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(54) **ALUMINUM ALLOY PRODUCTS HAVING SELECTIVELY RECRYSTALLIZED MICROSTRUCTURE AND METHODS OF MAKING**

ALUMINIUMLEGIERUNGSPRODUKTE MIT SELEKTIV REKRISTALLISIERTER MIKROSTRUKTUR UND HERSTELLUNGSVERFAHREN

PRODUITS EN ALLIAGE D'ALUMINIUM AYANT UNE MICROSTRUCTURE SÉLECTIVEMENT RECRISTALLISÉE ET PROCÉDÉS DE FABRICATION

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(73) Proprietor: **Novelis Inc.**
Atlanta, GA 30326 (US)

(72) Inventors:
- **WU, Cedric**
  Marietta, Georgia 30062 (US)
- **KAMAT, Rajeev G.**
  Marietta, Georgia 30062 (US)
- **WANG, Yi**
  Issaquah, WA 98029 (US)
- **WAGSTAFF, Samuel Robert**
  Marietta, Georgia 30066 (US)
- **MOHANTY, Rashmi Ranjan**
  Roswell, Georgia 30075 (US)
- **KULKARNI, Rahul Vilas**
  Marietta, Georgia 30066 (US)
- **BENDZINSKI, Duane E.**
  Woodstock, Georgia 30189 (US)
- **YUAN, Yudie**
  Roswell, Georgia 30075 (US)

(74) Representative: **Weickmann & Weickmann PartmbB**
Postfach 860 820
81635 München (DE)

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Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of and priority to U.S. Provisional Application No. 62/548,013, filed on August 21, 2017.

FIELD

[0002] The present disclosure generally provides aluminum alloy products having a selectively recrystallized microstructure at the surface of the product. The disclosure also provides methods of making aluminum alloy products, such as through casting and rolling. The disclosure also provides various end uses of such products, such as in automotive, transportation, electronics, and industrial applications.

BACKGROUND

[0003] Aluminum alloy products are desirable for use in a number of different applications, especially those where light weight, strength, and durability are desirable. For example, aluminum alloys are increasingly replacing steel as a structural component of automobiles and other transportation equipment. Because aluminum alloys are generally about 2.8 times less dense than steel, the use of such materials reduces the weight of the equipment and allows for substantial improvements in energy efficiency. Even so, the use of aluminum alloy products can pose certain challenges.

[0004] One particular challenge relates to the tendency of aluminum alloy products to undergo recrystallization during and following certain processing steps. In metallurgy, recrystallization refers to the process by which deformed grains (e.g., formed as the result of rolling or other mechanical shaping activities) reorient and convert into defect-free grains that nucleate and gradually replace the deformed grains. Recrystallization generally improves the ductility of the material, but generally does so at the expense of strength and hardness. Thus, in applications where strength and hardness are important, such as in certain applications where aluminum alloys may be used to replace steel, recrystallization can limit the use of certain aluminum alloys as steel replacement, US 2011/027610 A1 and WO 2005/049878 A2 disclose methods of making rolled products from 7xxx series aluminum alloys, the methods involving an inter annealing step.

SUMMARY

[0005] The covered embodiments of this disclosure are defined by the claims, not this summary. This summary provides 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] The subject matter of the present invention is defined in the appended claims. The present disclosure provides novel aluminum alloy articles that have surface portions with a higher degree of recrystallization or recrystallization quotient than portions in the interior of the article, where a higher portion of the aluminum alloy material has a recovered and/or unrecrystallized microstructure. Even though the aluminum alloy articles of the present disclosure are made from a monolithic aluminum alloy material, they possess certain benefits of cladded aluminum alloy materials, such as strength in the core of the article and ductility in the clad of the article. The present disclosure also provides methods of making such aluminum alloy articles. The aluminum alloy article is a rolled article, such as an aluminum alloy sheet, where the material near the surface of the sheet has a recrystallized microstructure and the material in the interior of the sheet has a recovered and/or unrecrystallized microstructure. The resulting article exhibits the strength benefits of material in a recovered and/or unrecrystallized microstructure coupled with desirable bendability and corrosion properties of material in a recrystallized microstructure.

[0007] The present disclosure provides an aluminum alloy article, which is comprised of an aluminum alloy material and further comprises: (a) a first surface portion; (b) a second surface portion opposing the first surface portion; and (c) an intermediate portion between the first surface portion and the second surface portion; wherein the first surface portion and the second surface portion comprise a rolled surface; and wherein the aluminum alloy material of the first surface portion and the second surface portion have a higher degree of recrystallization or recrystallization quotient than the aluminum alloy material of the intermediate portion. In some embodiments, the aluminum alloy article is an ingot, a strip, a shate, a slab, a billet, or other aluminum alloy product.

The aluminum alloy article is a rolled aluminum alloy article, which is formed by a process that includes rolling the aluminum alloy article, for example, until a desired thickness is achieved. In some embodiments, the rolled aluminum alloy article is an aluminum alloy sheet, shate, plate, extrusion, casting or forging in any suitable temper, e.g., an O temper or a temper ranging from the T1 to T9 tempers, and any suitable gauge. The aluminum alloy article is made from a 7xxx series alloy as provided herein.

[0008] The present disclosure also provides a method of making an aluminum alloy article as defined in the claims. In some embodiments thereof, the aluminum alloy articles are subjected to a final solution heat treatment, for example, the article can be solution heat treated either through a CASH (continuous annealing and solution heat treatment) or hot stamping process.

[0009] The disclosure also provides an aluminum alloy article made by the processes disclosed herein.

[0010] Described herein are articles of manufacture comprising the disclosed aluminum alloy articles. The article of manufacture comprises a rolled aluminum alloy article. Examples of such articles of manufacture include, but are not limited to, a component of an automobile, truck, trailer, train, railroad car, airplane, such as a body panel or other part for any of the foregoing, a bridge, a pipeline, a pipe, a tubing, a boat, a ship, a storage container, a storage tank, an article of furniture, a window, a door, a railing, a functional or decorative architectural piece, a pipe railing, an electrical component, a conduit, a beverage container, a food container, or a foil. In some embodiments, the articles of manufacture are automotive or transportation body parts, including motor vehicle body parts (e.g., bumpers, side beams, roof beams, cross beams, pillar reinforcements, inner panels, outer panels, side panels, hood inners, hood outers, and trunk lid panels). The articles of manufacture can also include aerospace products and electronic device housings.

[0011] Additional aspects and embodiments are set forth in the detailed description, claims, non-limiting examples, and drawings, which are included herein.

BRIEF DESCRIPTION OF THE FIGURES

[0012] The specification makes reference to the following appended figures, in which use of like reference numerals in different figures is intended to illustrate like or analogous components.

FIG. 1 provides a schematic overview of a process for preparing aluminum alloy articles.

FIG. 2 shows an optical micrograph (OM) of Alloy A1, which is lab rolled and processed, and which shows a recovered and/or unrecrystallized microstructure through the thickness of the sample.

FIG. 3A shows an optical micrograph (OM) of Alloy A1, which is plant rolled with inter-annealing. FIG. 3B shows a surface portion from FIG. 3A, showing a recrystallized microstructure. FIG. 3C shows nine black and white reduced-size versions of FIG. 3B, highlighting various colors shown in FIG. 3B, which may reveal certain features. FIG. 3D shows a center portion from FIG. 3A, showing a recovered and/or unrecrystallized microstructure. FIG. 3E shows nine black and white reduced-size versions of FIG. 3D, highlighting various colors shown in FIG. 3D, which may reveal certain features. For example, significant horizontal lines are shown in the images of FIG. 3E, corresponding to the recovered and/or unrecrystallized microstructure with various crystal orientation. For the surface portion shown in FIGs. 3B and 3C, little of the horizontal structure is seen, indicated significantly more recrystallized microstructure at the surface portion.

FIG. 4A shows an optical micrograph of Alloy A5, plant rolled without inter-annealing during the cold rolling process. FIG. 4B shows a surface portion from FIG. 4A, showing recrystallized microstructure. FIG. 4C is from the center portion from FIG. 4A, showing recovered and/or unrecrystallized microstructure.

Cross-sections of aluminum alloy sheet recorded by EBSD are depicted in the images shown on the right hand side of FIG. 5A, FIG. 5B, and FIG. 5C, where the aluminum alloy sheet of Alloy A1 is rolled to a final gauge and finished with a T6 temper. The low angle boundaries (2-15°) are marked as darker-color horizontal lines (shown separately in black in the top left images of FIGs. 5A-5C), while the medium to high angle boundaries (>15°) are marked as lighter-color horizontal lines (also shown separately in black the bottom left images of FIGs. 5A-5C). FIG. 5A is Alloy A1 lab processed, without inter-annealing during the cold rolling process, which has a uniform microstructure that is recovered and/or unrecrystallized throughout the whole thickness, while FIG. 5B is Alloy A1 plant processed, with inter-annealing during the cold rolling process, which shows a recrystallization microstructure near the surface and a recovered and/or unrecrystallized microstructure in the center. FIG. 5C shows Alloy A5, plant processed, without inter-annealing during the cold rolling process, which has a microstructure between that shown in FIG. 5A and FIG. 5B.

FIG. 6 shows the results of bendability testing for certain aluminum alloy articles, where bendability is tested in the longitudinal and transverse direction (relative to the rolling direction).

FIG. 7A, FIG. 7B, FIG. 7C, FIG. 7D, and FIG. 7E show photographs of aluminum alloy sheet following testing for exfoliation corrosion.

FIG. 8 shows the results of yield strength testing for a series of aluminum alloy sheets.

DETAILED DESCRIPTION

[0013] The present disclosure provides aluminum alloy articles that exhibit a novel combination of recrystallized, and recovered and/or unrecrystallized, microstructure, and methods of making such articles. These articles can exhibit increased strength over articles made from fully recrystallized material, while retaining the bendability and corrosion resistance that such materials generally possess.

Definitions and Descriptions:

[0014] 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.

[0015] In this description, reference is made to alloys identified by AA numbers and other related designations, such as "series" or "7xxx." 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.

[0016] 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.

[0017] 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.

[0018] As used herein, a sheet generally refers to an aluminum product having a thickness of less than about 4 mm. For example, a sheet may have a thickness of less than about 4 mm, less than about 3 mm, less than about 2 mm, less than about 1 mm, less than about 0.5 mm, or less than about 0.3 mm (e.g., about 0.2 mm).

