.” An F condition or temper refers to an aluminum alloy as fabricated. An O condition or temper refers to an aluminum alloy after annealing. 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 that is 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.

[0040] As used herein, the meaning of “room temperature” can include a temperature of from about 15 °C to about 30 °C, for example about 15 °C, about 16 °C, about 17 °C, about 18 °C, about 19 °C, about 20 °C, about 21 °C, about 22 °C, about 23 °C, about 24 °C, about 25 °C, about 26 °C, about 27 °C, about 28 °C, about 29 °C, or about 30 °C.

[0041] As used herein, terms such as “cast aluminum alloy product,” “cast aluminum alloy article,” “cast metal product,” “cast 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, or any combination thereof.

[0042] All ranges disclosed herein are to be understood to encompass both 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.

[0043] 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 examples of each alloy, the remainder is aluminum, with a maximum wt.% of 0.15% for the sum of the impurities.

[0044] *Methods of Making Aluminum Alloy Products*

[0045] Described herein are novel methods for preparing aluminum alloy products that exhibit desirable mechanical properties. In some embodiments, the method described herein produces a 6xxx series aluminum alloy for use as can end stock, can tab stock, or can body stock. For example, the method described herein produces a 6xxx series aluminum alloy for use as can end stock to produce can ends, can tab stock to produce tabs, and can body stock to produce can bodies. In some embodiments, the method described herein produces a 6xxx series aluminum alloy that can be rolled to thin gauges (e.g., less than 0.3 mm thick) for use as can end stock, can tab stock, or can body stock. Conventionally, 6xxx series aluminum alloys were not provided at thin gauges because these alloys would not achieve good mechanical properties (e.g., a combination of strength and formability) at thin gauges and processing inefficiencies. For example, continuous annealing and solution heat treatment of a 6xxx series aluminum alloy at thin gauges (e.g., less than 0.3 mm thick) is very difficult and not economical. Secondly, a 6xxx series aluminum alloy needs to be provided to a customer in a T4 temper for forming and requires further heat treatment to a T6 temper, which made 6xxx series aluminum alloy undesirable for use as can body stock. These factors prevented the use of 6xxx series aluminum alloy at thin gauges for can body stock.

[0046] Surprisingly, the method described herein provides a finely controlled process for producing 6xxx series aluminum alloys that achieves good strength and formability properties at thin gauges. The process for producing the 6xxx series aluminum alloys at thin gauges includes heat treating the 6xxx series aluminum alloy at a thicker gauge (e.g., 0.5 mm to 2.5 mm) before implementing a cold rolling step to achieve the thin gauges. For example, the method may include solution heat treating the hot rolled product. Therefore, instead of supplying coils of the 6xxx series aluminum alloys in a T4 temper for subsequent heat treatment by the customer, the 6xxx series aluminum alloys can be provided as heat treated sheets to avoid the post-forming heat treatment step that can cause deformations of the 6xxx series aluminum alloys. Additionally, the 6xxx series aluminum alloys do not exhibit end-age softening due to the reduced amount of Mg content compared to AA5182 aluminum alloy, which is a common problem for can end stock.

[0047] In some embodiments, the method includes casting, homogenizing, hot rolling, solution heat treatment, cold rolling, and aging to produce an aluminum alloy product. In one exemplary embodiment, an aluminum alloy is cast to produce a cast aluminum alloy product, the cast aluminum alloy product is homogenized to form a homogenized aluminum alloy product, the homogenized aluminum alloy product is subjected to one or more hot rolling passes to produce a hot rolled product, the hot rolled product is solution heat treated to produce a solution heat treated hot rolled product, and the solution heat treated hot rolled product is cold rolled to produce the aluminum alloy product. In some embodiments, the cold rolling step results in a thickness reduction of greater than 80 % to a final gauge. In some embodiments, the final gauge of the aluminum alloy product may be less than 0.30 mm (e.g., from 0.180 mm to 0.250 mm). The cold rolling thickness reduction after solution heat treatment provides a thin-gauge aluminum alloy that exhibits a combination of strength and formability for use as can end stock.

[0048] The cold rolling step can increase sheet strength of the aluminum alloy product by work hardening. Additionally, the cold rolling step can contribute to the combination of strength and formability of the thin-gauge aluminum alloy by providing dislocations as nuclei for precipitation hardening. For instance, the cold rolling step can elongate and add dislocations to a grain structure of the aluminum alloy product to improve the strength while maintaining formability due to recovery from cooling at a relatively slow rate. By cooling the hot rolled product relatively slowly, the microstructure of the aluminum alloy can develop precipitates that impinge or hinder further deformation, thereby maintaining or improving strength of the aluminum alloy after the cold rolling step. Optionally, the aluminum alloy product is subjected to additional processing steps, as described below, to form an aluminum alloy article. In some

embodiments, the aluminum alloy product can be used in can end stock applications. In additional or alternative embodiments, the aluminum alloy product can be used in can tab stock applications or can body stock applications.

[0049] Among other properties, the methods of preparing aluminum alloys as described herein result in aluminum alloy products that display desirable elongation and forming properties. In some cases, the mechanical properties can be achieved due to the method of processing the aluminum alloy. For example, the processing methods, as further described herein, can include any combination of a hot rolling step using 21 or fewer passes, a cold rolling step using six or fewer passes, and a solution heat treatment step with a solution heat treatment temperature of about 450 °C to 580 °C. The resulting aluminum alloy products exhibit desirable forming properties. In certain aspects, the method of preparing and processing the aluminum alloy products may influence or even determine whether the products will have properties adequate for a desired application.

[0050] *Casting*

[0051] The aluminum alloys, as further described herein, can be cast into a cast aluminum alloy product using any suitable casting method. For example, the casting process can include a direct chill (DC) casting process or a continuous casting (CC) process. In some non-limiting examples, the aluminum alloys for use in the casting step can be a primary material produced from raw materials (e.g., purified aluminum and additional alloying elements). In some further examples, the aluminum alloys for use in the casting step can be a recycled material, produced at least in part by aluminum scrap and optionally in combination with a primary material. In some cases, aluminum alloys for use in the casting step can contain at least about 40% of recycled content. For example, the aluminum alloy for use in the casting step can contain at least about 60%, at least about 70%, at least about 80%, at least about 90%, or at least about 95% of recycled content.

[0052] In some embodiments, a continuous casting system can include a pair of moving opposed casting surfaces (e.g., moving opposed belts, rolls or blocks), a casting cavity between the pair of moving opposed casting surfaces, and a molten metal injector. The molten metal injector can have an end opening from which molten metal can exit the molten metal injector and be injected into the casting cavity. A cast aluminum alloy product, such as a cast ingot, cast slab, or other cast product, can be processed by any desirable techniques. The cast aluminum alloy product can then be subjected to further processing steps. For example, the

processing methods as described herein can include the steps of homogenizing, hot rolling, solution heat treating, cold rolling, and/or aging to result in an aluminum alloy product.

[0053] *Homogenization*

[0054] The homogenization step as described herein was designed for the aluminum alloys described herein. The homogenization step can include heating the cast aluminum alloy product to attain a temperature from about 400 °C to about 600 °C (e.g., from about 400 °C to about 500 °C, from about 450 °C to about 550 °C, 450 °C to about 580 °C, from about 540 °C to about 600 °C, or from about 570 °C to about 600 °C) to produce a homogenized cast aluminum alloy product. For example, the cast aluminum alloy product can be heated to a temperature of 400 °C, 410 °C, 420 °C, 430 °C, 440 °C, 450 °C, 460 °C, 470 °C, 480 °C, 490 °C, 500 °C, 510 °C, 520 °C, 530 °C, 540 °C, 550 °C, 560 °C, 570 °C, 580 °C, 590 °C, or 600 °C. In some embodiments, heating the cast aluminum alloy takes up to about 15 hours (e.g., from about 20 minutes to about 15 hours or from about 5 hours to about 10 hours, inclusively). For example, the cast aluminum alloy product may be heated to a temperature of from about 400 °C to about 600 °C in about 20 minutes, about 30 minutes, about 45 minutes, about 1 hour, about 1.5 hours, about 2 hours, about 3 hours, about 4 hours, about 5 hours, about 6 hours, about 7 hours, about 8 hours, about 9 hours, about 10 hours, about 11 hours, about 12 hours, about 13 hours, about 14 hours, or about 15 hours, or anywhere in between. In some embodiments, the homogenization step involves heating the cast aluminum alloy product for up to 60 hours in a furnace. In some embodiments, the homogenization step involves heating the cast aluminum alloy product to a temperature of 540 °C and soaking the cast aluminum alloy product for about 2 hours to produce a homogenized cast aluminum alloy product.

[0055] In some cases, the heating rate can be about 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 can be from about 10 °C/min to about 100 °C/min (e.g., from about 10 °C/min to about 90 °C/min, from about 10 °C/min to about 70 °C/min, from about 10 °C/min to about 60 °C/min, from about 20 °C/min to about 90 °C/min, from about 30 °C/min to about 80 °C/min, from about 40 °C/min to about 70 °C/min, or from about 50 °C/min to about 60 °C/min).

[0056] The cast aluminum alloy product is then allowed to soak (i.e., held at the indicated temperature) for a period of time. According to one non-limiting example, the cast aluminum alloy product is allowed to soak for up to about 15 hours (e.g., from about 20 minutes to about 15 hours or from about 5 hours to about 10 hours, inclusively). For example, the cast aluminum

alloy product can be soaked at a temperature of from about 540 °C to about 600 °C for about 20 minutes, about 30 minutes, about 45 minutes, about 1 hour, about 1.5 hours, about 2 hours, about 3 hours, about 4 hours, about 5 hours, about 6 hours, about 7 hours, about 8 hours, about 9 hours, about 10 hours, about 11 hours, about 12 hours, about 13 hours, about 14 hours, or about 15 hours, or anywhere in between.

[0057] *Hot Rolling*

[0058] Following the homogenization step, a hot rolling step can be performed. The hot rolling step can include a hot reversing mill operation and/or a hot tandem mill operation. In certain cases, the cast aluminum alloy product is laid down and hot rolled at a hot rolling temperature from 250° C to 560° C (e.g., from 300° C to 400° C, from 350° C to 500° C, from 510 °C to 550 °C or from 520 °C to 540 °C). For example, the hot rolling step can be performed at a temperature of about 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, 505 °C, 510 °C, 515 °C, 520 °C, 525 °C, 530 °C, 535 °C, 540 °C, 545 °C, 550 °C, 555 °C, 560 °C. In certain cases, the hot roll exit temperature can range from about 200 °C to about 290 °C (e.g., from about 210 °C to about 280 °C or from about 220 °C to about 270 °C). For example, the hot roll exit temperature can be about 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, or anywhere in between.

[0059] In certain cases, the cast aluminum alloy product is hot rolled from a transfer bar gauge to a hot band gauge to form a hot rolled product. The cast aluminum alloy product may enter the hot rolling step at a transfer bar gauge of from 20 mm to 50 mm (e.g., from 20 mm to 35 mm, from 30 mm to 40 mm, or from 35 mm to 50 mm. For example, the cast aluminum alloy product can exhibit a transfer bar gauge of 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. During the hot rolling step, the cast aluminum alloy product can be hot rolled from the transfer bar gauge to a hot band gauge of from 0.5 mm to 3.5 mm (e.g., from 1.0 mm to 2.5 mm, from 0.5 mm to 1.5 mm, or from 2.0 mm to 3.0 mm gauge), which is referred to as a hot rolled product. For example, the cast aluminum alloy product can be hot rolled to produce a hot rolled product having a hot band gauge of 3.5 mm, 3.4 mm, 3.3 mm, 3.2 mm, 3.1 mm, 3.0 mm, 2.9 mm, 2.8 mm, 2.7 mm, 2.6 mm, 2.5 mm, 2.4 mm, 2.3 mm, 2.2

mm, 2.1 mm, 2.0 mm, 1.9 mm, 1.8 mm, 1.7 mm, 1.6 mm, 1.5 mm, 1.4 mm, 1.3 mm, 1.2 mm, 1.1 mm, 1.0 mm, 0.9 mm, 0.8 mm, 0.7 mm, 0.6 mm, or 0.5 mm.

[0060] In some examples, the hot rolling step may include a plurality of hot rolling passes to achieve a thickness reduction to the hot band gauge. In some embodiments, the hot rolling step may include 21 or fewer passes to produce the hot rolled product at hot band gauge (e.g., less than 20 passes, less than 15 passes, less than 10 passes, or less than 5 passes). For example, the hot rolling step may use 21 passes, 20 passes, 19 passes, 18 passes, 17 passes, 16 passes, 15 passes, 14 passes, 13 passes, 12 passes, 11 passes, 10 passes, 9 passes, 8 passes, 7 passes, 6 passes, 5 passes, 4 passes, 3 passes, 2 passes, or 1 pass to produce the hot rolled product having a hot band gauge from 0.5 mm to 3.5 mm.