[0019] As used herein, the term slab indicates an alloy thickness in a range of 5 mm to 50 mm. For example, a slab may have a thickness of about 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, or 50 mm.

[0020] Reference may be made in this application to alloy temper or condition. For an understanding of the alloy temper descriptions most commonly used, see "American National Standards (ANSI) H35 on Alloy and Temper Designation Systems." An F condition or temper refers to an aluminum alloy as fabricated. An O condition or temper refers to an aluminum alloy after annealing. An Hxx condition or temper, also referred to herein as an H temper, refers to a non-heat treatable aluminum alloy after cold rolling with or without thermal treatment (e.g., annealing). Suitable H tempers include HX1, HX2, HX3 HX4, HX5, HX6, HX7, HX8, or HX9 tempers. A T1 condition or temper refers to an aluminum alloy cooled from hot working and naturally aged (e.g., at room temperature). A T2 condition or temper refers to an aluminum alloy cooled from hot working, cold worked and naturally aged. A T3 condition or temper refers to an aluminum alloy solution heat treated, cold worked, and naturally aged. A T4 condition or temper refers to an aluminum alloy solution heat treated and naturally aged. A T5 condition or temper refers to an aluminum alloy cooled from hot working and artificially aged (at elevated temperatures). A T6 condition or temper refers to an aluminum alloy solution heat treated and artificially aged. A T7 condition or temper refers to an aluminum alloy solution heat treated and artificially overaged. A T8x condition or temper refers to an aluminum alloy solution heat treated, cold worked, and artificially aged. A T9 condition or temper refers to an aluminum alloy solution heat treated, artificially aged, and cold worked. A W condition or temper refers to an aluminum alloy after solution heat treatment.

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

[0022] 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. As used herein, the meaning of "ambient conditions" can include temperatures of about room temperature, relative humidity of from about 20 % to about 100 %, and barometric pressure of from about 975 millibar (mbar) to about 1050 mbar. For example, relative humidity can be about 20 %, about 21 %, about 22 %, about 23 %, about 24 %, about 25 %, about 26 %, about 27 %, about 28 %, about 29 %, about 30 %, about 31 %, about 32 %, about 33 %, about 34 %, about 35 %, about 36 %, about 37 %, about 38 %, about 39 %, about 40 %, about 41 %, about 42 %, about 43 %, about 44 %, about 45 %, about 46 %, about 47 %, about 48 %, about 49 %, about 50 %, about 51 %, about 52 %, about 53 %, about 54 %, about 55 %, about 56 %, about 57 %, about

58 %, about 59 %, about 60 %, about 61 %, about 62 %, about 63 %, about 64 %, about 65 %, about 66 %, about 67 %, about 68 %, about 69 %, about 70 %, about 71 %, about 72 %, about 73 %, about 74 %, about 75 %, about 76 %, about 77 %, about 78 %, about 79 %, about 80 %, about 81 %, about 82%, about 83 %, about 84 %, about 85 %, about 86 %, about 87 %, about 88 %, about 89 %, about 90 %, about 91 %, about 92 %, about 93 %, about 94 %, about 95 %, about 96 %, about 97 %, about 98 %, about 99 %, about 100 %, or anywhere in between. For example, barometric pressure can be about 975 mbar, about 980 mbar, about 985 mbar, about 990 mbar, about 995 mbar, about 1000 mbar, about 1005 mbar, about 1010 mbar, about 1015 mbar, about 1020 mbar, about 1025 mbar, about 1030 mbar, about 1035 mbar, about 1040 mbar, about 1045 mbar, about 1050 mbar, or anywhere in between.

[0023] All ranges disclosed herein are to be understood to encompass 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. Unless stated otherwise, the expression "up to" when referring to the compositional amount of an element means that element is optional and includes a zero percent composition of that particular element. Unless stated otherwise, all compositional percentages are in weight percent (wt. %).

[0024] As used herein, the meaning of "a," "an," and "the" includes singular and plural references unless the context clearly dictates otherwise.

[0025] In the following examples, the aluminum alloy products and their components are described in terms of their elemental composition in weight percent (wt. %). In each alloy, the remainder is aluminum, with a maximum wt. % of 0.15 % for the sum of all impurities.

[0026] Incidental elements, such as grain refiners and deoxidizers, or other additives may be present in the invention and may add other characteristics on their own without departing from or significantly altering the alloy described herein or the characteristics of the alloy described herein.

[0027] Unavoidable impurities, including materials or elements may be present in the alloy in minor amounts due to inherent properties of aluminum or leaching from contact with processing equipment. Some impurities typically found in aluminum include iron and silicon. The alloy, as described, may contain no more than about 0.25 wt. % of any element besides the alloying elements, incidental elements, and unavoidable impurities.

Aluminum Alloy Article

[0028] The present disclosure provides an aluminum alloy article, comprising an aluminum alloy material and having a first surface portion; a second surface portion opposing the first surface portion; and an intermediate portion between the first surface portion and the second surface portion; wherein the aluminum alloy material of the first surface portion and the second surface portion have a higher degree of recrystallization or recrystallization quotient than the aluminum alloy material of the intermediate portion. The first surface portion and the second surface portion each comprise a rolled surface.

[0029] The aluminum alloy material is a 7xxx series aluminum alloy. In some embodiments, the aluminum alloy material is a 7xxx series aluminum alloy that comprises, among other standard elements, an amount of zirconium (Zr), for example, from 0.01 wt. % to 0.50 wt. %, based on the total elemental composition of the alloy.

[0030] In some embodiments where the aluminum alloy material is a 7xxx series aluminum alloy, the aluminum alloy material can be selected from any suitable 7xxx series aluminum alloy, including, but not limited to, the following 7xxx series aluminum alloys: AA7011, AA7019, AA7020, AA7021, AA7039, AA7072, AA7075, AA7085, AA7108, AA7108A, AA7015, AA7017, AA7018, AA7019A, AA7024, AA7025, AA7028, AA7030, AA7031, AA7033, AA7035, AA7035A, AA7046, AA7046A, AA7003, AA7004, AA7005, AA7009, AA7010, AA7011, AA7012, AA7014, AA7016, AA7116, AA7122, AA7023, AA7026, AA7029, AA7129, AA7229, AA7032, AA7033, AA7034, AA7036, AA7136, AA7037, AA7040, AA7140, AA7041, AA7049, AA7049A, AA7149,7204, AA7249, AA7349, AA7449, AA7050, AA7050A, AA7150, AA7250, AA7055, AA7155, AA7255, AA7056, AA7060, AA7064, AA7065, AA7068, AA7168, AA7175, AA7475, AA7076, AA7178, AA7278, AA7278A, AA7081, AA7181, AA7185, AA7090, AA7093, AA7095, and AA7099.

[0031] In some embodiments, the aluminum alloy material has the elemental composition set forth in Table 1.

Table 1

Element	Weight Percentage (wt. %)
Zn	4.0 - 15.0
Cu	0.1 - 3.5
Mg	1.0 - 4.0
Fe	0.05 - 0.50

(continued)

Element	Weight Percentage (wt. %)
Si	0.05 - 0.30
Zr	0.01 - 0.50
Mn	0 - 0.25
Cr	0 - 0.20
Ti	0 - 0.15
Impurities	0 - 0.15
Al	Remainder

[0032] In some embodiments, the aluminum alloy material has the elemental composition set forth in Table 2.

Table 2

Element	Weight Percentage (wt. %)
Zn	5.6 - 9.3
Cu	0.2 - 2.6
Mg	1.4 - 2.8
Fe	0.10 - 0.35
Si	0.05 - 0.20
Zr	0.05 - 0.25
Mn	0 - 0.05
Cr	0 - 0.10
Ti	0 - 0.05
Impurities	0 - 0.15
Al	Remainder

[0033] Optionally, the aluminum alloy material includes zinc (Zn) in an amount of from 4% to 15% (e.g., from 5.4% to 9.5%, from 5.6% to 9.3%, from 5.8% to 9.2%, or from 4.0% to 5.0%) based on the total weight of the alloy. For example, the aluminum alloy material can include 4.0%, 4.1%, 4.2%, 4.3%, 4.4 %, 4.5%, 4.6 %, 4.7 %, 4.8 %, 4.9 %, 5.0 %, 5.1%, 5.2 %, 5.3%, 5.4%, 5.5%, 5.6%, 5.7%, 5.8%, 5.9%, 6.0%, 6.1%, 6.2 %, 6.3%, 6.4%, 6.5%, 6.6%, 6.7%, 6.8%, 6.9%, 7.0%, 7.1%, 7.2%, 7.3%, 7.4%, 7.5%, 7.6%, 7.7%, 7.8%, 7.9%, 8.0%, 8.1%, 8.2%, 8.3%, 8.4%, 8.5%, 8.6%, 8.7%, 8.8%, 8.9%, 9.0%, 9.1%, 9.2%, 9.3%, 9.4%, 9.5%, 9.6% 9.7%, 9.8%, 9.9%, 10.0%, 10.1%, 10.2%, 10.3%, 10.4%, 10.5%, 10.6%, 10.7%, 10.8%, 10.9%, 11.0%, 11.1%, 11.2%, 11.3%, 11.4%, 11.5%, 11.6%, 11.7%, 11.8%, 11.9%, 12.0%, 12.1%, 12.2%, 12.3%, 12.4%, 12.5%, 12.6%, 12.7%, 12.8%, 12.9%, 13.0%, 13.1%, 13.2 %, 13.3%, 13.4 %, 13.5%, 13.6%, 13.7%, 13.8%, 13.9 %, 14.0%, 14.1%, 14.2%, 14.3%, 14.4%, 14.5%, 14.6%, 14.7%, 14.8%, 14.9%, or 15.0% Zn. All are expressed in wt. %.

[0034] Optionally, the aluminum alloy material includes copper (Cu) in an amount of from 0.1% to 3.5% (e.g., from 0.2% to 2.6%, from 0.3% to 2.5%, or from 0.15% to 0.6%) based on the total weight of the alloy. For example, the aluminum alloy material can include 0.1%, 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%, 0.35%, 0.40%, 0.45%, 0.50%, 0.55%, 0.60%, 0.65%, 0.70% 0.75%, 0.80%, 0.85%, 0.90%, 0.95%, 1.0%, 1.1%, 1.2%, 1.3%, 1.4%, 1.5%, 1.6%, 1.7%, 1.8%, 1.9%, 2.0%, 2.1%, 2.2%, 2.3%, 2.4%, 2.5%, 2.6%, 2.7%, 2.8%, 2.9%, 3.0%, 3.1%, 3.2%, 3.3%, 3.4%, or 3.5% Cu. All are expressed in wt. %.