[0061] *Solution Heat Treatment*

[0062] In some examples, a solution heat treatment step can be performed on the hot rolled product, the cold rolled product, or both. In some embodiments, the hot rolled product may enter solution heat treatment step with an input gauge thickness ranging from 0.5 mm to 3.5 mm (e.g., from 0.8 mm to 2.5 mm). The solution heat treating step can include heating the hot rolled product or the cold rolled product from room temperature (e.g., ambient temperature) to a peak metal temperature. For example, the hot rolled product can be cooled to ambient temperature prior to the solution heat treating step. In some cases, the peak metal temperature may be referred to as a solution heat treatment temperature. Optionally, the peak metal temperature can be from about 450 °C to about 580 °C (e.g., from about 460 °C to about 570 °C, from about 470 °C to 560 °C, from about 520 °C to about 530 °C, from about 515 °C to about 520 °C, or from about 515 °C to about 545 °C). For example, the peak metal temperature can be 450 °C, 460 °C, 470 °C, 480 °C, 490 °C, 500 °C, 510 °C, 520 °C, 530 °C, 540 °C, 550 °C, 560 °C, 570 °C, 580 °C, or anywhere in between. The hot rolled product or cold rolled product can soak at the peak metal temperature for a period of time. In certain aspects, the hot rolled product or cold rolled product is allowed to soak for up to 50 seconds (e.g., from about 1 seconds to about 50 seconds, inclusively) at the solution heat treatment temperature. For example, the hot rolled product or cold rolled product can be soaked at the temperature of from about 450 °C to about 580 °C for 1 second, 2 seconds, 3 seconds, 4 seconds, 5 seconds, 6 seconds, 7 seconds, 8 seconds, 9 seconds, 10 seconds, 11 seconds, 12 seconds, 13 seconds, 14 seconds, 15 seconds, 16 seconds, 17 seconds, 18 seconds, 19 seconds, 20 seconds, 21 seconds, 22 seconds, 23 seconds, 24 seconds, 25 seconds, 26 seconds, 27 seconds, 28 seconds, 29 seconds, 30 seconds, 31 seconds, 32 seconds, 33 seconds, 34 seconds, 35 seconds, 36 seconds,

37 seconds, 38 seconds, 39 seconds, 40 seconds, 41 seconds, 42 seconds, 43 seconds, 44 seconds, 45 seconds, 46 seconds, 47 seconds, 48 seconds, 49 seconds, 50 seconds, or anywhere in between. The solution heat treating step can involve heating the hot rolled product at the solution heat treatment temperature for up to 50 seconds prior to the cold rolling step. A line speed of the solution heat treatment step can be at least 20 meters/min (e.g., at least 10 meters/min, from 20 meters/min to 30 meters/min, from 20 meters/min to 40 meters/min, etc.).

[0063] In some embodiments, the hot rolled product is not subjected to solution heat treatment after hot rolling. For example, the hot rolled product can be cool coiled (as detailed below) and then cold rolled to a final gauge thickness. In some embodiments, the hot rolled product is supplied directly to the cold rolling step.

[0064] In some embodiments, the hot rolled product is coiled after hot rolling. During coiling, the hot rolled product can be heat treated with the residual heat from the hot rolling step. In some embodiments, the hot rolled product is coiled at or near the hot rolling exit temperature. For example, the temperature of the hot rolled product can be maintained at the hot rolling exit temperature during coiling. In other embodiments, coiling the hot rolled product can begin at the hot rolling exit temperature as the hot rolled product cools to a cold rolling temperature.

[0065] In some examples, a cold rolled product undergoes solution heat treatment. For example, the cold rolled product can be subjected to solution heat treatment in between at least two cold rolling passes (e.g., two cold rolling passes, three cold rolling passes, four cold rolling passes, five cold rolling passes, etc.). As a non-limiting example, the cold rolled product can undergo solution heat treatment in between cold rolling passes, or after the cold rolling step.

[0066] *Cold Rolling*

[0067] Following the solution heat treatment step, a cold rolling step can be performed to produce a final gauge aluminum alloy product. In certain cases, the hot rolled product is cooled to room temperature (e.g., about ambient temperature) prior to performing the cold rolling step. An entry temperature of the hot rolled product to the cold rolling step can range from 20 °C to 80 °C. In some examples, the cold rolling step is performed in a cold rolling mill with a single stand. In alternative examples, the cold rolling step is performed in a tandem cold rolling mill with at least two stands arranged in series (e.g., at least three stands, at least four stands, at least five stands, or at least six stands arranged in series). In certain cases, the cold rolling step is a two-stage cold rolling step combining the single-stand cold rolling mill with the tandem cold rolling mill. For example, the two-stage cold rolling step can comprise a first cold rolling step using the tandem cold rolling mill and a second cold rolling step using the single-stand cold

rolling mill. Alternatively, the two-stage cold rolling step can comprise a first cold rolling step using the single-stand cold rolling mill and a second cold rolling step using the tandem cold rolling mill.

[0068] In certain aspects, the hot rolled products can be cold rolled to a final gauge thickness in a cold rolling step, i.e., into a final gauge aluminum alloy product. For example, the solution heat treated hot rolled product is cold rolled to a final gauge aluminum alloy product. In some examples, the cold rolling step may include a plurality of cold rolling passes to achieve a thickness reduction to the final gauge thickness. In some embodiments, the cold rolling step may include 6 or fewer passes to produce the final gauge cold rolled product (e.g., less than 6 passes, less than 5 passes, less than 4 passes, less than 3 passes, or a single pass). In certain aspects, the passes of the cold rolling step may be referred to as reductions (e.g., a thickness reduction). For example, the cold rolling step may use three passes to produce the final gauge cold rolled product by using the cold rolling step to reduce the thickness of the hot rolled product from 3.0 mm to a final gauge thickness less than 0.30 mm. The cold rolled product can be rolled to the final gauge thickness of from 0.180 mm to 0.250 mm (e.g., 0.190 to 0.250 mm). Compared to conventional AA5182 aluminum alloys, the cold rolling step to produce the final gauge cold rolled product of the 6xxx series aluminum alloy can use fewer passes due to the 6xxx series aluminum alloy having a softer condition compared to conventional AA5182 aluminum alloys. This reduction in passes of the cold rolling step can reduce time spent and conserve resources for improved carbon efficiency, thereby reducing manufacturing costs and environmental impact associated with producing the final gauge aluminum alloy product.

[0069] In some examples, a cold rolling step results in a cold work thickness reduction of the hot rolled product of at least 80% (e.g., at least 90%, at least 95%, or from about 85% to about 95%) to a final gauge. For example, the cold rolling step results in a thickness reduction of the hot rolled product of about 85%, about 86%, about 87%, about 88%, about 89%, about 90%, about 91%, about 92%, about 93%, about 94%, or about 95%. A cold rolled product resulting from the cold rolling step may exit with a cold roll exit temperature of about 150 °C or greater (e.g., from about 170 °C to about 190 °C, from about 165 °C to about 185 °C, from about 150 °C to about 220 °C, from about 160 °C to about 220 °C, or from about 170 °C to about 220 °C). For example, the cold roll exit temperature can be about 150 °C, about 155 °C, about 160 °C, about 165 °C, about 170 °C, about 175 °C, about 180 °C, about 185 °C, about 190 °C, about 195 °C, about 200 °C, about 205 °C, about 210 °C, about 215 °C, or about 220 °C. The cold rolled product can undergo precipitation hardening using residual heat corresponding to the cold roll exit temperature.

[0070] In certain aspects, the hot rolled product (e.g., the solution heat treated hot rolled product) is cold rolled to a final gauge aluminum alloy product (e.g., a sheet or a shate) in the cold rolling step. In some examples, the final gauge aluminum alloy product has a thickness ranging from about 0.180 mm to 0.250 mm (e.g., from about 0.180 mm to about 0.210 mm or from about 0.220 mm to about 0.250 mm). For example, the final gauge aluminum alloy product may have a thickness of 0.208 mm for can end stock applications. As another example, the final gauge aluminum alloy product may have a thickness of 0.240 mm for can tab stock applications.

[0071] *Coil Cooling*

[0072] Optionally, the cold rolled product can be coiled upon exit from the cold rolling mill. In some examples, the cold rolled product is coiled into a cold rolled coil upon exit from the cold rolling mill. The cold rolled coil can be referred to as a coiled aluminum alloy product. In some further examples, the cold rolled coil is cooled, e.g., air cooled. The cooling step can be performed at a rate of about 5 °C/hour (°C/h) to about 500 °C/h. For example, the coil cooling step can be performed at a rate of about 5 °C/h, 10 °C/h, 15 °C/h, 20 °C/h, 25 °C/h, 50 °C/h, 100 °C/h, 200 °C/h, 300 °C/h, 400 °C/h, 500 °C/h, or anywhere in between. In some further examples, the cooled coil is stored for a period of time. In some examples, the cold rolled coil is aged by maintaining the cold rolled coil at a temperature of about 150 °C to about 250 °C (e.g., about 150 °C to about 200 °C or about 150 °C to about 250 °C). The cold rolled coil can be aged for 1 hour to 10 hours, such as for 1 hour, 2 hours, 3 hours, 4 hours, 5 hours, 6 hours, 7 hours, 8 hours, 9 hours, 10 hours, or anywhere in between. In alternative examples, the cooled coil is stored at room temperature for a period of time. The cold rolled coil can undergo precipitation hardening as the cold rolled coil cools from the cold roll exit temperature. Instead of providing an additional step of heating the cold rolled coil in an oven or furnace, the cold rolled coil can rely upon the residual heat from the cold rolling step for precipitation hardening. In some examples, the precipitation hardening can correspond to optional artificial aging of the cold rolled coil.

[0073] *Optional Inter-Annealing*

[0074] In some non-limiting examples, an optional inter-annealing step can be performed during the two-stage cold rolling step. For example, the hot rolled product can be cold rolled to a first cold rolled product (first cold rolling step), optionally coiled, annealed, and subsequently cold rolled to a final gauge aluminum alloy product (second cold rolling step). In

some aspects, the optional inter-annealing can be performed in a batch process (i.e., a batch inter-annealing step) or in a continuous process. The inter-annealing step can be performed at a temperature of from about 300 °C to about 450 °C (e.g., about 310 °C, about 320 °C, about 330 °C, about 340 °C, about 350 °C, about 360 °C, about 370 °C, about 380 °C, about 390 °C, about 400 °C, about 410 °C, about 420 °C, about 430 °C, about 440 °C, or about 450 °C).

[0075] In some cases, the heating rate in the inter-annealing step can be about 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 can be from about 10 °C/min to about 100 °C/min (e.g., from about 10 °C/min to about 90 °C/min, from about 10 °C/min to about 70 °C/min, from about 10 °C/min to about 60 °C/min, from about 20 °C/min to about 90 °C/min, from about 30 °C/min to about 80 °C/min, from about 40 °C/min to about 70 °C/min, or from about 50 °C/min to about 60 °C/min).

[0076] In some embodiments, the first cold rolled product is allowed to soak for a period of time during the inter-annealing step. According to one non-limiting example, the first cold rolled product is allowed to soak for up to about 5 hours (e.g., from about 30 minutes to about 4 hours, from about 45 minutes to about 3 hours, or from about 1 hour to about 2 hours, inclusively). For example, the first cold rolled product can be soaked at a temperature of from about 300 °C to about 450 °C for about 20 minutes, about 30 minutes, about 45 minutes, about 1 hour, about 1.5 hours, about 2 hours, about 3 hours, about 4 hours, about 5 hours, or anywhere in between.

[0077] Optionally, the first cold rolled product can be cooled, e.g., air cooled, after the inter-annealing step. The cooling step can be performed at a rate of about 5 °C/hour (°C/h) to 20 °C/h (e.g., from 6 °C/h to 18 °C/h, from 8 °C/h to 15 °C/h, or from 10 °C/h to 14 °C/h). For example, the coil cooling step can be performed at a rate of about 5 °C/h, 6 °C/h, 7 °C/h, 8 °C/h, 9 °C/h, 10 °C/h, 11 °C/h, 12 °C/h, 13 °C/h, 14 °C/h, 15 °C/h, 16 °C/h, 17 °C/h, 18 °C/h, 19 °C/h, 20 °C/h, or anywhere in between. In some examples, the cooled coil is cooled to room temperature. In some still further examples, the cooled coil is stored for a period of time.

[0078] In some embodiments, the method does not include artificially aging the cold rolled product. For example, the cold rolled product may possess sufficient strength and formability.

[0079] *Aluminum Alloy Compositions*

[0080] 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, e.g., formability and

deep drawability. Among other properties, the aluminum alloys described herein display excellent elongation and forming properties.

[0081] In some embodiments, the method described herein can be used to produce a 6xxx series aluminum alloy for can end stock. In additional or alternative embodiments, the method described herein can be used to produce a 6xxx series aluminum alloy for can tab stock to produce tabs or can body stock to produce can bodies. Exemplary 6xxx series aluminum alloys for use in the methods described herein can include AA6101, AA6101A, AA6101B, AA6201, AA6201A, AA6401, AA6501, AA6002, AA6003, AA6103, AA6005, AA6005A, AA6005B, AA6005C, AA6105, AA6205, AA6305, AA6006, AA6106, AA6206, AA6306, AA6008, AA6009, AA6010, AA6110, AA6110A, AA6011, AA6111, AA6012, AA6012A, AA6013, AA6113, AA6014, AA6015, AA6016, AA6016A, AA6116, AA6018, AA6019, AA6020, AA6021, AA6022, AA6023, AA6024, AA6025, AA6026, AA6027, AA6028, AA6031, AA6032, AA6033, AA6040, AA6041, AA6042, AA6043, AA6151, AA6351, AA6351A, AA6451, AA6951, AA6053, AA6055, AA6056, AA6156, AA6060, AA6160, AA6260, AA6360, AA6460, AA6460B, AA6560, AA6660, AA6061, AA6061A, AA6261, AA6361, AA6162, AA6262, AA6262A, AA6063, AA6063A, AA6463, AA6463A, AA6763, AA6963, AA6064, AA6064A, AA6065, AA6066, AA6068, AA6069, AA6070, AA6081, AA6181, AA6181A, AA6082, AA6082A, AA6182, AA6091, or AA6092.

[0082] In some cases, an aluminum alloy as described herein can have the following elemental composition as provided in **Table 1**.

Table 1

Element	Weight Percentage (wt.%)
Si	0.40 – 1.40
Fe	0.20 – 0.80
Cu	0.05 – 1.00
Mn	0.05 – 0.80
Mg	0.50 – 1.10
Zn	Up to 0.20
Cr	Up to 0.30
Bi	Up to 0.60
Pb	Up to 0.60
Others	0 – 0.15 (total)

Al

[0083] In some cases, an aluminum alloy as described herein can have the following elemental composition as provided in **Table 2**.

Table 2

Element	Weight Percentage (wt.%)
Si	0.60 – 1.10
Fe	Up to 0.40
Cu	0.50 – 0.90
Mn	0.10 – 0.45
Mg	0.50 – 1.00
Zn	Up to 0.15
Cr	Up to 0.10
Bi	Up to 0.05
Pb	Up to 0.05
Others	0 – 0.15 (total)
Al	

[0084] *Silicon (Si)*

[0085] In some examples, the alloy includes silicon (Si) in an amount from 0.40 % to 1.40 % (e.g., from 0.50 % to 1.30 %, from 0.60 % to 1.20 %, or from 0.70 % to 1.10 %) based on the total weight of the alloy. For example, the alloy can include 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 %, 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 %, 1.30 %, 1.31 %, 1.32 %, 1.33 %, 1.34 %, 1.35 %, 1.36 %, 1.37 %, 1.38 %, 1.39 %, or 1.40 % Si. All percentages are expressed in wt. %.

[0086] *Iron (Fe)*

[0087] In some examples, the alloy also includes iron (Fe) in an amount from 0.20 % to 0.80 % (e.g., from 0.20 % to 0.70 %, from 0.30 % to 0.80 %, from 0.30 % to 0.60 %, or from 0.40 % to 0.50 %) based on the total weight of the alloy. For example, the alloy can include 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 %, 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 %, or 0.80 % Fe. All percentages are expressed in wt. %.

[0088] *Copper (Cu)*

[0089] In some examples, the disclosed alloy includes copper (Cu) in an amount from 0.05 % to 1.00 % (e.g., from 0.05 % to 0.85 %, from 0.15 % to 0.90 %, from 0.25 % to 0.80 %, from 0.35 % to 0.70 %, or from 0.45 % to 0.60 %) 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 %, 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 %, 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 % Cu. All percentages are expressed in wt. %.

[0090] *Manganese (Mn)*

[0091] In some examples, the alloy can include manganese (Mn) in an amount from 0.05 % to 0.80 % (e.g., from 0.15 % to 0.70 %, from 0.25 % to 0.60 %, from 0.35 % to 0.50 %, from 0.50 % to 0.75 %, from 0.20 % to 0.80 %, from 0.30 % to 0.70 %, or from 0.30 % to 0.50 %) 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 %, 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 %, 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 % Mn. All percentages are expressed in wt. %.

0.74 %, 0.75 %, 0.76 %, 0.77 %, 0.78 %, 0.79 %, or 0.80 % Mn. All percentages are expressed in wt. %.

[0092] *Magnesium (Mg)*

[0093] In some examples, the alloy can include magnesium (Mg) in an amount from 0.50 % to 1.10% (e.g., from 0.60 % to 1.00 %, from 0.70 % to 0.90 %, or from 0.50 % to 1.00 %) based on the total weight of the alloy. For example, the alloy can include 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 %, 1.00 %, 1.01 %, 1.02 %, 1.03 %, 1.04 %, 1.05 %, 1.06 %, 1.07 %, 1.08 %, 1.09 %, or 1.10 %, Mg. All percentages are expressed in wt. %. The Mg content for use in the alloys described herein is carefully controlled based on the desired properties of the resulting alloy. For example, Mg can adversely affect the reusability or recovery of the aluminum alloys described herein.

[0094] *Zinc (Zn)*

[0095] In some examples, the alloy includes zinc (Zn) in an amount up to 0.20 % (e.g., up to 0.05 %, up to 0.10 %, up to 0.15 %, %, from 0.001 % to 0.20 %, or from 0.005 % to 0.20 %) 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 %, 0.08 %, 0.09 %, 0.10 %, 0.11 %, 0.12 %, 0.13 %, 0.14 %, 0.15 %, 0.16 %, 0.17 %, 0.18 %, 0.19 %, or 0.20 % Zn. In some cases, Zn is not present in the alloy (i.e., 0 %). All percentages are expressed in wt. %.

[0096] *Chromium (Cr)*

[0097] In some examples, the alloy includes chromium (Cr) in an amount up to 0.30 % (e.g., up to 0.20 %, up to 0.25 %, up to 0.05 %, 0.001 % to 0.25 %, 0.005% to 0.10 %, or 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 %, 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 % Cr. In some cases, Cr is not present in the alloy (i.e., 0 %). All percentages are expressed in wt. %.

[0098] *Bismuth (Bi)*

[0099] In some examples, the alloy includes bismuth (Bi) in an amount up to 0.60 % (e.g., up to 0.05 %, up to 0.10 %, up to 0.20 %, up to 0.30 %, up to 0.40 %, up to 0.50 %, 0.001 % to 0.50 %, 0.005 % to 0.35 %, or 0.01 % to 0.40 %) 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 %, 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 %, 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 %, or 0.60 % Bi. In some cases, Bi is not present in the alloy (i.e., 0 %). All percentages are expressed in wt. %.

[0100] *Lead (Pb)*

[0101] In some examples, the alloy includes lead (Pb) in an amount up to 0.60 % (e.g., up to 0.05 %, up to 0.10 %, up to 0.20 %, up to 0.30 %, up to 0.40 %, up to 0.50 %, 0.001 % to 0.50 %, 0.005 % to 0.35 %, or 0.01 % to 0.40 %) 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 %, 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 %, 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 %, or 0.60 % Pb. In some cases, Pb is not present in the alloy (i.e., 0 %). All percentages are expressed in wt. %.

[0102] Optionally, the alloy compositions can further include other minor elements, sometimes referred to as impurities, in amounts of 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 each. These impurities may include, but are not limited to, Na, Ga, V, Ni, Sc, Ag, B, Zr, Li, Ti, Sn, Ca, Hf, Sr, or combinations thereof. Accordingly, Na, Ga, V, Ni, Sc, Ag, B, Zr, Li, Ti, Sn, Ca, Hf, or Sr may be present in an alloy in amounts of 0.05 % or below, 0.04 % or below, 0.03 % or below, 0.02 % or below, or 0.01 % or below. In certain aspects, the sum of all impurities does not exceed 0.15 % (e.g., 0.1 %). All percentages are expressed in wt. %. In certain aspects, the remaining percentage of the alloy is aluminum.

[0103] *Recycled Content*

[0104] The 6xxx series aluminum alloys described herein can tolerate relatively high amounts of recycled aluminum alloy materials and still exhibit desirable mechanical properties. As discussed above, AA5182 aluminum alloy includes high amounts of Mg which decreases reusability and recyclability of the aluminum alloy products. AA5182 aluminum alloy requires a high Mg content to achieve the necessary strength requirements for thin-gauge can end stock to produce can ends. This limits the use of recycled aluminum alloy materials to produce AA5182 aluminum alloy. Advantageously, the 6xxx series aluminum alloys described herein can be produced from higher amounts of recycled aluminum materials than AA5182 aluminum alloy due to the lower Mg content and can achieve similar properties as AA5182 aluminum alloy. Additionally, the 6xxx series aluminum alloy described herein can lower the carbon footprint and energy consumption associated with producing the aluminum alloy due to less rolling passes, while reducing manufacturing and/or processing costs.

[0105] The impact of the impurities and/or alloying elements on the mechanical properties of the 6xxx series aluminum alloy is reduced by providing a tailored aluminum alloy composition to compensate for the impurities and specific methods of producing the aluminum alloy. The aluminum alloys described herein can contain at least 20 wt. % recycled content (e.g., recycled aluminum materials). For example, the aluminum alloys can contain at least about 20 wt. %, at least about 25 wt. %, at least about 30 wt. %, at least about 35 wt. %, at least about 40 wt. %, at least about 45 wt. %, at least about 50 wt. %, at least about 55 wt. %, at least about 60 wt. %, at least about 65 wt. %, at least about 70 wt. %, at least about 75 wt. %, at least about 80 wt. %, at least about 85 wt. %, at least about 90 wt. %, or at least about 95 wt. % recycled content. This enables a higher amount of less expensive, higher impurity recycled aluminum materials (e.g., used beverage can) for producing aluminum alloys that can still exhibit desirable properties. The aluminum alloy compositions described herein can include higher amounts of recycled aluminum alloy with little or no additional primary aluminum and a reduced amount of more expensive alloying elements (e.g., Mg).

[0106] In some embodiments, the aluminum alloy composition described herein provides a composition that is well-suited for utilizing used beverage can (UBC) scrap or other aluminum alloy containers as recycled material. UBC scrap is a mixture of various aluminum alloys (e.g., from different aluminum alloys used for can bodies and can ends) and can often include foreign substances, such as rainwater, drink remainders, organic matter (e.g., paints and laminated films), and other materials. UBC scrap generally includes a mixture of metal from various aluminum alloys, such as metal from can bodies (e.g., AA3104, AA3004, or other 3xxx series

aluminum alloys) and can ends (e.g., AA5182 or other 5xxx series aluminum alloys). UBC scrap can be shredded and de-coated or de-lacquered prior to being melted for use as liquid metal stock in casting a new metal product. In some embodiments, higher amounts of used beverage cans may be used to produce the 6xxx series aluminum alloy described herein compared to AA5182 aluminum alloy, thereby reducing the amount of primary aluminum needed and reducing the total cost and maintaining equivalent or better rolling productivity.

[0107] Additionally, a beverage can may include a can body comprising a 3xxx series aluminum alloy and a can end comprising the 6xxx series aluminum alloy described herein. The aforementioned beverage can that utilizes the 6xxx series aluminum alloy as the can end has a lower overall Mg content than conventional cans including 5xxx series aluminum alloys as the can end. The 6xxx series aluminum alloy provides a beverage can (mix of 3xxx series and 6xxx series aluminum alloy) that has a melt chemistry that is easier for processing when recycling beverage cans due to the lower Mg content.

[0108] In some embodiments, at least one of the can body, the can tab, or the can end is produced from the 6xxx series aluminum alloy described herein. For example, the beverage can may include a can body, can tab, and can end comprising the 6xxx series aluminum alloy described herein. Accordingly, the 6xxx series aluminum alloy provides a uniform beverage can be constructed using the same series of aluminum alloys, enabling an easier recycling process due to improved melt chemistry and uniformity of the beverage can material. In some implementations, the uniform beverage can improve the recyclability of UBC scrap due to increased commonality in the aluminum alloy composition, thereby reducing additions of primary aluminum. Therefore, the 6xxx series aluminum alloy described herein improves the overall life cycle of the beverage can compared to conventional cans and has improved recycling characteristics.