[0035] Optionally, the aluminum alloy material includes magnesium (Mg) in an amount of from 1.0% to 4.0% (e.g., from 1.0% to 3.0%, from 1.4% to 2.8%, or from 1.6% to 2.6%). For example, the aluminum alloy material can include 1.0%, 1.1%, 1.2%, 1.3%, 1.4%, 1.5%, 1.6%, 1.7%, 1.8%, 1.9%, 2.0%, 2.1%, 2.2%, 2.3%, 2.4%, 2.5%, 2.6%, 2.7%, 2.8%, 2.9%, 3.0%, 3.1%, 3.2%, 3.3%, 3.4%, 3.5%, 3.6%, 3.7%, 3.8%, 3.9%, or 4.0% Mg. All are expressed in wt. %.

[0036] Optionally, the aluminum alloy material includes a combined content of Zn, Cu, and Mg ranging from 5% to 14% (e.g., from 5.5% to 13.5%, from 6% to 13%, from 6.5% to 12.5%, or from 7% to 12%). For example, the combined content of Zn, Cu, and Mg can be 5.0%, 5.5%, 6.0%, 6.5%, 7.0%, 7.5%, 8.0%, 8.5%, 9.0%, 9.5%, 10.0%, 10.5%, 11.0%, 11.5%, 12.0%, 12.5%, 13.0%, 13.5%, or 14.0%. All are expressed in wt. %.

[0037] Optionally, the aluminum alloy material includes iron (Fe) in an amount of from 0.05% to 0.50% (e.g., from 0.10% to 0.35% or from 0.10% to 0.25%) based on the total weight of the alloy. For example, the aluminum alloy material 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%, or 0.50% Fe. All are expressed in wt. %.

[0038] Optionally, the aluminum alloy material includes silicon (Si) in an amount of from 0.05% to 0.30% (e.g., from 0.05% to 0.25% or from 0.07% to 0.15%) based on the total weight of the alloy. For example, the aluminum alloy material can include 0.05%, 0.06%, 0.07%, 0.08%, 0.09%, 0.10% 0.11%, 0.12%, 0.13%, 0.14%, 0.15%, 0.16%, 0.17%, 0.18%, 0.19%, 0.20%, 0.21%, 0.22 %, 0.23%, 0.24 %, 0.25%, 0.26 %, 0.27 %, 0.28%, 0.29%, or 0.30% Si. All are expressed in wt. %.

[0039] Optionally, the aluminum alloy material includes zirconium (Zr) in an amount of from 0.01% to 0.50% (e.g., from 0.05% to 0.25%, or from 0.05% to 0.20% or from 0.09% to 0.15%) based on the total weight of the alloy. For example, the aluminum alloy material can include 0.01%, 0.02%, 0.03%, 0.04%, 0.05%, 0.06%, 0.07%, 0.08%, 0.09%, 0.10%, 0.11%, 0.12%, 0.13%, 0.14%, 0.15%, 0.16%, 0.17%, 0.18%, 0.19%, 0.20%, 0.21%, 0.22%, 0.23%, 0.24%, 0.25%, 0.26%, 0.27%, 0.28%, 0.29%, 0.30%, 0.31%, 0.32%, 0.33%, 0.34%, 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% Zr. In other examples, the alloys can include Zr in an amount less than 0.05% (e.g., 0.04%, 0.03%, 0.02%, or 0.01%) based on the total weight of the alloy. All are expressed in wt. %.

[0040] In some instances, the presence of Zr in the alloy may form Al_3Zr dispersoids, which can assist in pinning the grain boundaries of the aluminum alloy material. In the region of the aluminum alloy article near a rolled surface, the higher strain introduced from the rolling process can at least partially overcome the pinning and allow for a higher degree of recrystallization or recrystallization quotient. Meanwhile, in the interior portions of the aluminum alloy article, the pinning is not overcome and recrystallization occurs to a much lower degree. In some embodiments, Al_3Zr dispersoids are present in the aluminum alloy material, the dispersoids having a number-average diameter ranging from 1 nm to 20 nm.

[0041] Optionally, the aluminum alloy material includes manganese (Mn) in an amount of up to 0.25% (e.g., from 0.01% to 0.10% or from 0.02% to 0.05%) based on the total weight of the alloy. For example, the aluminum alloy material can include 0.01%, 0.02%, 0.03%, 0.04%, 0.05%, 0.06%, 0.07%, 0.08%, 0.09%, 0.10%, 0.11%, 0.12%, 0.13%, 0.14%, 0.15%, 0.16%, 0.17%, 0.18%, 0.19%, 0.20%, 0.21%, 0.22%, 0.23%, 0.24%, or 0.25% Mn. In some cases, Mn is not present in the alloy (i.e., 0%). All are expressed in wt. %.

[0042] Optionally, the aluminum alloy material includes chromium (Cr) in an amount of up to 0.20%, or up to 0.10% (e.g., from 0.01% to 0.10%, from 0.01% to 0.05%, or from 0.03% to 0.05%) based on the total weight of the alloy. For example, the aluminum alloy material can include 0.01%, 0.02%, 0.03%, 0.04%, 0.05%, 0.06%, 0.07%, 0.08%, 0.09%, 0.10%, 0.11%, 0.12%, 0.13%, 0.14%, 0.15%, 0.16%, 0.17%, 0.18%, 0.19%, or 0.20% Cr. In some cases, Cr is not present in the alloy (i.e., 0%). All are expressed in wt. %.

[0043] Optionally, the aluminum alloy material includes titanium (Ti) in an amount of up to 0.15% (e.g., from 0.001% to 0.10%, from 0.001% to 0.05%, or from 0.003% to 0.035%) based on the total weight of the alloy. For example, the alloy can include 0.001%, 0.002%, 0.003%, 0.004%, 0.005%, 0.006%, 0.007%, 0.008%, 0.009%, 0.010%, 0.011% 0.012%, 0.013%, 0.014%, 0.015%, 0.016%, 0.017%, 0.018%, 0.019%, 0.020%, 0.021% 0.022%, 0.023%, 0.024%, 0.025%, 0.026%, 0.027%, 0.028%, 0.029%, 0.030%, 0.031%, 0.032%, 0.033%, 0.034%, 0.035%, 0.036%, 0.037%, 0.038%, 0.039%, 0.040%, 0.041%, 0.042%, 0.043%, 0.044%, 0.045%, 0.046%, 0.047%, 0.048%, 0.049%, 0.050% , 0.055%, 0.060%, 0.065%, 0.070%, 0.075%, 0.080%, 0.085%, 0.090%, 0.095%, 0.100%, 0.110%, 0.120%, 0.130%, 0.140%, or 0.150% Ti. In some cases, Ti is not present in the alloy (i.e., 0%). All are expressed in wt. %.

[0044] Optionally, the aluminum alloy material includes one or more elements selected from the group consisting of Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu in an amount of up to 0.10% (e.g., from 0.01% to 0.10%, from 0.01% to 0.05%, or from 0.03% to 0.05%), based on the total weight of the alloy. For example, the aluminum alloy material can include 0.01%, 0.02%, 0.03%, 0.04%, 0.05%, 0.06%, 0.07%, 0.08%, 0.09%, or 0.10 % of one or more elements selected from the group consisting of Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu. All are expressed in wt. %.

[0045] Optionally, the aluminum alloy material includes one or more elements selected from the group consisting of Mo, Nb, Be, B, Co, Sn, Sr, V, In, Hf, Ag, Sc, and Ni in an amount of up to 0.10% (e.g., from 0.01% to 0.10%, from 0.01% to 0.05%, or from 0.03% to 0.05%), based on the total weight of the alloy. For example, the aluminum alloy material can include 0.01%, 0.02%, 0.03%, 0.04%, 0.05%, 0.06%, 0.07%, 0.08%, 0.09%, or 0.10 % of one or more elements selected from the group consisting of Mo, Nb, Be, B, Co, Sn, Sr, V, In, Hf, Ag, Sc, and Ni. All are expressed in wt. %.

[0046] Optionally, the aluminum alloy material includes 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. In some embodiments, these impurities include, but are not limited to, Ga, Ca, Bi, Na, Pb, or combinations thereof. Accordingly, in some embodiments, one or more elements selected from the group consisting of Ga, Ca, Bi, Na, and Pb may be present in the aluminum alloy material 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. The sum of all impurities does not exceed 0.15% (e.g., 0.10%). All are expressed in wt. %. The remaining percentage of the alloy is aluminum.

[0047] The alloy compositions disclosed herein, including the aluminum alloy material of any of foregoing embodiments, have aluminum (Al) as a major component, for example, in an amount of at least 85.0% of the alloy. Optionally, the alloy compositions have at least 85.5% Al, or at least 86.0% Al, or at least 86.5% Al, or at least 87.0% Al, or at least 87.5% Al, or at least 88.0% Al, or at least 88.5% Al, or at least 89.0% Al, or at least 89.5% Al, or at least 90.0% Al, or at least 90.5% Al, or at least 91.0% Al, or at least 91.5% Al, or at least 92.0% Al. All are expressed in wt. %.

[0048] The aluminum alloy articles disclosed herein can be any suitable aluminum alloy article. As noted above, the articles have a first surface portion and an opposing second surface portion. In some cases, the surface of the first surface portion and the surface of the second surface portion represent opposite sides of an article, such that the two surfaces may be parallel or generally parallel to each other or disposed away from each other and separated by a thickness, e.g., a first thickness, which may represent a distance between the two surfaces along a line perpendicular to the two surfaces or the shortest distance between the two surfaces.

[0049] As noted above, the first surface portion comprises a rolled surface and the second surface portion comprises a rolled surface, i.e. the surfaces of an article formed by rolling a cast aluminum product, such as a slab, an ingot, a shate, a sheet, a plate and the like. In some embodiments, these rolled surfaces are formed according to the processes set forth below. The rolled surface of the first surface portion and the rolled surface of the second surface portion are formed by a process that comprises cold rolling. The cold rolling is preceded by hot rolling.