[0109] *Alloy Properties*

[0110] In some examples, the aluminum alloy products described herein have a yield strength of about 150 MPa to about 425 MPa (e.g., about 200 MPa to about 300 MPa, about 180 MPa to about 320 MPa, about 150 MPa to about 250 MPa, about 250 MPa to about 350 MPa, about 200 MPa to about 400 MPa, or about 300 MPa to about 425 MPa). For example, the aluminum alloy products can have a yield strength of about 150 MPa, about 155 MPa, about 160 MPa, about 165 MPa, about 170 MPa, about 175 MPa, about 180 MPa, about 185 MPa, about 190 MPa, about 195 MPa, about 200 MPa, about 205 MPa, about 210 MPa, about 215 MPa, about 220 MPa, about 225 MPa, about 230 MPa, about 235 MPa, about 240 MPa, about 245 MPa,

about 250 MPa, about 255 MPa, about 260 MPa, about 265 MPa, about 270 MPa, about 275 MPa, about 280 MPa, about 285 MPa, about 295 MPa, about 300 MPa, about 305 MPa, about 310 MPa, about 315 MPa, about 320 MPa, about 325 MPa, about 330 MPa, about 335 MPa, about 340 MPa, about 345 MPa, about 350 MPa, about 355 MPa, about 360 MPa, about 365 MPa, about 370 MPa, about 375 MPa, about 380 MPa, about 385 MPa, about 390 MPa, about 395 MPa, about 400 MPa, about 405 MPa, about 410 MPa, about 415 MPa, about 420 MPa, or about 425 MPa. The aluminum alloy products described herein can exhibit the yield strengths as described herein when measured in a longitudinal (L) direction, a transverse (T) direction, and/or in a diagonal (D) direction, each respective to the rolling direction.

[0111] In some examples, the aluminum alloy products described herein have an ultimate tensile strength of about 300 MPa to about 450 MPa (e.g., about 325 MPa to about 450 MPa, about 350 MPa to about 450 MPa, about 375 MPa to about 450 MPa, or about 400 MPa to about 450 MPa). For example, the aluminum alloy products can have an ultimate tensile strength of about 300 MPa, about 310 MPa, about 320 MPa, about 330 MPa, about 340 MPa, about 350 MPa, about 360 MPa, about 370 MPa, about 380 MPa, about 390 MPa, about 400 MPa, about 410 MPa, about 420 MPa, about 430 MPa, about 440 MPa, or about 450 MPa. The aluminum alloy products described herein can exhibit the ultimate tensile strength as described herein when measured in a longitudinal (L) direction, a transverse (T) direction, and/or in a diagonal (D) direction, each respective to the rolling direction.

[0112] In some cases, the aluminum alloy products described herein can have an elongation of about 1% to about 20% (e.g., from about 1% to about 10%, from about 5% to about 15%, from about 5% to about 15%, or from about 10% to about 20%). For example, the aluminum alloy products can have an elongation of about 3%, about 4%, 5%, about 6%, about 7%, about 8%, about 9%, about 10 %, about 11 %, about 12 %, about 13 %, about 14 %, about 15 %, about 16 %, about 17 %, about 18 %, about 19 %, about 20 %, or anywhere in between. The aluminum alloy products described herein can exhibit the elongations as described herein when measured in a longitudinal (L) direction, a transverse (T) direction, and/or in a diagonal (D) direction, each respective to the rolling direction.

[0113] In some examples, the aluminum alloy products described herein exhibit good surface finish qualities (e.g., brightness and/or gloss). For example, the aluminum alloy products described herein have a higher gloss value (e.g., spectral reflection) after rolling than conventional AA5182 aluminum alloys, indicating that the aluminum alloy products exhibit a higher degree of shine or brightness when reflecting light from a light source. The gloss value of the aluminum alloy products can indicate a product quality or contribute to a product

impression of the aluminum alloy products to a customer. Accordingly, in some cases, a customer may prefer the aluminum alloy products described herein over AA5182 aluminum alloys at least in part due to the higher gloss value of the aluminum alloy products.

[0114] *Methods of Using*

[0115] The aluminum alloy products (e.g., final gauge aluminum alloy product) described herein can be used in beverage can applications and other container applications. For example, the disclosed aluminum alloy products can be used to produce portions of beverage or food containers. In some examples, the disclosed aluminum alloy products may be used to produce can ends, can bodies, tabs, or lids used for beverage or food containers. In some examples, the aluminum alloy products can be used to produce can ends. In some examples, the aluminum alloy products can be used to produce can tabs. In some examples, the aluminum alloy products can be used to produce can bodies.

[0116] The examples disclosed herein will serve to further illustrate aspects of the invention without, at the same time, however, constituting any limitation thereof. On the contrary, it is to be clearly understood that resort may be had to various embodiments, modifications and equivalents thereof which, after reading the description herein, may suggest themselves to those skilled in the art without departing from the spirit of the invention. The examples and embodiments described herein may also make use of conventional procedures unless otherwise stated. Some of the procedures are described herein for illustrative purposes.

[0117] *Illustrations*

[0118] Illustration 1: A method of producing an aluminum alloy product, comprising: casting an aluminum alloy to produce a cast aluminum alloy product, wherein the aluminum alloy comprises a 6xxx series aluminum alloy; homogenizing the cast aluminum alloy product to produce a homogenized cast aluminum alloy product; hot rolling the homogenized cast aluminum alloy product to produce a hot rolled product; optionally, i) solution heat treating the hot rolled product at a solution heat treatment temperature of about 450 °C to 600 °C; or ii) coiling the hot rolled product at a hot rolling exit temperature; cold rolling the hot rolled product to produce a cold rolled product, wherein the cold rolled product is rolled to a final gauge thickness from 0.180 mm to 0.250 mm, wherein an exit temperature of the cold rolled product is 150 °C or greater; and optionally, solution heat treating the cold rolled product at a solution heat treatment temperature of about 450 °C to 580 °C

[0119] Illustration 2: The method of any previous or subsequent illustration, further comprising: coiling the cold rolled product to produce a coiled aluminum alloy product, wherein the cold rolled product is configured to undergo precipitation hardening during coil cooling.

[0120] Illustration 3: The method of any previous or subsequent illustration, further comprising coating the coiled aluminum alloy product.

[0121] Illustration 4: The method of any previous or subsequent illustration, wherein the cast step comprises direct chill casting.

[0122] Illustration 5: The method of any previous or subsequent illustration, wherein the aluminum alloy product comprises 0.20 – 1.40 wt. % Si, 0.20 – 0.80 wt. % Fe, 0.05 – 1.00 wt. % Cu, 0.05 – 0.80 wt. % Mn, 0.50 – 1.60 wt. % Mg, up to 0.25 wt. % Zn, up to 0.30 wt. % Cr, up to 0.60 wt. % Bi, up to 0.60 wt. % Pb, up to 0.15 wt. % impurities, and the remainder Al.

[0123] Illustration 6: The method of any previous or subsequent illustration, wherein the homogenizing step is performed at a homogenization temperature from about 540 °C to 600 °C.

[0124] Illustration 7: The method of any previous or subsequent illustration, wherein the hot rolled product is cooled to about ambient temperature prior to the solution heat treating step.

[0125] Illustration 8: The method of any previous or subsequent illustration, wherein the solution heat treating step comprises heating the hot rolled product at the solution heat treatment temperature for up to 50 seconds prior to the cold rolling step.

[0126] Illustration 9: The method of any previous or subsequent illustration, wherein a line speed of the solution heat treating step is at least 20 meters/min.

[0127] Illustration 10: The method of any previous or subsequent illustration, wherein an entry temperature of the hot rolled product to the cold rolling step is from 20 °C to 80 °C.

[0128] Illustration 11: The method of any previous or subsequent illustration, wherein the cold rolling step comprises 6 or fewer cold rolling passes to produce the cold rolled product.

[0129] Illustration 12: The method of any previous or subsequent illustration, wherein the method does not include artificial aging after the cold rolling step.

[0130] Illustration 13: The method of any previous or subsequent illustration, wherein the cold rolling step is performed in a cold rolling mill comprising at least two stands arranged in series.

[0131] Illustration 14: The method of any previous or subsequent illustration, wherein the cold rolling step comprises a single pass to produce the cold rolled product.

[0132] Illustration 15: The method of any of any previous or subsequent illustration, wherein the exit temperature of the cold rolled product is from about 150 °C to 220 °C.

[0133] Illustration 16: The method of any of any previous or subsequent illustration, wherein the cold rolling step produces at least 80% cold work thickness reduction from the hot rolled product to the cold rolled product.

[0134] Illustration 17: The method of any previous or subsequent illustration, wherein the cold rolling step produces a cold work thickness reduction from about 85% to 95%.

[0135] Illustration 18: The method of any previous or subsequent illustration, wherein the hot rolling step is configured to produce the hot rolled product having a hot band gauge of from about 0.5 mm to 3.5 mm.

[0136] Illustration 19: The method of any previous or subsequent illustration, wherein the hot rolling step is characterized by using 21 or fewer passes to produce the hot rolled product.

[0137] Illustration 20: The method of any previous or subsequent illustration, wherein precipitation hardening is configured to occur using residual heat corresponding to the exit temperature of the cold rolled product.

[0138] Illustration 21: The method of any previous or subsequent illustration, wherein the aluminum alloy product has a yield strength of about 150 MPa to 425 MPa.

[0139] Illustration 22: The method of any previous or subsequent illustration, wherein the aluminum alloy product has an elongation from 1% to 20%.

[0140] Illustration 23: The method of any previous or subsequent illustration, further comprising solution heat treating the cold rolled product.

[0141] Illustration 24: The method of any previous or subsequent illustration, wherein the cold rolling step comprises 6 or fewer cold rolling passes to produce the cold rolled product; wherein the method further comprises solution heat treating the cold product in between at least two cold rolling passes.

[0142] Illustration 25: The method of any previous or subsequent aspect, further comprising aging the coiled aluminum alloy product at a temperature from 150 °C to 250 °C for 1 hour to 10 hours.

[0143] Illustration 26: An aluminum alloy can end stock, wherein the aluminum alloy can end stock comprises an aluminum alloy product prepared by a method of any previous or subsequent aspect.

[0144] Illustration 27: The aluminum alloy can end stock of any previous or subsequent illustration, wherein the aluminum alloy can end stock comprises at least 20 wt. % of recycled aluminum materials.

[0145] Illustration 28: The aluminum alloy can end stock of any previous or subsequent illustration, wherein the recycled aluminum materials comprise used beverage can scrap.

[0146] Illustration 29: The method of any previous or subsequent illustration, wherein coiling the hot rolled product at the hot rolling exit temperature comprises maintaining the hot rolled product at the hot rolling exit temperature during coiling or coiling the hot rolled product at the hot rolling exit temperature as the hot rolled product cools to a cold rolling temperature.

[0147] *Example 1*

[0148] Sample aluminum alloys were tested to determine the properties of the aluminum alloys described herein. Comparative Example 1 was prepared from a conventional AA5182 aluminum alloy, which is currently employed as can end stock. Alloy 1 is a 6xxx series aluminum alloy described herein. **Table 3** provides the aluminum alloy composition for Comparative Example 1 and Alloy 1. In **Table 3**, all values are provided in weight percent (wt. %) based on the total weight of the aluminum alloy composition. The alloys can contain aluminum and up to 0.15 wt.% total impurities.

Table 3

	Si (wt. %)	Fe (wt. %)	Cu (wt. %)	Mn (wt. %)	Mg (wt. %)	Impurities (wt. %)	Al
Alloy 1	0.60	0.24	0.55	0.20	0.70	Up to 0.15	Balance
Comp. 1	0.10	0.24	0.04	0.41	4.55	Up to 0.15	Balance

[0149] **FIG. 1** is a schematic depicting a method 100 for producing Alloy 1. Alloy 1 was direct chill cast to provide an ingot 110 with an initial thickness of 660 mm. The ingot 110 was subjected to a homogenization step as described above. The ingot 110 was then subjected to hot rolling using less than 20 hot rolling passes to provide a hot rolled product with a thickness of 2.1 mm. The hot rolled product was further subjected to a solution heat treatment prior to cold rolling in a cold mill to provide a final gauge aluminum alloy product. In the solution heat treatment step, the hot rolled product was continuously annealed and solutionized at a peak metal temperature of about 515 °C to 520 °C. The solution heat treated hot rolled product was cold rolled using a tandem mill with three stands to a final gauge thickness. The thickness of the hot rolled product was reduced by 90% from a thickness of 2.1 mm to 0.208 mm to produce an aluminum alloy product. After exiting the cold rolling step, the final gauge aluminum alloy product was coiled and underwent precipitation hardening in a coil cooling step.

[0150] **FIG. 2** is a bar graph showing the electrical conductivity of Alloy 1 as received and subsequent to processing steps. The first two bars of **FIG. 2** indicate the electrical conductivity of Alloy 1 as received (after hot rolling). The third and ninth bars of **FIG. 2** indicate the

electrical conductivity of Alloy 1 after a solution heat treatment step at a solution heat treatment temperature of 540 °C and 560 °C, respectively. The fourth, fifth, and sixth bars of **FIG. 2** indicate the electrical conductivity of Alloy 1 subsequent to a cold work thickness reduction of 70%, 80%, and 90%, respectively, after the solution heat treatment step at 540 °C. Similarly, the tenth, eleventh, and twelfth bars of **FIG. 2** indicate the electrical conductivity of Alloy 1 subsequent to a cold work thickness reduction of 70%, 80%, and 90%, respectively, after the solution heat treatment step at 560 °C.