[0050] The aluminum alloy article can have any suitable physical configuration. Optionally, the aluminum alloy article is a rolled aluminum alloy plate, shate or sheet. In some embodiments, the aluminum alloy article is a rolled aluminum alloy shate. The rolled aluminum alloy shate can have any suitable thickness, but, in some embodiments, it has a thickness ranging from 4 mm to 15 mm, or no more than 14 mm, or no more than 13 mm, or no more than 12 mm, or no more than 11 mm, or no more than 10 mm, or no more than 9 mm, or no more than 8 mm, or no more than 7 mm, or no more than 6 mm, or no more than 5 mm. In some embodiments, the aluminum alloy article is a rolled aluminum alloy sheet. The rolled aluminum alloy sheet can have any suitable thickness, but, in some embodiments, it has a thickness ranging from 0.05 mm to 4 mm, or no more than 3 mm, or no more than 2 mm, or no more than 1 mm, or no more than 0.5 mm, or no more than 0.3 mm, or no more than 0.1 mm. In some embodiments, the aluminum alloy article is a rolled aluminum alloy shate or a rolled aluminum alloy sheet having a thickness of 15 mm, or 14 mm, or 13 mm, or 12 mm, or 11 mm, or 10 mm, or 9 mm, or 8 mm, or 7 mm, or 6 mm, or 5 mm, or 4 mm, or 3 mm, or 2 mm, or 1 mm, or 0.5 mm, or 0.3 mm, or 0.1 mm.

[0051] The disclosure refers to certain "surface portion(s)," such as a first surface portion and a second surface portion. Such surface portions include a surface of the article, i.e. a rolled surface, and a certain amount of material (e.g., a uniform depth of material) beneath the surface and along the thickness of the article (i.e., the line running perpendicular to the respective surfaces of the first surface portion and the second surface portion). Optionally, the first surface portion extends from the surface of the first surface portion to a depth of no more than 40.0%, or no more than 35.0%, or no more than 33.3%, or no more than 30.0%, or no more than 25.0%, or no more than 20.0%, or no more than 15.0%, or no more than 10.0%, of the thickness of the aluminum alloy article. In some embodiments, the second surface portion extends from the surface of the second surface portion to a depth of no more than 40.0%, or no more than 35.0%, or no more than 33.3%, or no more than 30.0%, or no more than 25.0%, or no more than 20.0%, or no more than 15.0%, or no more than 10.0%, of the thickness of the aluminum alloy article. In some embodiments, the first surface portion and the second surface portion are of the same depth, i.e., are symmetrical in depth with respect to the midpoint of the distance between the two surfaces. In some other embodiments, however, the first surface portion and the second surface portion have different depths.

[0052] The disclosure also refers to an "intermediate portion" that lies between the first surface portion and the second surface portion. Optionally, the intermediate portion includes the remaining material between the two surfaces that is not included in the first surface portion and the second surface portion, such that the intermediate portion extends from the depth of the first surface portion to the depth of the second surface portion. Thus, in some embodiments, all material between the two surfaces is included in either the first surface portion, the second surface portion, or the intermediate portion. Optionally, the intermediate portion does not include all of the remaining material between the two surfaces that is not included in the first surface portion and the second surface portion. In some embodiments, the intermediate portion lies between the depth of the first surface portion and the depth of the second surface portion, includes the midpoint in the thickness between the depth of the first surface portion and the depth of the second surface portion, and includes no more than 10.0%, or no more than 20.0%, or no more than 30.0%, or no more than 40.0%, or no more than 50.0%, or no more than 60.0%, or no more than 70.0%, or no more than 80.0%, or no more than 90.0%, or no more than 95.0%, or no more than 97.0%, or no more than 99.0%, of the thickness between the depth of the first surface portion and the depth of the second surface portion. In some embodiments, the midpoint in the thickness between the depth of the first surface portion and the depth of the second surface portion lies at the midpoint in the thickness of the intermediate portion.

[0053] The disclosure provides aluminum alloy articles in which the aluminum alloy material of the first surface portion has a higher degree of recrystallization or recrystallization quotient than the aluminum alloy material of the intermediate portion. The second surface portion also has a higher degree of recrystallization or recrystallization quotient than the aluminum alloy material of the intermediate portion, such that, in the case of an aluminum alloy plate, shate or sheet, the areas nearer to the two surfaces of the plate, shate or sheet have a higher degree of recrystallization or recrystallization quotient than the area lying in the interior of the plate, shate or sheet.

[0054] The degree of recrystallization or recrystallization quotient can be determined by any suitable method known in the art. For example, in a micrograph, such as a scanning electron micrograph (SEM) or an optical micrograph (OM), the higher degree of recrystallization recrystallization quotient can be observed in terms of a grain structure having a higher degree of uniformity. In some other examples, electron backscatter diffraction (EBSD) can also be used to assess the degree of recrystallization. The degree of recrystallization is set forth in terms of a "recrystallization quotient," which, as used herein, refers to the formula: 1 - LAGB/(MAGB+HAGB). The recrystallization quotient refers to or is representative of a percentage, amount, or volume of material that is recrystallized as compared to a total amount or volume of material. LAGB refers to the quantity of grain boundaries in a given volume having misorientation between adjacent grains of 2° to 15° (i.e., a quantity of low-angle grain boundaries). MAGB refers to the quantity of grain boundaries in a given volume having misorientation between adjacent grains of greater than 15° but no more than 30° (i.e., the quantity of medium-angle grain boundaries). HAGB refers to the quantity of grain boundaries in a given volume having misorientation between adjacent grains of more than 30° (i.e., the quantity of high-angle grain boundaries). Quantities or values of LAGB, MAGB, and HAGB may be determined by measuring the angle of misorientation between adjacent grains, as recorded by EBSD. The recovery or recrystallization of materials may reduce the stored energy in materials when heavily deformed materials are annealed at high temperature. Recovery competes with recrystallization, as both are driven by the stored energy during annealing. Recovery can be defined as annealing processes occurring in deformed materials that occur without the migration of a high-angle grain boundary. The deformed structure is often a cellular structure with walls having dislocation angles. As recovery proceeds, these cell walls undergo a transition towards a genuine subgrain structure. This occurs through a gradual elimination of extraneous dislocations and the rearrangement of the remaining dislocations into low-angle grain boundaries. However, recrystallization is the formation of a new grain structure in a deformed material by the formation and migration of high angle grain boundaries driven by the stored energy of deformation. Therefore, the LAGB is eliminated during the recrystallization process.

[0055] The aluminum alloy material of the first surface portion has a recrystallization quotient that is higher than the recrystallization quotient of the aluminum alloy material of the intermediate portion. Optionally, the first surface portion has a recrystallization quotient that at least 0.01 higher (e.g., 0.01-1.0), or at least 0.03 higher, or at least 0.05 higher, or at least 0.07 higher, or at least 0.10 higher, or at least 0.15 higher, or at least 0.20 higher, or at least 0.25 higher, or at least 0.30 higher, or at least 0.35 higher, or at least 0.40 higher, or at least 0.45 higher, or at least 0.50 higher, than the recrystallization quotient of the aluminum alloy material of the intermediate portion.

[0056] The aluminum alloy material of the second surface portion has a recrystallization quotient that is higher than the recrystallization quotient of the aluminum alloy material of the intermediate portion. Optionally, the second surface portion has a recrystallization quotient that at least 0.01 higher (e.g., 0.01-1.0), or at least 0.03 higher, or at least 0.05 higher, or at least 0.07 higher, or at least 0.10 higher, or at least 0.15 higher, or at least 0.20 higher, or at least 0.25 higher, or at least 0.30 higher, or at least 0.35 higher, or at least 0.40 higher, or at least 0.45 higher, or at least 0.50 higher, than the recrystallization quotient of the aluminum alloy material of the intermediate portion.

[0057] Optionally, the aluminum alloy material of the first surface portion has a recrystallization quotient of at least 0.50, or at least 0.55, or at least 0.60, or at least 0.65, or at least 0.70, or at least 0.75, or at least 0.80, or at least 0.85, or at least 0.90. For example, the first surface portion may have a recrystallization quotient of 0.5 to 1.0.

[0058] Optionally, the aluminum alloy material of the second surface portion has a recrystallization quotient of at least 0.50, or at least 0.55, or at least 0.60, or at least 0.65, or at least 0.70, or at least 0.75, or at least 0.80, or at least 0.85, or at least 0.90. For example, the second surface portion may have a recrystallization quotient of 0.5 to 1.0.

[0059] Optionally, the aluminum alloy material of the intermediate portion has a recrystallization quotient of no more than 0.25, or no more than 0.30, or no more than 0.35, or no more than 0.40, or no more than 0.45, or no more than 0.50, or no more than 0.55, or no more than 0.60, or no more than 0.65. For example, the intermediate portion may have a recrystallization quotient of 0 to 0.65 or 0.01 to 0.65.

[0060] Optionally, the aluminum alloy article, when subjected to bendability testing according to Specification VDA 238-100, has a β angle of no more than 138°, or no more than 137°, no more than 136°, no more than 135°, no more than 134°, no more than 133°, no more than 132°, or no more than 131°, such as between 100° and 142°.

[0061] Optionally, the aluminum alloy article, when subjected to exfoliation corrosion testing according to ASTM Test No. G34-01, has an exfoliation corrosion rating of EA.

Methods of Preparing Aluminum Alloy Articles

[0062] In certain aspects, the disclosed aluminum alloy articles are products of a disclosed method. Without intending to limit the scope of the inventions set forth herein, the properties of the aluminum alloy articles set forth herein are partially determined by the formation of certain microstructures during the preparation thereof.

[0063] FIG. 1 provides an overview of a method of making an aluminum alloy article. The method of FIG. 1 begins at step 105 where an aluminum alloy 106 is cast to form an aluminum alloy cast product 107, such as an ingot or other cast product. At step 110 the aluminum alloy cast product 107 is homogenized to form a homogenized aluminum alloy cast product 111. At step 115, the homogenized aluminum alloy cast product 111 is subjected to one or more hot rolling passes and one or more cold rolling passes to form a first rolled aluminum alloy product 112. At step 120, the first rolled aluminum alloy product 112 is annealed to form a first annealed aluminum alloy product 121. At step 125, the first annealed aluminum alloy product 121 is subjected to a second rolling process to form a second rolled aluminum product 126, which may correspond to an aluminum alloy article. Optionally, the second rolled aluminum product 126 is subjected to one or more additional forming or stamping processes to form an aluminum alloy article.

Casting

[0064] The methods disclosed herein comprise a step of casting a molten aluminum alloy to form an aluminum alloy cast product. In some embodiments, the molten alloy may be treated before casting. The treatment can include one or more of degassing, inline fluxing, and filtering. Aluminum alloy cast products can be formed using any casting process performed according to standards commonly used in the aluminum industry as known to one of ordinary skill in the art.

[0065] As a few non-limiting examples, the casting process can include a Direct Chill (DC) casting process or a Continuous Casting (CC) process. The 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. In some embodiments, the CC process may include, but is not limited to, the use of twin-belt casters, twin-roll casters, or block casters. In some embodiments, the casting process is performed by a CC process to form a cast product in the form of a billet, a slab, a shate, a strip, and the like.

[0066] A clad layer in a cast product may be attached to a core layer in a cast product to form a cladded product by any means known to persons of ordinary skill in the art. For example, a clad layer can be attached to a core layer by direct chill co-casting (i.e., fusion casting) as described in, for example, U.S. Patent Nos. 7,748,434 and 8,927,113; by hot and cold rolling a composite cast ingot as described in U.S. Patent No. 7,472,740; or by roll bonding to achieve the required metallurgical bonding between the core and the cladding. The initial dimensions and final dimensions of the clad aluminum alloy products described herein can be determined by the desired properties of the overall final product.

[0067] The roll bonding process can be carried out in different manners, as known to those of ordinary skill in the art. For example, the roll-bonding process can include both hot rolling and cold rolling. Further, the roll bonding process can be a one-step process or a multi-step process in which the material is gauged down during successive rolling steps. Separate rolling steps can optionally be separated by other processing steps, including, for example, annealing steps, cleaning steps, heating steps, cooling steps, and the like.

[0068] A cast product, such as an ingot, billet, slab, shate, strip, etc., can be processed by any means known to those of ordinary skill in the art. Optionally, the processing steps can be used to prepare sheets. Such processing steps include, but are not limited to, homogenization, hot rolling, cold rolling, solution heat treatment, and an optional pre-aging step, as known to those of ordinary skill in the art. The processing steps can be suitably applied to any cast product, including, but not limited to, ingots, billets, slabs, strips, plates, shates, etc., using modifications and techniques as known to those of skill in the art. Specific processing steps may be used to prepare aluminum alloy articles with particular recrystallization quotient distributions, as described below.

[0069] In some cases, the casting process may impact the recrystallization and reforming that may occur during subsequent processing steps. For example, the distribution of dispersoid-forming elements in a cast product, such as an ingot, may impact the ability of a cast product to undergo recrystallization. By selectively segregating dispersoid-forming elements during the casting process, different regions of the cast products and processed products and articles may be more or less prone to undergo recrystallization. Dispersoid forming elements include, for example, Mn, Cr, Ti, Zr, and Sc, which may precipitate out of supersaturated solutions in the form of nano-scale precipitates, which may be, for example, from 10 nm in diameter to 30 nm in diameter. These precipitates may have sizes that do not promote recrystallization nucleation in the way that larger particles do. Instead, these particles may inhibit the motion of dislocations and grain boundaries such that recrystallization is inhibited. The volume or mass fraction of these dispersoids may determine or impact the specific recrystallization behavior in a cast product.

[0070] In large-scale castings, depletion or accumulation of alloying elements can occur. This is known as macro-segregation, which may be caused by the relative movement of solid and liquid phases which are of inherently different compositions. The center of an ingot may be particularly susceptible to macrosegregation, such as during casting. For example, this area of an ingot may exhibit depletion of eutectic forming elements, with the relative depletion proportional to casting speed. This property is further elucidated by Yu and Granger in "Macrosegregation in Aluminum Alloy Ingot Cast by the Semicontinuous Direct Chill (DC) Method, International Conference on Aluminum alloys - Their physical and mechanical properties, Charlottesville, Virginia. Warley (UK): EMAS; 1986, p. 17-29.

[0071] Similarly, dispersoid forming elements may also be selectively enriched in the centerline, and the enrichment may also be enhanced by increasing the casting speed. Thus, by varying the casting speed, the distributions of dispersoid-forming elements may be optimized at the center of the ingot, which can impact the rate at which recrystallization may occur. For example, by increasing the casting speed in an ingot containing dispersoid-forming elements, their concentration at the center of the ingot may be increased as compared to slower casting rates. The enhanced dispersoid content in the corresponding solidified ingot can then be used during subsequent processing steps (e.g., rolling, annealing, etc.) to impact the rate of recrystallization at the center of a processed object. In this way, casting can impact the amount and rate of recrystallization at an intermediate portion relative to surface portions during subsequent rolling and annealing steps, for example. Accordingly, methods disclosed herein may optionally utilize a high-rate casting step, such as greater than about 1.5 inches per minute (IPM), such as 1.5-10 IPM, 2.5-10 IPM, 3.5-10 IPM, or 4.5-10 IPM.

Stress Relieving

[0072] The methods disclosed herein can also optionally comprise a stress relieving step, which includes heating the aluminum alloy cast product prepared from an alloy composition described herein to attain a peak metal temperature (PMT) of at least 300 °C up to 420 °C. In some embodiments, the stress relieving is carried out at a temperature of 300 °C, or 310 °C, or 320 °C, or 330 °C, or 340 °C, or 350 °C, or 360 °C, or 370 °C, or 380 °C, or 390 °C, or 400 °C, or 410 °C, or 420 °C. In general, the heating is carried out for a period of at least 8 hours and up to, for example, 24 hours. In some embodiments, the heating is carried out for 8 hours, or 9 hours, or 10 hours, or 11 hours, or 12 hours, or 13 hours, or 14 hours, or 15 hours, or 16 hours, or 17 hours, or 18 hours, or 19 hours, or 20 hours, or 21 hours, or 22 hours, or 23 hours, or 24 hours. During stress relieving, the microstructure of an aluminum alloy cast or rolled product may be modified, such as by a recrystallization process or recovery process.

Homogenization

[0073] The homogenization step can include heating an aluminum alloy cast product prepared from an alloy composition described herein to attain a peak metal temperature (PMT) of at least 450 °C (e.g., at least 450 °C, at least 460 °C, at least 470 °C, at least 480 °C, at least 490 °C, at least 500 °C, at least 510 °C, at least 520 °C, at least 530 °C, at least 540 °C, at least 550 °C, at least 560 °C, at least 570 °C, or at least 580 °C). For example, the aluminum alloy product can be heated to a temperature of from 520 °C to 580 °C, from 530 °C to 575 °C, from 535 °C to 570 °C, from 540 °C to 565 °C, from 545 °C to 560 °C, from 530 °C to 560 °C, or from 550 °C to 580 °C. Optionally, the heating rate to the PMT is 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. Optionally, the heating rate to the PMT is from 10 °C/min to 100 °C/min (e.g., 10 °C/min to 90 °C/min, 10 °C/min to 70 °C/min, 10 °C/min to 60 °C/min, from 20 °C/min to 90 °C/min, from 30 °C/min to 80 °C/min, from 40 °C/min to 70 °C/min, or from 50 °C/min to 60 °C/min).

[0074] In some instances, the aluminum alloy cast product is then allowed to soak (i.e., held at a particular temperature, such as a PMT) for a period of time. In some embodiments, the aluminum alloy cast product is allowed to soak for up to 15 hours (e.g., from 30 minutes to 6 hours, inclusively). For example, in some embodiments, the aluminum alloy product is soaked at a temperature of at least 450 °C for 30 minutes, for 1 hour, for 2 hours, for 3 hours, for 4 hours, for 5 hours, for 6 hours, for 7 hours, for 8 hours, for 9 hours, for 10 hours, for 11 hours, for 12 hours, for 13 hours, for 14 hours, for 15 hours, or for any time period in between.

[0075] In some embodiments, the homogenization described herein can be carried out in a two-stage homogenization process. In some embodiments, the homogenization process can include the above-described heating and soaking steps, which can be referred to as the first stage, and can further include a second stage. In the second stage of the homogenization process, the temperature of the aluminum alloy cast product is increased to a temperature higher than the temperature used for the first stage of the homogenization process. The aluminum alloy cast product temperature can be increased, for example, to a temperature at least 5 °C higher than the aluminum alloy cast product temperature during the first stage of the homogenization process. For example, the aluminum alloy cast product temperature can be increased to a temperature of at least 455 °C (e.g., at least 460 °C, at least 465 °C, or at least 470 °C). The heating rate to the second stage homogenization temperature can be 5 °C/hour or less, 3 °C/hour or less, or 2.5 °C/hour or less. The aluminum alloy cast product is then allowed to soak for a period of time during the second stage. In some embodiments, the aluminum alloy cast product is allowed to soak for up to 10 hours (e.g., from 30 minutes to 10 hours, inclusively). For example, the aluminum alloy cast product can be soaked at the temperature of at least 455 °C for 30 minutes, for 1 hour, for 2 hours, for 3 hours, for 4 hours, for 5 hours, for 6 hours, for 7 hours, for 8 hours, for 9 hours, or for 10 hours. In some embodiments, following homogenization, the aluminum alloy cast product is allowed to cool to room temperature in the air.

Hot Rolling

[0076] Following the homogenization step, one or more hot rolling passes are performed. In certain cases, the aluminum alloy products are laid down and hot rolled at a temperature ranging from 250 °C to 550 °C (e.g., from 300 °C to 500 °C, or from 350 °C to 450 °C).

[0077] In certain embodiments, the aluminum alloy product is hot rolled to a 4 mm to 15 mm thick gauge (e.g., from 5 mm to 12 mm thick gauge), which is referred to as a shate. For example, the aluminum alloy product can be hot rolled to a 15 mm thick gauge, a 14 mm thick gauge, a 13 mm thick gauge, a 12 mm thick gauge, a 11 mm thick gauge, a 10 mm thick gauge, a 9 mm thick gauge, a 8 mm thick gauge, a 7 mm thick gauge, a 6 mm thick gauge, or a 5 mm thick gauge, or anywhere in between.

[0078] In certain other embodiments, the aluminum alloy product can be hot rolled to a gauge greater than 15 mm thick (i.e., a plate). For example, the aluminum alloy product can be hot rolled to a 25 mm thick gauge, a 24 mm thick gauge, a 23 mm thick gauge, a 22 mm thick gauge, a 21 mm thick gauge, a 20 mm thick gauge, a 19 mm thick gauge, a 18 mm thick gauge, a 17 mm thick gauge, or a 16 mm thick gauge, or any suitable gauge in between or above 25 mm thick.