[0151] The seventh and eighth bars of **FIG. 2** indicate the electrical conductivity of Alloy 1 subsequent to being subjected to coil cooling at a temperature of 160 °C and 180 °C, respectively, after the solution heat treatment step at 540 °C. **FIG. 2** shows a substantial increase in electrical conductivity of Alloy 1 subsequent to coil cooling, indicating that precipitation is occurring at these temperatures during coil cooling. Thus, the increase in electrical conductivity demonstrates that Alloy 1 undergoes precipitation hardening during coil cooling, thereby eliminating a conventional heating step for precipitation hardening of aluminum alloys using a furnace or oven. A similar increase in electrical conductivity is shown for the thirteenth and fourteenth bars of **FIG. 2** that indicate the electrical conductivity of Alloy 1 subsequent to being subjected to coil cooling from 160 °C and 180 °C, respectively, after the solution heat treatment step at 560 °C.

[0152] **FIG. 3** is a bar graph showing the yield strengths, spread, and elongation of test samples taken from Alloy 1 after various processing steps. Tensile properties were evaluated in a longitudinal direction with respect to the rolling direction during processing. Alloy 1 was processed using a solution heat treatment step at about 560 °C. The first bar of **FIG. 3** corresponds to Alloy 1 as received, prior to the solution heat treatment step. The second, third, and fourth bars of **FIG. 3** indicate the yield strength, spread, and elongation of Alloy 1 subsequent to a cold work thickness reduction of about 70%, 80%, and 90%, respectively. The fifth, sixth, and seventh bars of **FIG. 3** indicate the yield strength, spread, and elongation of Alloy 1 subsequent to the cold work thickness reduction and coil cooling from 160 °C.

[0153] Similarly, the eighth, ninth, and tenth bars of **FIG. 3** indicate the yield strength, spread, and elongation of Alloy 1 subsequent to the cold work thickness reduction and coil cooling from 180 °C. The mechanical properties of Alloy 1 most closely match those of conventional AA5182 aluminum alloys used in can end stock after a cold work thickness reduction of about 80% and coil cooling from 180 °C, which corresponds to the ninth bar of **FIG. 3**. Similar results were achieved with a solution heat treatment step at about 540 °C, as depicted in **FIG. 4**. The

eleventh and twelfth bars of **FIG. 3** indicate the yield strength, spread, and elongation of Alloy 1 having a T4 temper and a T6 temper, respectively.

[0154] Example 2

[0155] Additional sample aluminum alloys were tested to determine the properties of the aluminum alloys described herein. Comparative Example 1 (described above) was prepared from a conventional AA5182 aluminum alloy, which is currently employed as can end stock. Example Alloy 2 is a 6xxx series aluminum alloy described herein. **Table 4** provides the aluminum alloy composition for Example Alloy 2 with the up to 0.05 wt. % impurities and the balance Al. In **Table 4**, all values are provided in weight percent (wt. %) based on the total weight of the aluminum alloy composition.

Table 4

	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Ga	V	Zr
Ex. Alloy 2	0.50 — 0.63	0.20 — 0.26	0.51 — 0.59	0.18 — 0.22	0.66 — 0.74	0.04 — 0.10	Up to 0.03	Up to 0.05	Up to 0.08	Up to 0.03	Up to 0.03	Up to 0.03

[0156] Example Alloy 2 was produced according to the following method. The alloy was direct chill cast to provide an ingot. The ingot was subjected to a homogenization step as described above. The ingot was then subjected to hot rolling to provide a hot rolled product with a thickness of 2.5 mm. The hot rolled product was further subjected to a solution heat treatment prior to cold rolling in a cold mill to provide a final gauge aluminum alloy product. In the solution heat treatment step, the hot rolled product was continuously annealed and solutionized at a peak metal temperature of about 500 °C to 525 °C. The solution heat treated hot rolled product was cold rolled using a tandem mill with three stands to a final gauge thickness. During cold rolling, the thickness of the hot band was reduced by 64 % in the first pass, 64 % in the second pass, and 36 % in the third pass, for a final thickness of 0.21 mm to produce an aluminum alloy product. After exiting the cold rolling step, the aluminum alloy product was coiled and underwent precipitation hardening in a coil cooling step. The coiling cooling was conducted at a temperature of 180 °C. The aluminum alloy products were then coated, lubricated, and produced into can ends for testing.

[0157] **FIG. 5** shows a graph of the whiteness index values of Comparative Example 1 and Example Alloy 2. **FIG. 6** shows a graph of the gloss values taken at 60° of Comparative Example 1 and Example Alloy 2. The can ends of Example Alloy 2, produced from a 6xxx

series aluminum alloy, had whiteness and gloss values that were higher than Comparative Example 1. Specifically, Example Alloy 2 demonstrated a whiteness index value that was 40 % greater than Comparative Example 1. Similarly, Example Alloy 2 had a gloss value that was 100 % greater than Comparative Example 1. The data demonstrates that Example Alloy 2 has superior visual and aesthetic characteristics compared to AA5182 alloy (Comparative Example 1) when used as a can end.

[0158] FIG. 7 shows a graph of the yield strength, ultimate tensile strength, and elongation properties of Example Alloy 2 after different processing conditions. The first three sets of bars represent the final gauge aluminum alloy product after solution heat treatment and cold rolling, and before coiling, taken in the as-rolled direction (L, 0°), transverse direction (T, 90°), and diagonal direction (D, 45°), respectively. The fourth, fifth, sixth, and seventh set of bars represent the final gauge aluminum alloy product after coil cooling at 140 °C, 150 °C, 160 °C, and 180 °C, respectively, taken in the as-rolled direction (L, 0°). The eighth, ninth, and tenth set of bars represent the final gauge aluminum alloy product after coil cooling at 180 °C taken in the as-rolled direction (L, 0°), transverse direction (T, 90°), and diagonal direction (D, 45°), respectively. The eleventh, twelfth, and thirteenth set of bars represent the final gauge aluminum alloy product after coil cooling at 180 °C and coating (with a lubricant or lacquer in an oven for two cycles at 180 °C to 300 °C, respectively) taken in the as-rolled direction (L, 0°), transverse direction (T, 90°), and diagonal direction (D, 45°), respectively. As shown in FIG. 4, Example Alloy 2 demonstrated an increase in yield strength and ultimate tensile strength when subjected to coil coiling. In fact, precipitation appears to be dominant when the final gauge aluminum alloy product is subjected to coil cooling at a temperature from 140 °C to 150 °C, which resulted in the highest strength and elongation values. Additionally, an increase in strength is measured after coating the can ends in a simulated coating process.

[0159] FIG. 8 shows a graph of the propagation energy (KJ/m²) of Example Alloy 2 and Comparative Example 1 as measured by the Kahn Tear test. Can ends are typically coated with a durable and corrosion resistant finish in an oven at elevated temperatures. A conventional coated AA5182 alloy for can end stock has a propagation energy of about 42 KJ/m², represented by the blue line in the graph. Example Alloy 2 was coated in an oven for two cycles at temperatures of 180 °C and 300 °C, respectively. Example Alloy 2 exhibited a propagation energy of about 50 KJ/m² prior to coating and a propagation energy of about 58 KJ/m² after coating. The propagation energy of Example Alloy 2 was higher than the coated AA5182 alloy, demonstrating a better fracture toughness for Example Alloy 2.

[0160] FIG. 9 shows a graph of the shell buckle strength (psi) of Example Alloy 2 and Comparative Example 1 as measured by a calibrated commercially available shell/end pressurization bulker tester, Altek Model 9009. The graph provides the maximum buckle strength, the average buckle strength from 12 samples, and the minimum buckle strength. Example Alloy 2 exhibited a higher maximum buckle strength and average buckle strength than Comparative Example 1.

[0161] FIG. 10 shows a graph of the fresh buckle strength (psi) of Example Alloy 2 and Comparative Example 1 as measured by a calibrated commercially available shell/end pressurization bulker tester, Altek Model 9009. The fresh buckle strength was tested prior to aging of the samples. The graph provides the maximum buckle strength, the average buckle strength from 12 samples, and the minimum buckle strength. Example Alloy 2 exhibited a higher maximum buckle strength and average buckle strength than Comparative Example 1.

[0162] FIG. 11 shows a graph of the turbo-aged buckle strength (psi) of Example Alloy 2 and Comparative Example 1 as measured by a calibrated commercially available shell/end pressurization bulker tester, Altek Model 9009. The graph provides the maximum buckle strength, the average buckle strength from 12 samples, and the minimum buckle strength. Example Alloy 2 and Comparative Alloy (AA5182 alloy) were each turbo-aged at 90 °C for 30 minutes. Example Alloy 2 exhibited a higher maximum buckle strength and average buckle strength than the Comparative Alloy.

[0163] FIG. 12 shows a graph of the shell clamping pressure formability results at the most extreme test condition when the sheets of Example Alloy 2 and Comparative Example 1 were subjected to forming of shells at an inner pressure sleeve pressure of 220 psi and an upper piston pressure of 165 psi. Testing was performed by adjusting the inner pressure sleeve and upper piston pressures in a dedicated development shell manufacturing press. As shown in FIG. 12, the 6xxx series alloy of Example 2 exhibited better clamping formability than Comparative Example 1 for can ends.

[0164] All patents, publications, and abstracts cited above are incorporated herein by reference in their entirety. Various embodiments of the invention have been described in fulfillment of the various objectives of the invention. It should be recognized that these embodiments are merely illustrative of the principles of the present invention. Numerous modifications and adaptations thereof will be readily apparent to those skilled in the art without departing from the spirit and scope of the present invention as defined in the following claims.

WHAT IS CLAIMED IS:

1. A method of producing an aluminum alloy product, comprising:
casting an aluminum alloy to produce a cast aluminum alloy product, wherein the aluminum alloy comprises a 6xxx series aluminum alloy;
homogenizing the cast aluminum alloy product to produce a homogenized cast aluminum alloy product;
hot rolling the homogenized cast aluminum alloy product to produce a hot rolled product;
optionally, i) solution heat treating the hot rolled product at a solution heat treatment temperature of about 450 °C to 600 °C; or ii) coiling the hot rolled product at a hot rolling exit temperature;
cold rolling the hot rolled product to produce a cold rolled product, wherein the cold rolled product is rolled to a final gauge thickness from 0.180 mm to 0.250 mm, wherein an exit temperature of the cold rolled product is 150 °C or greater; and
optionally, solution heat treating the cold rolled product at a solution heat treatment temperature of about 450 °C to 580 °C.
2. The method of claim 1, further comprising:
coiling the cold rolled product to produce a coiled aluminum alloy product, wherein the cold rolled product is configured to undergo precipitation hardening during and/or after coiling.
3. The method of claim 2, further comprising coating the coiled aluminum alloy product.
4. The method of claim 1, wherein the cast step comprises direct chill casting.
5. The method of claim 1, wherein coiling the hot rolled product at the hot rolling exit temperature comprises maintaining the hot rolled product at the hot rolling exit temperature during coiling or coiling the hot rolled product initially at the hot rolling exit temperature as the hot rolled product cools to a cold rolling temperature.
6. The method of claim 1, wherein the aluminum alloy product comprises 0.20 – 1.40 wt. % Si, 0.20 – 0.80 wt. % Fe, 0.05 – 1.00 wt. % Cu, 0.05 – 0.80 wt. % Mn, 0.50 – 1.60 wt. % Mg, up to 0.25 wt. % Zn, up to 0.30 wt. % Cr, up to 0.60 wt. % Bi, up to 0.60 wt. % Pb, up to 0.15 wt. % impurities, and the remainder Al.

7. The method of claim 1, wherein the homogenizing step is performed at a homogenization temperature from about 540 °C to 600 °C.
8. The method of claim 1, wherein the hot rolled product is cooled to about ambient temperature prior to the solution heat treating step.
9. The method of claim 1, wherein the solution heat treating step comprises heating the hot rolled product at the solution heat treatment temperature for up to 50 seconds prior to the cold rolling step.
10. The method of claim 9, wherein a line speed of the solution heat treating step is at least 20 meters/min.
11. The method of claim 1, wherein an entry temperature of the hot rolled product to the cold rolling step is from 20 °C to 80 °C.
12. The method of claim 1, wherein the cold rolling step comprises 6 or fewer cold rolling passes to produce the cold rolled product.
13. The method of claim 1, wherein the method does not include artificial aging after the cold rolling step.
14. The method of claim 12, wherein the cold rolling step is performed in a cold rolling mill comprising at least two stands arranged in series.
15. The method of claim 12, wherein the cold rolling step comprises a single pass to produce the cold rolled product.
16. The method of claim 1, wherein the exit temperature of the cold rolled product is from about 150 °C to 220 °C.
17. The method of claim 1, wherein the cold rolling step produces at least 80% cold work thickness reduction from the hot rolled product to the cold rolled product.
18. The method of claim 17, wherein the cold rolling step produces a cold work thickness reduction from about 85% to 95%.
19. The method of claim 1, wherein the hot rolling step is configured to produce the hot rolled product having a hot band gauge of from about 0.5 mm to 3.5 mm.
20. The method of claim 1, wherein the hot rolling step is characterized by using 21 or fewer passes to produce the hot rolled product.