[0079] In other cases, the aluminum alloy product can be hot rolled to a gauge no more than 4 mm (i.e., a sheet). In some embodiments, the aluminum alloy product is hot rolled to a 1 mm to 4 mm thick gauge, which is referred to as a sheet. For example, the aluminum alloy product can be hot rolled to a 4 mm thick gauge, a 3 mm thick gauge, a 2 mm thick gauge, or a 1 mm thick gauge, or anywhere in between.

Cold Rolling and Annealing and Further Rolling

[0080] Following the hot rolling, one or more cold rolling passes are performed. In certain embodiments, the rolled product from the hot rolling step (e.g., the plate, shate, or sheet) can be cold rolled to a thin gauge shate or sheet. In some embodiments, this thin-gauge shate or sheet is cold rolled to have a thickness (i.e., a first thickness) ranging from 1.0 mm to 12.0 mm, or from 2.0 mm to 8.0 mm, or from 3.0 mm to 6.0 mm, or from 4.0 mm to 5.0 mm. In some embodiments, this thin-gauge shate or sheet is cold rolled to have a thickness 12.0 mm, 11.9 mm, 11.8 mm, 11.7 mm, 11.6 mm, 11.5 mm, 11.4 mm, 11.3 mm, 11.2 mm, 11.1 mm, 11.0 mm, 10.9 mm, 10.8 mm, 10.7 mm, 10.6 mm, 10.5 mm, 10.4 mm, 10.3 mm, 10.2 mm, 10.1 mm, 10.0 mm, 9.9 mm, 9.8 mm, 9.7 mm, 9.6 mm, 9.5 mm, 9.4 mm, 9.3 mm, 9.2 mm, 9.1 mm, 9.0 mm, 8.9 mm, 8.8 mm, 8.7 mm, 8.6 mm, 8.5 mm, 8.4 mm, 8.3 mm, 8.2 mm, 8.1 mm, 8.0 mm, 7.9 mm, 7.8 mm, 7.7 mm, 7.6 mm, 7.5 mm, 7.4 mm, 7.3 mm, 7.2 mm, 7.1 mm, 7.0 mm, 6.9 mm, 6.8 mm, 6.7 mm, 6.6 mm, 6.5 mm, 6.4 mm, 6.3 mm, 6.2 mm, 6.1 mm, 6.0 mm, 5.9 mm, 5.8 mm, 5.7 mm, 5.6 mm, 5.5 mm, 5.4 mm, 5.3 mm, 5.2 mm, 5.1 mm, 5.0 mm, 4.9 mm, 4.8 mm, 4.7 mm, 4.6 mm, 4.5 mm, 4.4 mm, 4.3 mm, 4.2 mm, 4.1 mm, 4.0 mm, 3.9 mm, 3.8 mm, 3.7 mm, 3.6 mm, 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, or 1.0 mm, or anywhere in between.

[0081] In some embodiments, the one or more cold rolling passes reduce the thickness of rolled aluminum product by at least 30%, or at least 35%, or at least 40%, or at least 45%, or at least 50%, or at least 55%, or at least 60%, or at least 65%, or at least 70%. In some embodiments, the one or more cold rolling passes reduce the cast product to a thickness (i.e., a first thickness) of no more than 10 mm, or no more than 9 mm, or no more than 8 mm, or no more than 7 mm, or no more than 6 mm, or no more than 5 mm.

[0082] Following one or more cold rolling passes, annealing is performed. This can also be referred to as an intermediate annealing or inter-annealing, as it is performed in the middle of the rolling process, as one or more additional rolling passes are carried out after the annealing.

[0083] The annealing step can include heating the rolled aluminum product from room temperature to a temperature from 380 °C to 500 °C (e.g., from 385 °C to 495 °C, from 390 °C to 490 °C, from 395 °C to 485 °C, from 400 °C to 480 °C, from 405 °C to 475 °C, from 410 °C to 470 °C, from 415 °C to 465 °C, from 420 °C to 460 °C, from 425 °C to 455 °C, from 430 °C to 460 °C, from 380 °C to 450 °C, from 405 °C to 475 °C, or from 430 °C to 500 °C).

[0084] This intermediate annealing step can, for example, lead to certain beneficial texture features in the resulting article. In particular, the intermediate annealing assists in the formation of the recrystallized microstructure on surface of the article and the recovered and/or unrecrystallized structure in the middle of the article. In some examples, the texture on surface of the article will be dominated by recrystallization components, including cube, cube_ND, and cube_RD, rather than deformation type components, such as Bs, S, and Cu. Therefore, the bending performance of the article is improved without reducing the strength.

[0085] The plate, shate, or sheet can soak at the intermediate annealing temperature for a period of time. In one non-limiting example, the plate, shate, or sheet is allowed to soak for up to approximately 2 hours (e.g., from about 15 to about 120 minutes, inclusively). For example, the plate, shate, or sheet can be soaked at the temperature of from about 400 °C to about 500 °C for 15 minutes, 20 minutes, 25 minutes, 30 minutes, 35 minutes, 40 minutes, 45 minutes, 50 minutes, 55 minutes, 60 minutes, 65 minutes, 70 minutes, 75 minutes, 80 minutes, 85 minutes, 90 minutes, 95 minutes, 100 minutes, 105 minutes, 110 minutes, 115 minutes, or 120 minutes, or anywhere in between.

[0086] In some embodiments, the intermediate annealing of the rolled aluminum alloy product is carried out at a temperature of no more than 45 °C, or no more than 40 °C, or no more than 35 °C, or no more than 30 °C, or no more than 25 °C, or no more than 20 °C, or no more than 15 °C, or no more than 10 °C, above the minimum recrystallization temperature of the aluminum alloy. In some embodiments, the intermediate annealing of the rolled aluminum alloy product is carried out at a temperature above the minimum recrystallization temperature of the aluminum alloy for no more than 3.0 hours, or no more than 2.5 hours, or no more than 2.0 hours, or no more than 1.5 hours, or no more than 1.0 hours.

[0087] The intermediate annealing comprises multiple annealing sub-steps. The annealing is carried out at a first temperature above the minimum recrystallization temperature for a first period of time and at a second temperature above the minimum recrystallization temperature for a second period of time The first temperature above the minimum recrystallization temperature is greater than the second temperature above the minimum recrystallization temperature. Annealing may, for example, subject the surface portions to higher temperature annealing conditions at earlier times than the intermediate portion. By using a two (or more) step intermediate annealing process in which the temperature at the second step is lower than that at the first step, the surface portions of the rolled aluminum alloy product may be subjected to recrystallization conditions for longer periods of time than the intermediate portion. This may also occur in a single step intermediate annealing process in which a single annealing temperature is used, but the effect may be more pronounced in a multiple step annealing process.

[0088] Following the intermediate annealing, further rolling is performed, such as cold rolling. In some embodiments, one or more additional cold rolling passes are performed. This additional rolling brings the aluminum alloy product to a final thickness (i.e., a second thickness). In some embodiments, the final thickness ranges from 0.1 mm to 4.0 mm. In some embodiments, the final thickness is 4.0 mm, 3.9 mm, 3.8 mm, 3.7 mm, 3.6 mm, 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, 0.5 mm, 0.4 mm, 0.3 mm, 0.2 mm, or 0.1 mm. In some further such embodiments, the final thickness is no more than 4.0 mm, or no more than 3.5 mm, or no more than 3.0 mm, or no more than 2.5 mm, or no more than 2.0 mm, or no more than 1.5 mm, or no more than 1.0 mm, or no more than 0.5 mm, or no more than 0.3 mm, or no more than 0.1 mm.

Finishing Steps

[0089] Optionally, following the intermediate annealing and/or the additional rolling, additional finishing steps can be carried out, including, but not limited to, one or more of solutionizing, quenching, ageing, and coiling.

[0090] In some embodiments, a solution heat treatment step can be carried out. The solution heat treatment step can include heating the aluminum alloy product from room temperature to a temperature of from 430 °C to 500 °C. For example, the solution heat treatment step can include heating the aluminum alloy product from room temperature to a temperature of from 440 °C to 500 °C, from 460 °C to 500 °C, or from 480 °C to 490 °C. In some examples, the heating rate for the solution heat treatment step can be from 250 °C/hour to 350 °C/hour (e.g., 250 °C/hour, 255 °C/hour, 260 °C/hour, 265 °C/hour, 270 °C/hour, 275 °C/hour, 280 °C/hour, 285 °C/hour, 290 °C/hour, 295 °C/hour, 300 °C/hour, 305 °C/hour, 310 °C/hour, 315 °C/hour, 320 °C/hour, 325 °C/hour, 330 °C/hour, 335 °C/hour, 340 °C/hour, 345 °C/hour, or 350 °C/hour).

[0091] In some embodiments, the aluminum alloy product can then be cooled to a temperature of about 25 °C at a quench speed that can vary between about 50 °C/s to 400 °C/s in a quenching step that is based on the selected gauge. For example, the quench rate can be from about 50 °C/s to about 375 °C/s, from about 60 °C/s to about 375 °C/s, from about 70 °C/s to about 350 °C/s, from about 80 °C/s to about 325 °C/s, from about 90 °C/s to about 300 °C/s, from about 100 °C/s to about 275 °C/s, from about 125 °C/s to about 250 °C/s, from about 150 °C/s to about 225 °C/s, or from about 175 °C/s to about 200 °C/s.

[0092] In the quenching step, the aluminum alloy product is rapidly quenched with a liquid (e.g., water) and/or gas or another selected quench medium. In certain aspects, the aluminum alloy product can be rapidly quenched with water. In certain embodiments, the aluminum alloy product is quenched with air.

[0093] In some embodiments, the aluminum alloy product can be artificially aged for a period of time to result in the T6 or T7 temper. In certain embodiments, the aluminum alloy product can be artificially aged (AA) at about 100 °C to 225 °C (e.g., 100 °C, 105 °C, 110 °C, 115 °C, 120 °C, 125 °C, 130 °C, 135 °C, 140 °C, 145 °C, 150 °C, 155 °C, 160 °C, 165 °C, 170 °C, 175 °C, 180 °C, 185 °C, 190 °C, 195 °C, 200 °C, 205 °C, 210 °C, 215 °C, 220 °C, or 225 °C) for a period of time. Optionally, the aluminum alloy product can be cold worked and artificially aged for a period from about 15 minutes to about 48 hours (e.g., 15 minutes, 30 minutes, 1 hour, 2 hours, 3 hours, 4 hours, 5 hours, 6 hours, 7 hours, 8 hours, 9 hours, 10 hours, 11 hours, 12 hours, 13 hours, 14 hours, 15 hours, 16 hours, 17 hours, 18 hours, 19 hours, 20 hours, 21 hours, 22 hours, 23 hours, 24 hours, 25 hours, 26 hours, 27 hours, 28 hours, 29 hours, 30 hours, 31 hours, 32 hours, 33 hours, 34 hours, 35 hours, 36 hours, 37 hours, 38 hours, 39 hours, 40 hours, 41 hours, 42 hours, 43 hours, 44 hours, 45 hours, 46 hours, 47 hours, or 48 hours, or anywhere in between).

[0094] In some embodiments, an annealing step during or after production can also be applied to produce the aluminum alloy product in a coil form for improved productivity or formability. For example, an alloy in coil form can be supplied in the O temper, using a hot or cold rolling step and an annealing step following the hot or cold rolling step. Forming may occur in O temper, which is followed by solution heat treatment, quenching and artificial aging/paint baking.

[0095] In certain aspects, to produce an aluminum alloy product in coil form and with high formability compared to F temper, an annealing step can be applied to the coil. Without intending to limit the invention, the purpose for the annealing and the annealing parameters may include (1) releasing the work-hardening in the material to gain formability; (2) recrystallizing or recovering the material without causing significant grain growth; (3) engineering or converting texture to be appropriate for forming and for reducing anisotropy during formability; and (4) avoiding the coarsening of pre-existing precipitation particles.

[0096] In one or more aspects, the disclosure provides aluminum alloy articles formed by the processes set forth above, or any embodiments thereof.

Articles of Manufacture

[0097] Described herein is an article of manufacture, which is comprised of an aluminum alloy product disclosed herein. The article of manufacture is comprised of a rolled aluminum alloy product. Examples of such articles of manufacture include, but are not limited to, an automobile, a truck, a trailer, a train, a railroad car, an airplane, a body panel or part for any of the foregoing, a bridge, a pipeline, a pipe, a tubing, a boat, a ship, a storage container, a storage tank, a an article of furniture, a window, a door, a railing, a functional or decorative architectural piece, a pipe railing, an electrical component, a conduit, a beverage container, a food container, or a foil.

[0098] In some other embodiments, the aluminum alloy articles disclosed herein can be used in automotive and/or transportation applications, including motor vehicle, aircraft, and railway applications, or any other desired application. In some examples, the aluminum alloy products disclosed herein can be used to prepare motor vehicle body part products, such as bumpers, side beams, roof beams, cross beams, pillar reinforcements (e.g., A-pillars, B-pillars, and C-pillars), inner panels, outer panels, side panels, inner hoods, outer hoods, or trunk lid panels. The aluminum alloys and methods according to the invention can also be used in aircraft or railway vehicle applications, to prepare, for example, external and internal panels.

[0099] In some other embodiments, the aluminum alloy articles disclosed herein can be used in electronics applications. For example, the aluminum alloy products disclosed herein can also be used to prepare housings for electronic devices, including mobile phones and tablet computers. In some examples, the alloys can be used to prepare housings for the outer casing of mobile phones (e.g., smart phones) and tablet bottom chassis.

[0100] In some other embodiments, the aluminum alloy articles disclosed herein can be used in industrial applications. For example, the aluminum alloy products disclosed herein can be used to prepare products for the general distribution market.

[0101] In some other embodiments, the aluminum alloy articles disclosed herein can be used as aerospace body parts. For example, the aluminum alloy articles disclosed herein can be used to prepare structural aerospace body parts, such as a wing, a fuselage, an aileron, a rudder, an elevator, a cowling, or a support. In some other embodiments, the aluminum alloy articles disclosed herein can be used to prepare non-structural aerospace body parts, such as a seat track, a seat frame, a panel, or a hinge.

[0102] The following examples serve to further illustrate certain embodiments of the present disclosure without, at the same time, however, constituting any limitation thereof.

EXAMPLE 1 - Alloy Compositions

[0103] Six aluminum alloys (A1/Alloy A1, A2/Alloy A2, A3/Alloy A3, A4/Alloy A4, A5/Alloy A5, and A6/Alloy A6) were prepared, whose elemental composition is set forth in Table 3 below. The elemental compositions are provided in weight percentages.

Table 3

Allo y	Cr	Cu	Fe	Ga	Mg	Mn	Ni	Si	Ti	V	Zn	Zr	Al
A1	0.0 3	1.1 3	0.1 8	0.01	2.2 5	0.0 3	0.00 3	0.1 0	0.0 5	0.0 1	7.9 2	0.14	bal
A2	0.1 0	1.1 2	0.1 8	0.01	2.2 4	0.0 4	0.00 3	0.0 9	0.0 5	0.0 1	7.8 6	0.14	bal
A3	0.0 4	1.7 0	0.1 9	0.01	2.5 6	0.0 5	0.00 3	0.1 0	0.0 4	0.0 1	5.5 1	0.14	bal
A4	0.0 4	1.7 7	0.2 0	0.01	2.6 7	0.0 4	0.00 3	0.0 8	0.0 4	0.0 1	5.3 8	0.14	bal
A5	0.0 3	1.2 4	0.1 9	0.01 0	2.3 1	0.0 3	0.00 3	0.0 8	0.0 5	0.0 1	7.6 4	0.13	bal

(continued)

Allo y	Cr	Cu	Fe	Ga	Mg	Mn	Ni	Si	Ti	V	Zn	Zr	Al
A6	0.2 4	1.6 3	0.1 7	n/a	2.7 5	0.0 2	n/a	0.0 4	0.0 2	n/a	5.9 4	0.00 1	bal
All expressed in wt. %. n/a = not present or present in trace quantities (<0.0005 wt. %)													

EXAMPLE 2 - Manufacture of Aluminum Alloy Sheet

[0104] The test aluminum alloy sheets with chemical composition corresponding to Alloys A1-A6 from Table 3 (Example 1), were cast by Direct Chill (DC) casting. All were stress relieved and homogenized, and subsequently hot-rolled to a hot band having a gauge of 10.5 mm. Each was then subjected to cold rolling. For each, the hot band went through 2 passes of cold rolling from 10.5 mm to 6 mm and 4 mm, respectively.

[0105] Inter-annealing of Alloys A1, A2 and A3 was performed at 4.0 mm gauge, with a 50 °C/hr ramping rate to 410 °C, soaked for 60 minutes, then furnace cooled to 350 °C and soaked for 1200 minutes. The coils were allowed to cool to room temperature in air. A final cold rolling was then performed on these three samples, Alloys A1, A2, and A3. The coils were cold rolled to final gauge of 2.0 mm with 1 pass.

[0106] For Alloys A4, A5, and A6, the hot band of 10.5 mm gauge was cold rolled to 6.0 mm, then to 4.0 mm, then to 2.8 mm, and then to 2.0 mm, without any inter-annealing steps.

[0107] Solution heat treatment of test blanks of samples of Alloys A1-A6 were carried out, where the samples were heated up using a furnace to a PMT of 480 °C and soaked for 5 minutes, before being taken out of the furnace and quenched in warm water at 55 °C at a quench rate of around 350 °C/sec. Artificial aging of samples of Alloys A1-A6 was carried out using a furnace at 125 °C and soaked for 24 hours to bring the samples to T6 temper.

EXAMPLE 3 - Optical Microscopy and Scanning Electron Micrographs with EBSD

[0108] Optical microscopy (OM) was carried out for aluminum alloy sheets made of the alloys of Example 1, such as according to Example 2. FIG. 2 shows an optical micrograph (OM) of a cross-section of a sample of Alloy A1 that was lab rolled with inter-annealing, and which shows recovered and/or unrecrystallized microstructure through the thickness of the sample. FIG. 3A shows an optical micrograph (OM) of a cross-section of a sample of Alloy A1 that was plant rolled with inter-annealing. The sample of Alloy A1 of FIG. 3A includes a first surface portion 205, an intermediate portion 210, and a second surface portion 215.

[0109] "Plant Rolled" samples were cold-rolled according to standard plant cold rolling processes. "Lab Rolled" samples were cold-rolled in a laboratory setting from 10.5 mm to 2.0 mm by conducting 17 different passes, each of which reduced the thickness by about 0.5 mm.

[0110] FIG. 3B shows a surface portion from FIG. 3A, showing recrystallized microstructure, corresponding to at least a portion of first surface portion 205 or second surface portion 215. In FIG. 3B, the grain structure of the sample can be seen, with individual grains not spread significantly in the surface portion, indicating that the crystal structure has been recovered and/or is unrecrystallized by the inter-annealing process. FIG. 3C shows nine modified reduced-size versions of FIG. 3B, generated by reducing FIG. 3B to 9 individual colors in order to highlight various colors shown in FIG. 3B as black.

[0111] FIG. 3D shows a center section from FIG. 3A, showing recovered and/or unrecrystallized microstructure, corresponding to at least a portion of intermediate portion 210. In FIG. 3D, the remnants of grains that were significantly spread during the initial rolling process can be seen. The remnants do not all recrystallize during the inter-annealing process and many regions remain spread in the center portion, reflecting the recovered and/or unrecrystallized nature of the intermediate portion 210. FIG. 3E shows nine modified reduced-size versions of FIG. 3D, generated by reducing FIG. 3D to 9 individual colors in order to highlight various colors shown in FIG. 3D as black.

[0112] FIG. 4A shows an optical micrograph of a sample of Alloy A5 that was plant rolled without inter-annealing during the cold rolling process, showing spread grains as horizontal structures in FIG 4A. FIG. 4B shows a section from the center portion in FIG. 4A corresponding to at least a portion of the intermediate portion, showing recovered and/or unrecrystallized microstructure. FIG. 4C shows a surface portion from FIG. 4A, showing recrystallized microstructure.