21. The method of claim 1, wherein precipitation hardening is configured to occur using residual heat corresponding to the exit temperature of the cold rolled product.
22. The method of claim 1, wherein the aluminum alloy product has a yield strength of about 150 MPa to 425 MPa.
23. The method of claim 1, wherein the aluminum alloy product has an elongation from 1% to 20%.
24. The method of claim 1, further comprising solution heat treating the cold rolled product.
25. The method of claim 1, wherein the cold rolling step comprises 6 or fewer cold rolling passes to produce the cold rolled product; wherein the method further comprises solution heat treating the cold rolled product in between at least two cold rolling passes.
26. The method of claim 2, further comprising aging the coiled aluminum alloy product at a temperature from 150 °C to 250 °C for 1 hour to 10 hours.
27. An aluminum alloy can end stock, wherein the aluminum alloy can end stock comprises an aluminum alloy product prepared by a method comprising any of claims 1-26.
28. The aluminum alloy can end stock of claim 27, wherein the aluminum alloy can end stock comprises at least 20 wt. % of recycled aluminum materials.
29. The aluminum alloy can end stock of claim 28, wherein the recycled aluminum materials comprise used beverage can scrap.

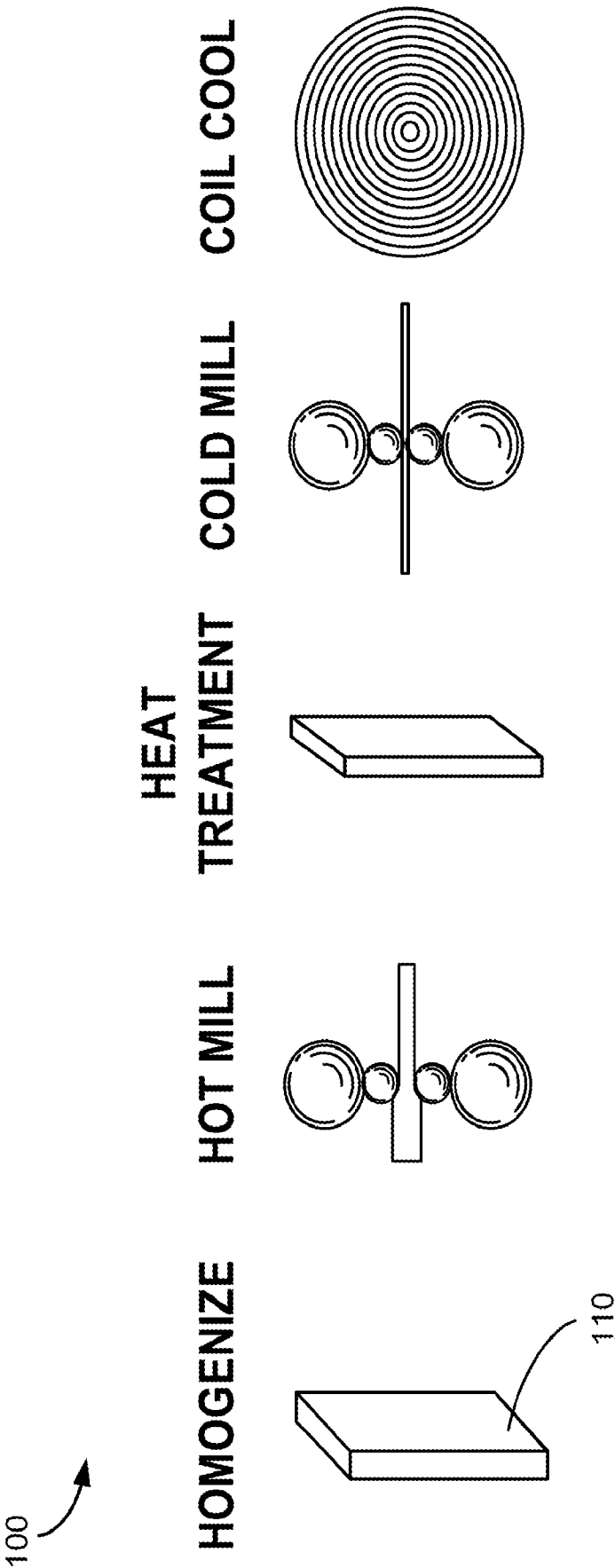


FIG. 1

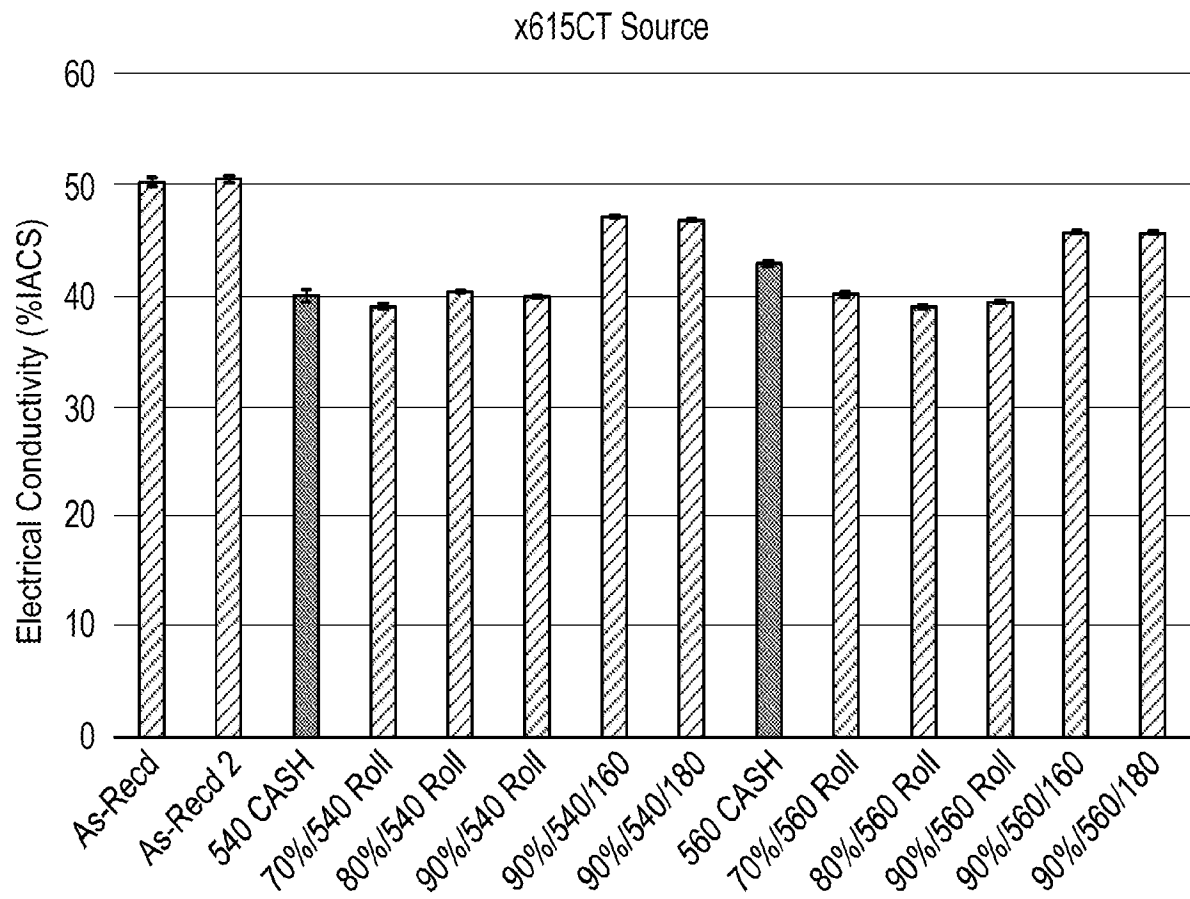


FIG. 2

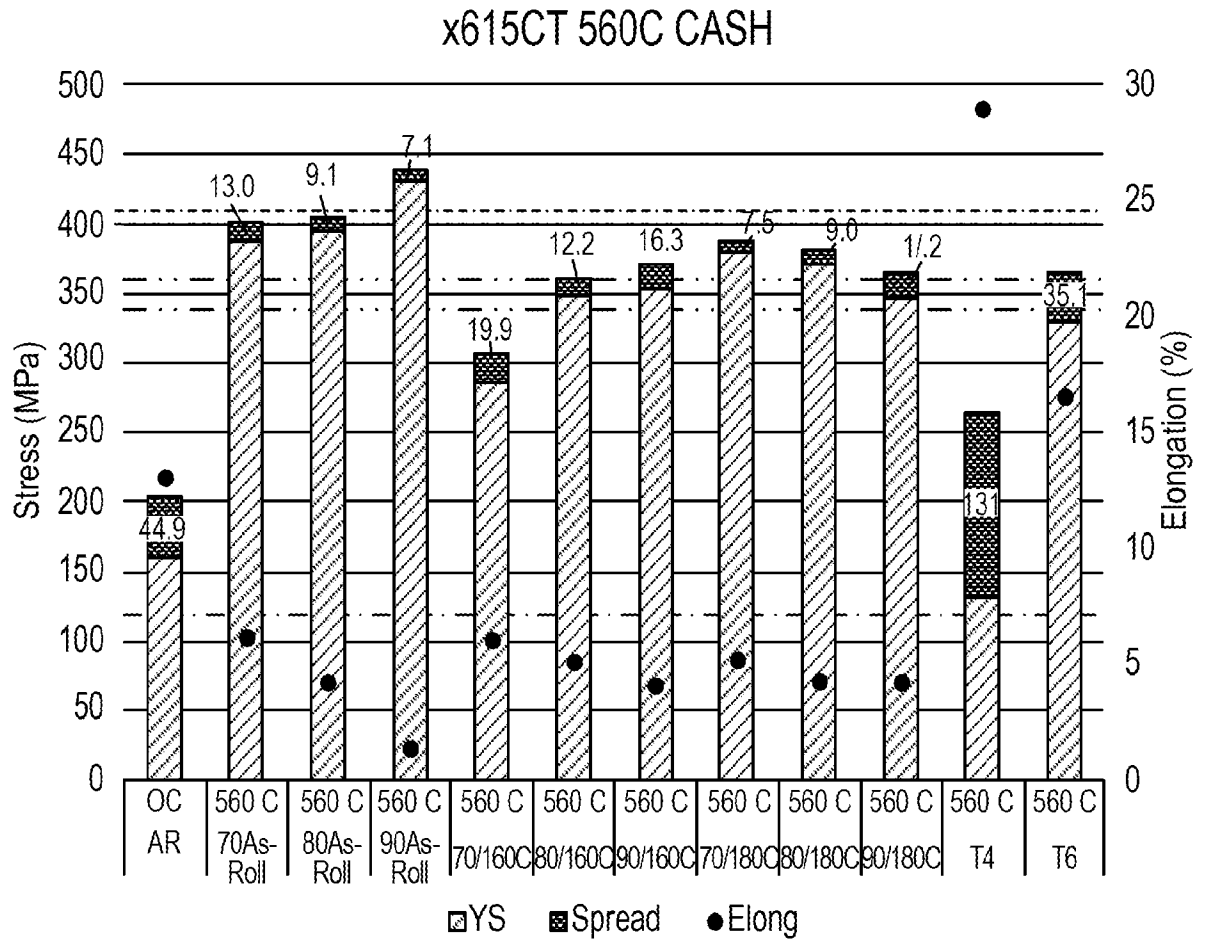


FIG. 3

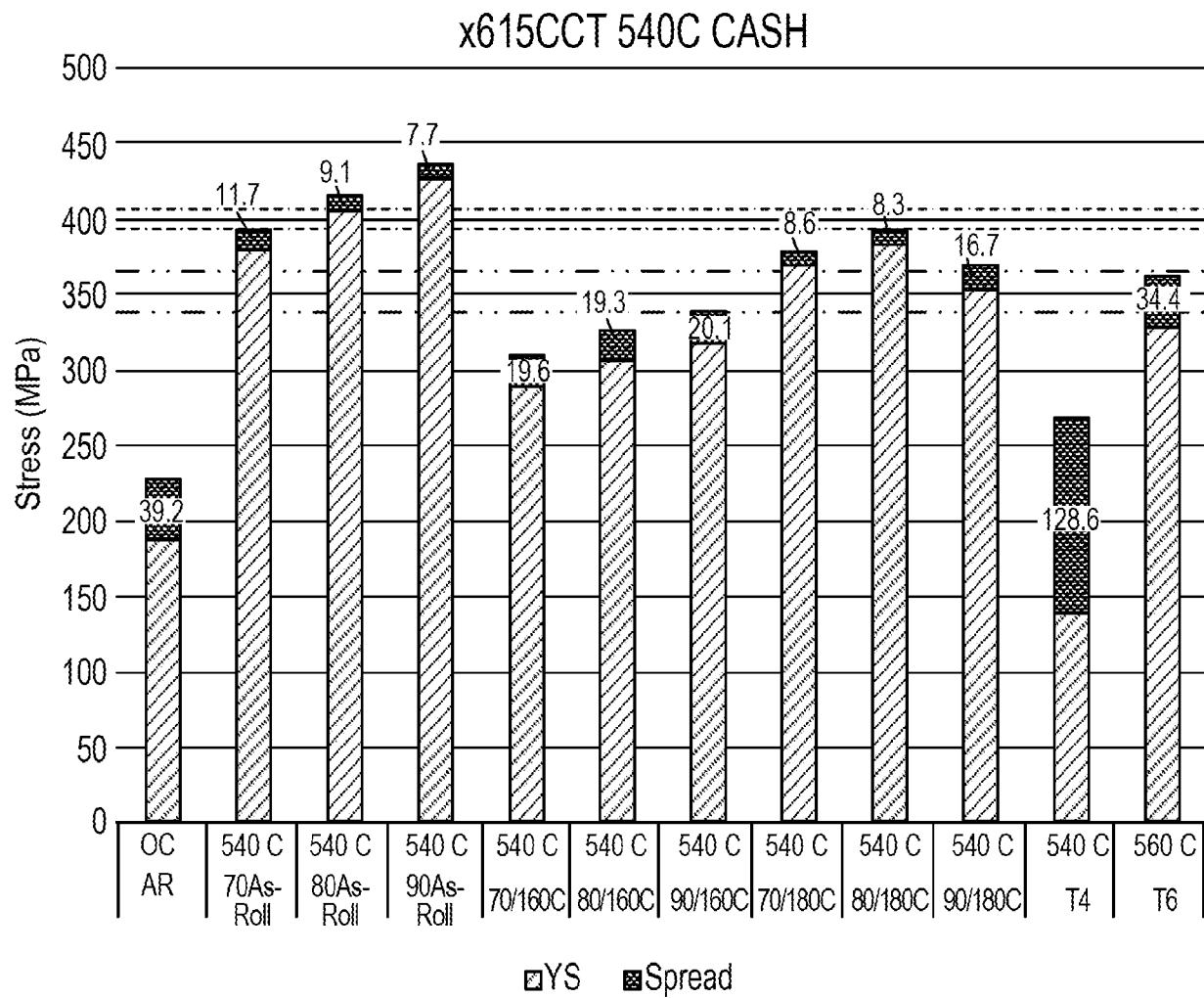


FIG. 4

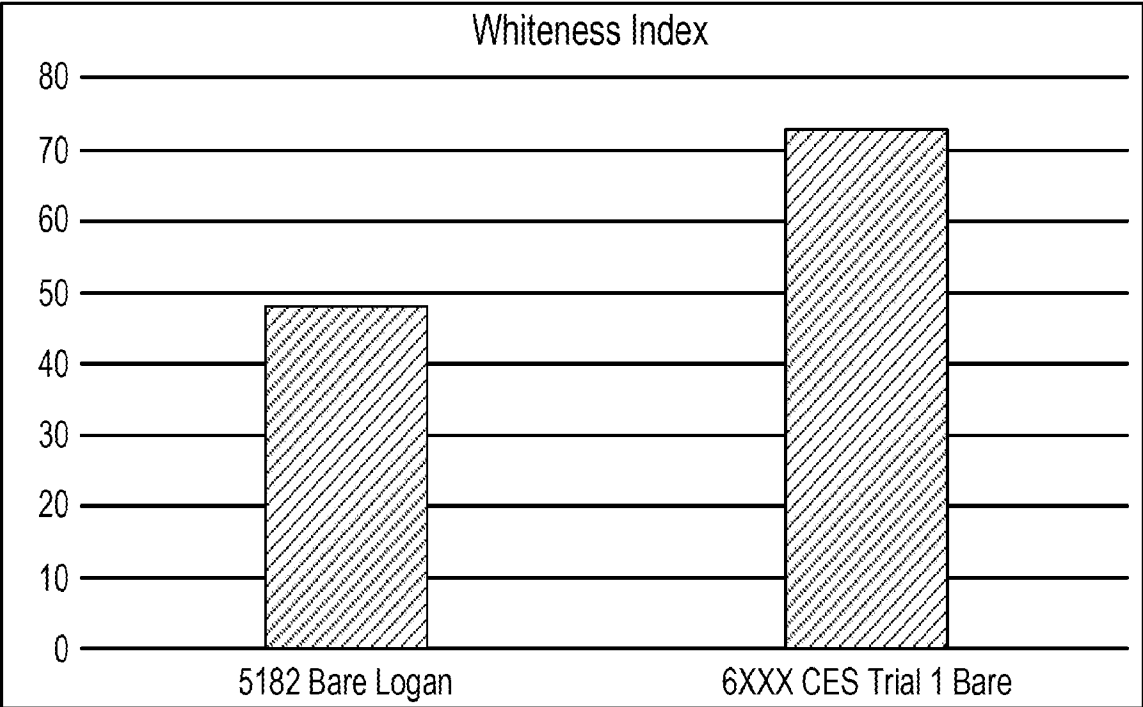


FIG. 5

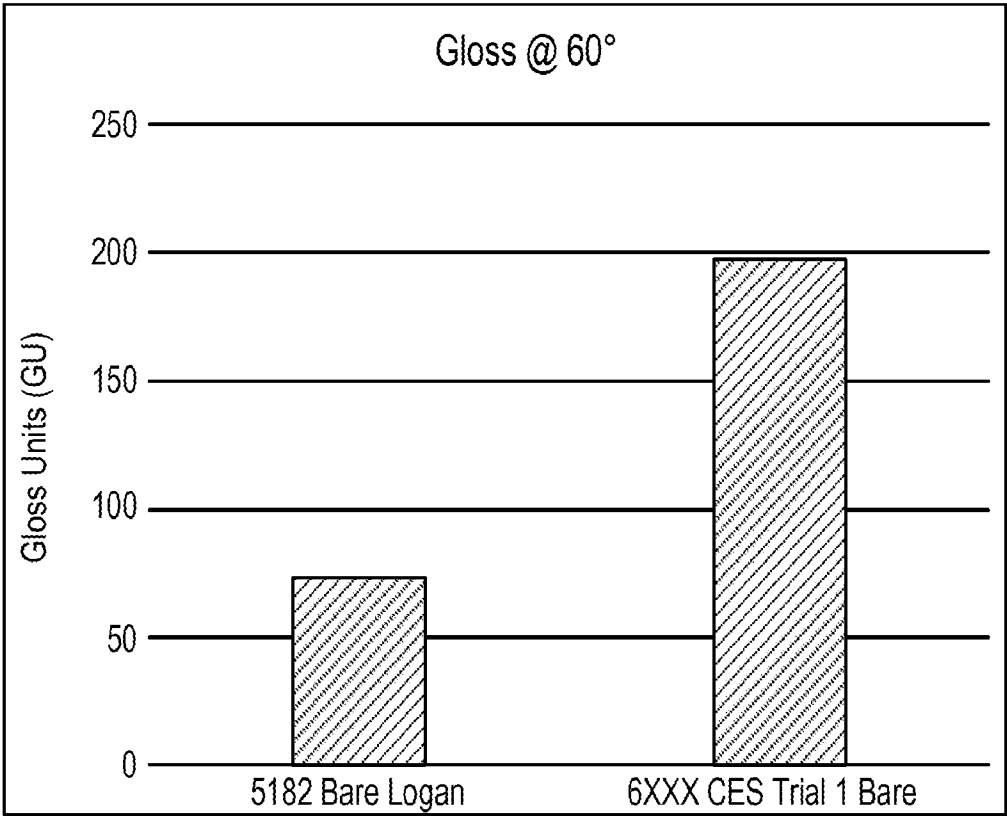


FIG. 6

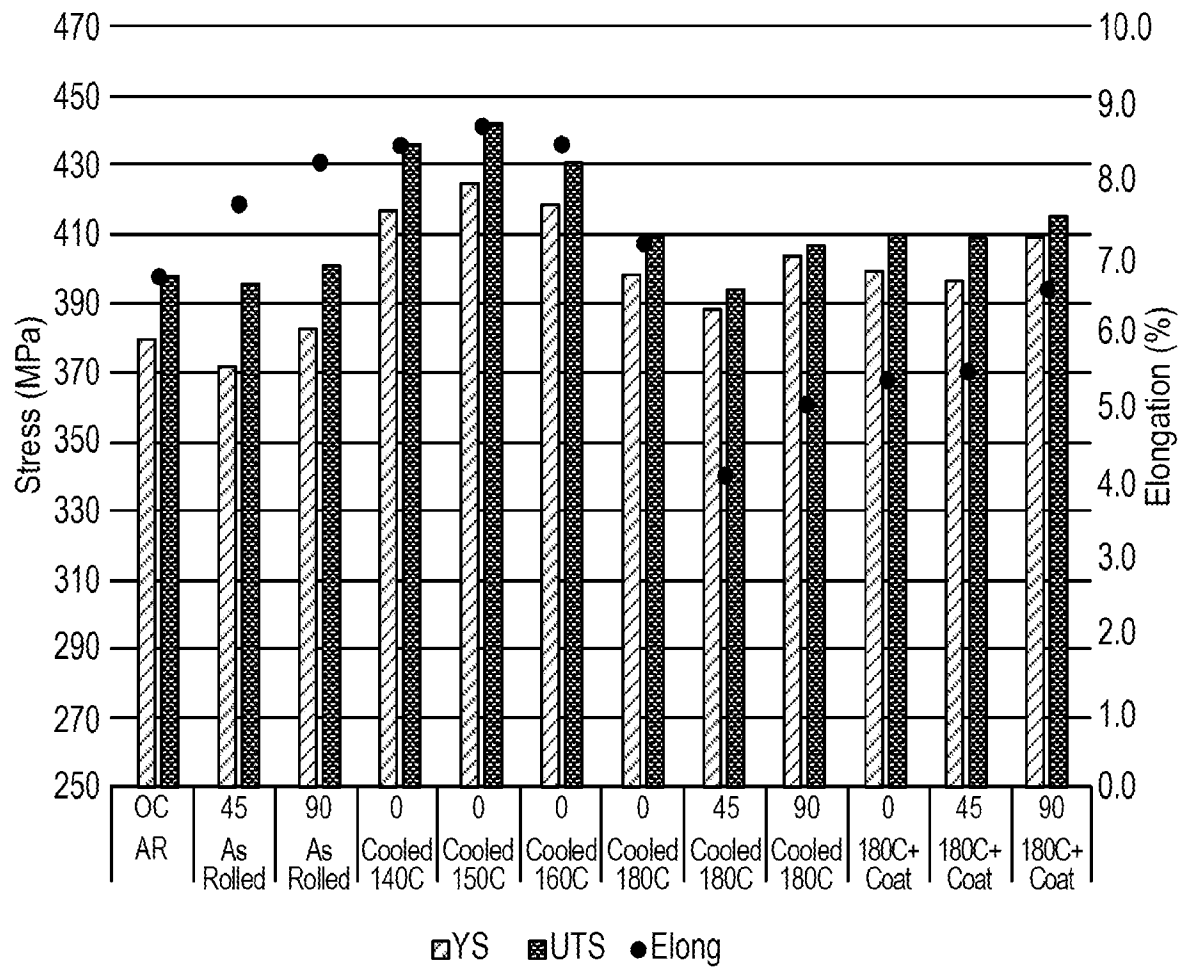


FIG. 7

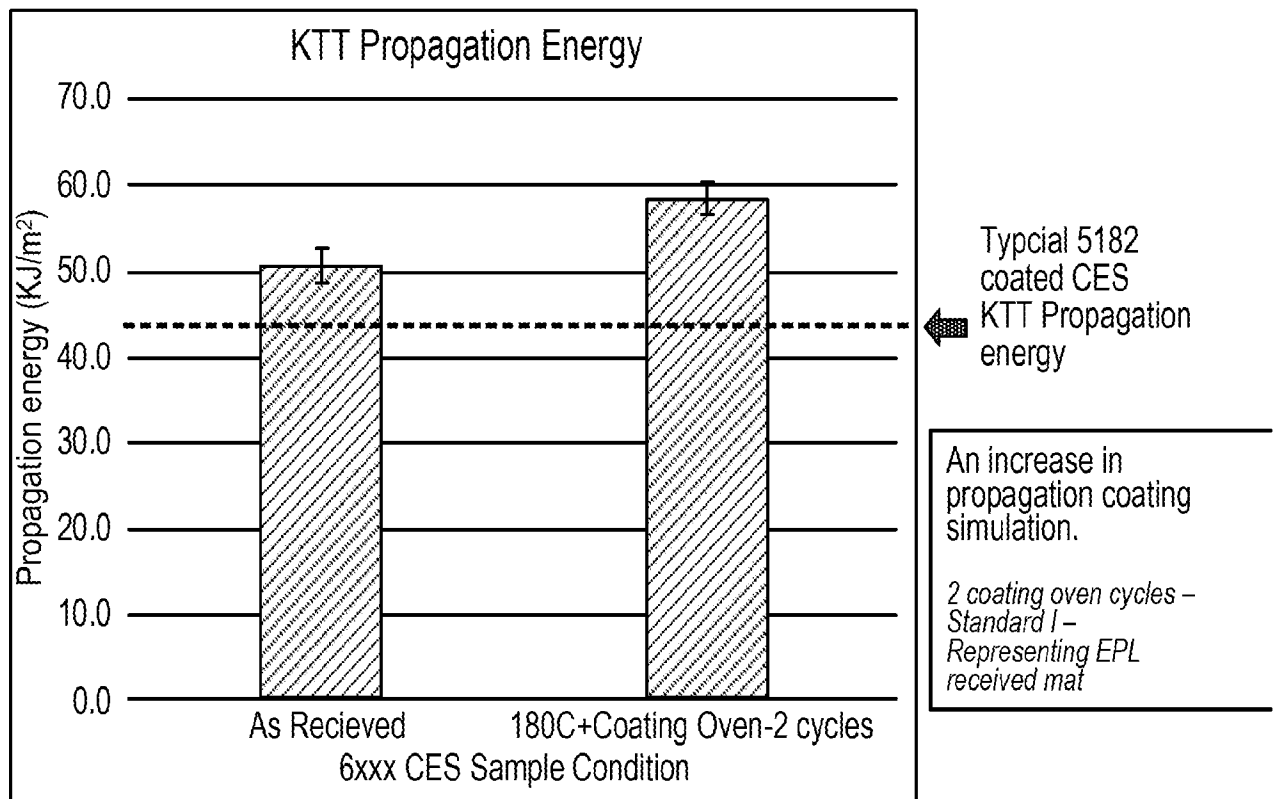


FIG. 8

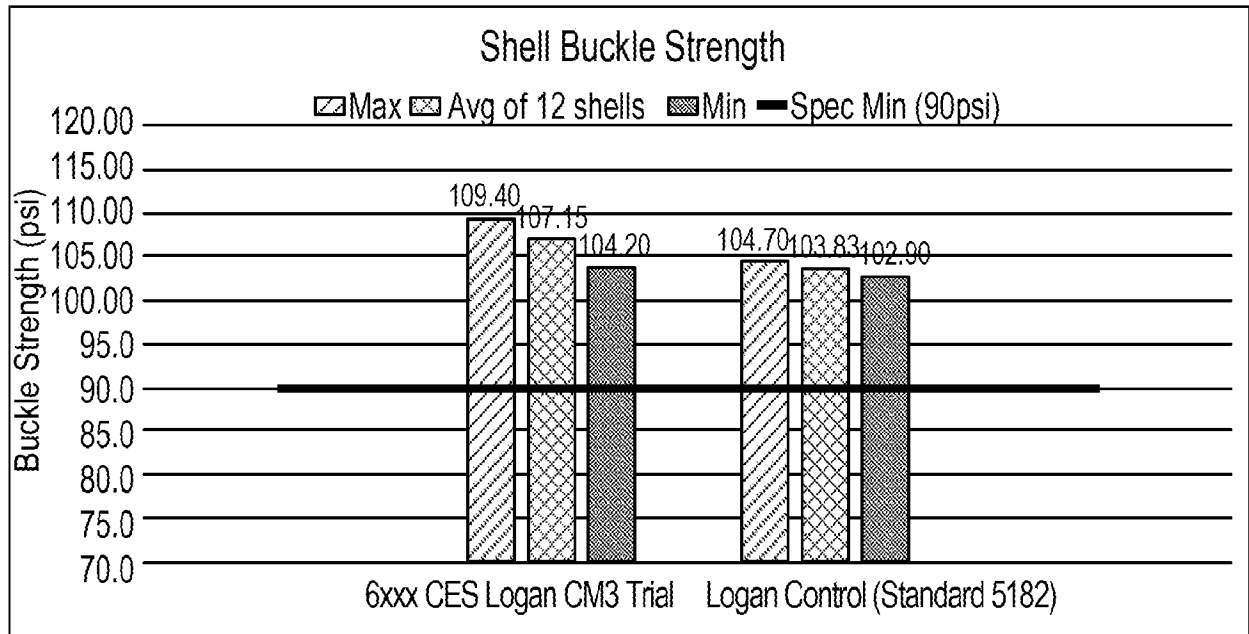


FIG. 9

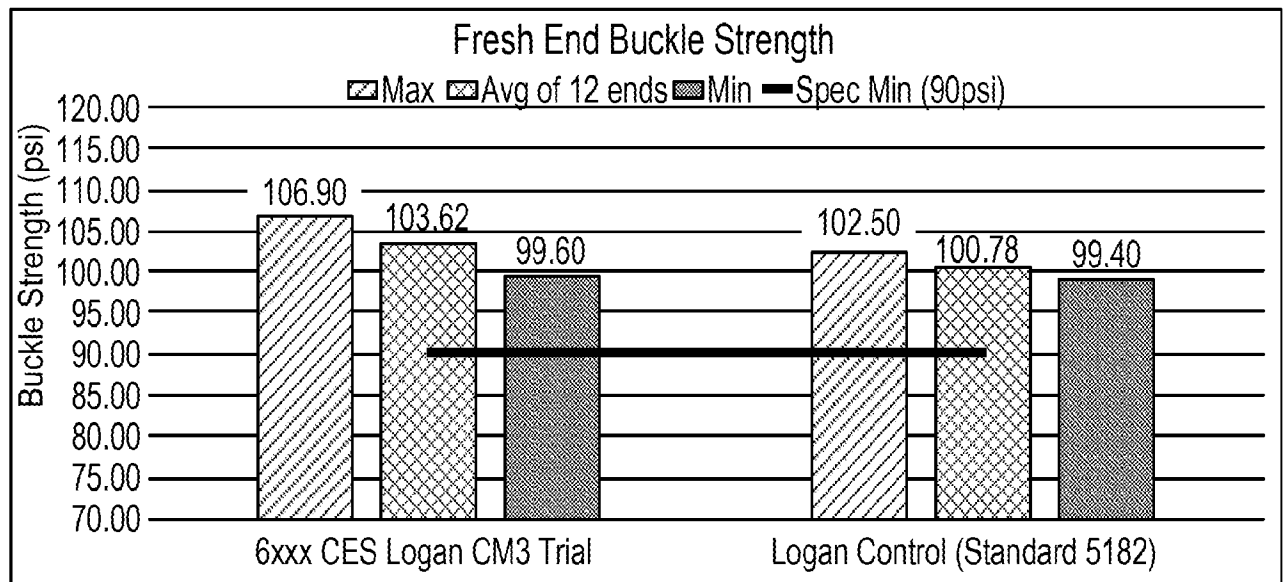


FIG. 10

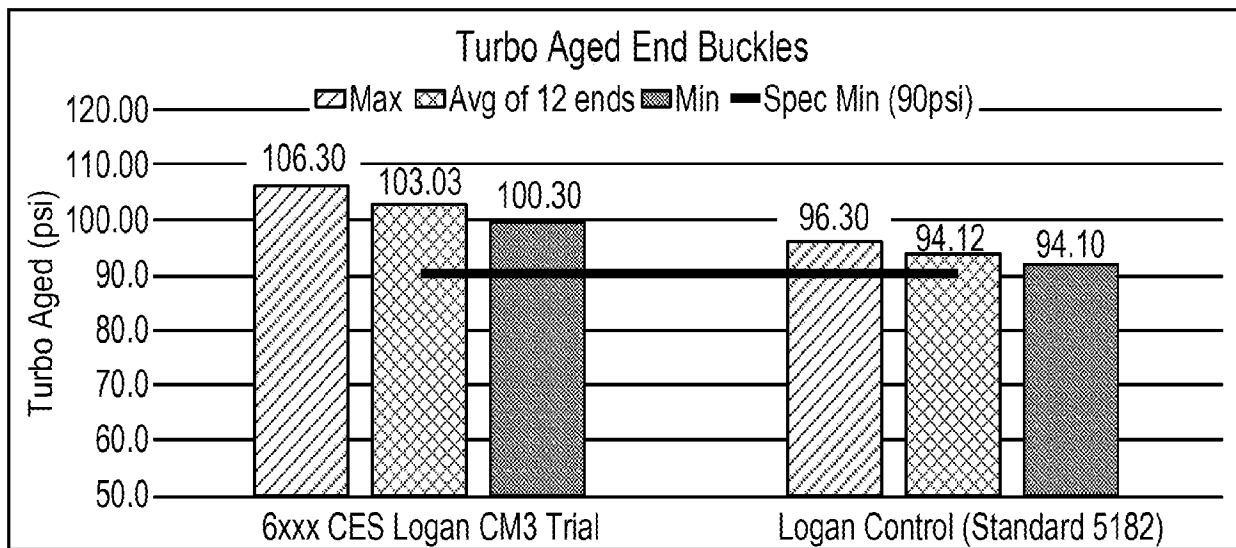


FIG. 11

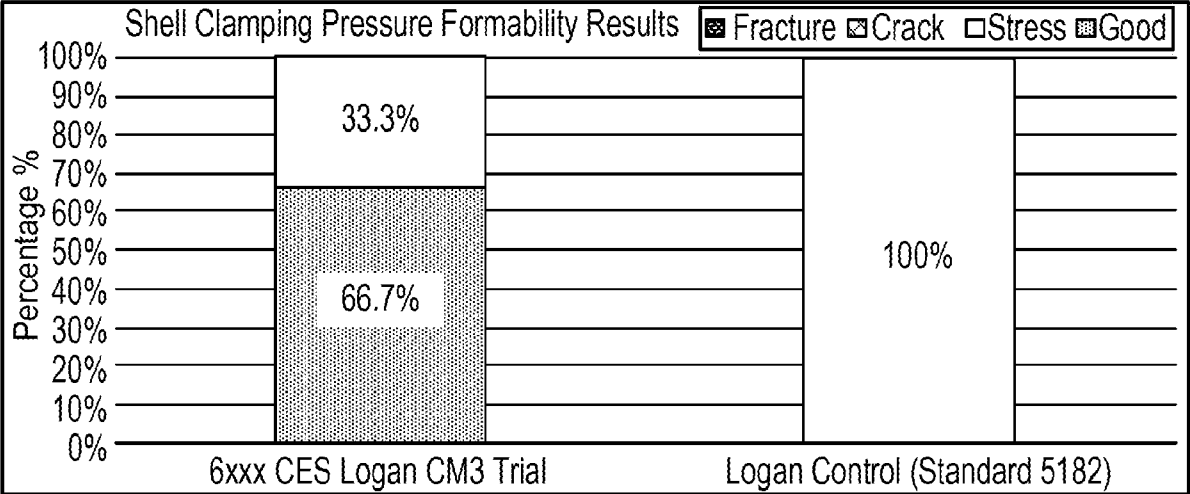


FIG. 12

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2024/036544

A. CLASSIFICATION OF SUBJECT MATTER

INV. C22C21/08 C22F1/05

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 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 2000 355723 A (KOBE STEEL LTD) 26 December 2000 (2000-12-26)	1-20, 22-29
Y	paragraphs [0001], [0022], [0023], [0030], [0034], [0042], [0043], [0052], [0053], [0056] - [0058]; claims 1,2; tables 1,2 -----	1-26
X	WO 2015/041021 A1 (KOBE STEEL LTD [JP]) 26 March 2015 (2015-03-26)	27-29
Y	paragraphs [0022] - [0024]; claim 1; table 1 -----	1-26
X	WO 2016/140054 A1 (KOBE STEEL LTD [JP]) 9 September 2016 (2016-09-09)	27-29
Y	paragraphs [0020], [0029]; claim 1; tables 1,2 -----	1-26



Further documents are listed in the continuation of Box C.



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

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

15 October 2024

Date of mailing of the international search report

23/10/2024

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2024/036544

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