[0113] Electron backscattering diffraction (EBSD) disorientation mapping was carried out on certain samples. Mapping of a cross-section of samples of Alloy A1 that were rolled to a final gauge and finished with a T6 temper is shown in FIGs. 5A, 5B, and 5C. The low angle boundaries (2-15) are marked as darker-color horizontal lines, while the medium to high angle boundaries (>15) are marked as lighter-color horizontal lines. FIG. 5A provides mapping for an Alloy A1 sample that was lab rolled, without inter-annealing during the cold rolling process, which has a uniform microstructure with recovered and/or unrecrystallized microstructure through the whole thickness, while FIG. 5B provides mapping for an Alloy A1 sample that was plant rolled, with inter-annealing during the cold rolling process, which shows the recrystallization microstructure near the surface and recovered and/or unrecrystallized microstructure in the center (i.e., intermediate portion). FIG. 5C shows mapping for an Alloy A5 sample that was plant rolled, without inter-annealing during the cold rolling process, which has a microstructure between that shown in FIG. 5A and FIG. 5B. Quantitative results from these images are presented in Table 4 below.

EXAMPLE 4 - Recrystallization Quotient

[0114] The recrystallization quotient (RQ) was calculated using the EBSD measurements described in Example 3. Orientation mapping was performed on a square grid across a cross-sectionally cut area. The mapped area was divided into three equally sized areas spanning the thickness of the sheet, and the recrystallization quotient was calculated for each area. Table 4 reports the values of the recrystallization quotient for each of the samples described in Example 3. The "Surface RQ" refers to RQ for the two surface areas (i.e., surface portions), "Center RQ" refers to the RQ for the center area (i.e., intermediate portion), and the "Overall RQ" refers to the RQ across the thickness of the entire sample. Note that "IA" refers to inter-annealing performed during the cold rolling process.

Table 4

Sample	Overall RQ	Surface RQ	Center RQ
Alloy A1, Lab Processed	0.512	0.532	0.467
Alloy A1, Plant Rolled without IA	0.684	0.819	0.553
Alloy A5, Plant Rolled with IA	0.758	0.871	0.592

[0115] The "Plant Rolled" samples were cold-rolled according to standard plant cold rolling processes. The "Lab Rolled" sample was cold-rolled in a laboratory setting from 10.5 mm to 2.0 mm by conducting 17 different passes, each of which reduced the thickness by about 0.5 mm.

EXAMPLE 5 - Bending

[0116] The bendability was measured for samples of aluminum alloy sheets prepared according to Example 2. The bendability for the samples was measured according to Spec VDA-238-100. The samples were tested in the longitudinal and transverse directions in T6 temper. FIG. 6 shows the 3-point bend results of Alloys A1, A2, A5 (without IA) and a sample of AA7075 sheet. The angle reported was β angle, thus the lower the better. For Alloys A1 and A2, the left bar is for the longitudinal direction and the right bar is for the transverse direction. For Alloys A5 and the AA7076 sample, only the longitudinal direction is shown. All were tested in the T6 temper.

EXAMPLE 6 - Exfoliation Corrosion

[0117] The exfoliation corrosion (EXCO) was measured for certain aluminum alloy sheets prepared according to Example 2. The EXCO was measured according to the procedure set forth in ASTM-G34, which involved the continuous immersion of test materials in a solution containing 4 M sodium chloride, 0.5 M potassium nitrate, and 0.1 M nitric acid at 25 ± 3 °C. The susceptibility to exfoliation was determined by visual examination, with performance ratings established by reference to standard photographs (see the G34 test procedure). Visual examination was conducted, along with longitudinal cross-section metallographic examination. FIGs. 7A-7E show photographs of tested aluminum alloy sheets, as identified in Table 5 below.

Table 5

Sample	Figure No.
Alloy A1, Plant Processed without IA	7A
Alloy A2, Plant Processed without IA	7B
Alloy A6, Plant Processed without IA	7C
Alloy A1, Lab Processed with IA	7D
Alloy A2, Lab Processed with IA	7E

EXAMPLE 7 - Yield Strength

[0118] The yield strength was measured for certain aluminum alloy sheets prepared according to Example 2. The yield strength was tested in accordance to ASTM E8 with 2" standard gauge length. FIG. 8 shows the results of yield strength testing on certain samples, where L, T, and D stand for longitudinal, transverse and diagonal, respectively, with respect to rolling direction. For Alloy A1, Alloy A2, Alloy A3, and Alloy A6, the three bars show the results of testing in the longitudinal, transverse, and diagonal directions, respectively, from left to right. For Alloy A5, the two bars show the results of testing in the longitudinal and transverse directions, respectively, from left to right.

[0119] 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 of ordinary skill in the art without departing from the scope of the invention as defined in the following claims.

Claims

1. A method of making an aluminum alloy article, the method comprising:

casting an aluminum alloy to form an aluminum alloy cast product;
homogenizing the aluminum alloy cast product to form a homogenized aluminum alloy cast product;
subjecting the homogenized aluminum alloy cast product to a first rolling process to form a first rolled aluminum alloy product having a first thickness, wherein the first rolling process comprises one or more hot rolling passes followed by one or more cold rolling passes;
annealing the first rolled aluminum alloy product at a temperature of not more than 50 °C above a minimum recrystallization temperature of the aluminum alloy to form a first annealed aluminum alloy product; and
subjecting the first annealed aluminum alloy product to a second rolling process to form a second rolled aluminum alloy product having a second thickness,
wherein the annealing is carried out at a first temperature above the minimum recrystallization temperature for a first period of time and at a second temperature above the minimum recrystallization temperature for a second period of time, wherein the first temperature above the minimum recrystallization temperature is greater than the second temperature above the minimum recrystallization temperature, and

wherein the aluminum alloy is a 7xxx series aluminum alloy.

2. The method of claim 1, wherein the first thickness is no more than 10 mm and/or,

wherein the annealing is carried out at the temperature above the minimum recrystallization temperature for no more than 3.0 hours and/or,
wherein the second thickness is no more than 4.0 mm.

3. The method of any one of claims 1 or 2, wherein the second rolled aluminum alloy product comprises:

a first surface portion, wherein the first surface portion comprises a first rolled surface, and wherein the first surface portion has a first recrystallization quotient;
a second surface portion opposing the first surface portion, wherein the second surface portion comprises a second rolled surface, and wherein the second surface portion has a second recrystallization quotient; and
an intermediate portion positioned between the first surface portion and the second surface portion, wherein the intermediate portion has a third recrystallization quotient, and wherein the third recrystallization quotient is less than at least one of the first recrystallization quotient or the second recrystallization quotient.

4. The method of claim 3, wherein the first recrystallization quotient is between 0.50 and 1.0, wherein the second recrystallization quotient is between 0.50 and 1.0, or wherein the third recrystallization quotient is between 0.01 and 0.65 and/or,
wherein the first surface portion extends from a first surface of the first surface portion to a first depth less than 40% of a thickness of the second rolled aluminum alloy product, and wherein the second surface portion extends from a second surface of the second surface portion to a second depth less than 40% of the thickness of the second rolled aluminum alloy product.

5. An aluminum alloy article comprising an aluminum alloy material, the aluminum alloy material comprising:

a first surface portion, wherein the first surface portion comprises a first rolled surface, and wherein the first surface portion has a first recrystallization quotient;
a second surface portion opposing the first surface portion, wherein the second surface portion comprises a second rolled surface, and wherein the second surface portion has a second recrystallization quotient; and
an intermediate portion positioned between the first surface portion and the second surface portion, wherein the intermediate portion has a third recrystallization quotient, and wherein the third recrystallization quotient is less than at least one of the first recrystallization quotient or the second recrystallization quotient,
wherein a recrystallization quotient corresponds to a percentage or fractional amount, volume, or mass of a portion of the aluminum alloy material that is recrystallized as compared to a total amount, volume, or mass of the portion of the aluminum alloy material,

wherein the aluminum alloy material is a 7xxx series aluminum alloy and
wherein both of the first rolled surface and the second rolled surface are formed by a process that comprises cold rolling.

6. The aluminum alloy article of claim 5, wherein the first surface portion extends from a surface of the first surface portion to a first depth of no more than 40.0% of a thickness of the aluminum alloy article.

7. The aluminum alloy article of claim 6, wherein the second surface portion extends from a surface of the second surface portion to a second depth of no more than 40.0% of the thickness of the aluminum alloy article.

8. The aluminum alloy article of any one of claims 5 to 7, wherein the intermediate portion extends from a first depth of the first surface portion to a second depth of the second surface portion.

9. The aluminum alloy article of claim 5, wherein the first recrystallization quotient is at least 0.50, wherein the second recrystallization quotient is at least 0.50, or wherein the third recrystallization quotient is no more than 0.65.

10. The aluminum alloy article of any one of claims 5 to 9, having a β angle of between 100° and 138° for bendability testing according to Specification VDA 238-100 and/or,
having an exfoliation corrosion rating of EA for exfoliation corrosion testing according to ASTM Test No. G34-01.

11. The aluminum alloy article of any one of claims 5 to 10, wherein the first surface portion extends from a first surface of the first surface portion to a first depth less than 40% of a thickness of the aluminum alloy article, and wherein the second surface portion extends from a second surface of the second surface portion to a second depth less than 40% of the thickness of the aluminum alloy article.

Patentansprüche

1. Verfahren zum Herstellen eines Aluminiumlegierungsgegenstands, wobei das Verfahren umfasst:

Gießen einer Aluminiumlegierung, um ein Aluminiumlegierungsgussprodukt zu bilden;
Homogenisieren des Aluminiumlegierungsgussprodukts, um ein homogenisiertes Aluminiumlegierungsgussprodukt zu bilden;
Unterziehen des homogenisierten Aluminiumlegierungsgussprodukts einem ersten Walzprozess, um ein erstes gewalztes Aluminiumlegierungsprodukt mit einer ersten Dicke zu bilden, wobei der erste Walzprozess einen oder mehrere Warmwalzstiche gefolgt von einem oder mehreren Kaltwalzstichen umfasst;
Tempern des ersten gewalzten Aluminiumlegierungsprodukts bei einer Temperatur von nicht mehr als 50 °C über einer minimalen Rekristallisationstemperatur der Aluminiumlegierung, um ein erstes getempertes Aluminiumlegierungsprodukt zu bilden; und
Unterziehen des ersten getemperten Aluminiumlegierungsprodukts einem zweiten Walzprozess, um ein zweites gewalztes Aluminiumlegierungsprodukt mit einer zweiten Dicke zu bilden,
wobei das Tempern bei einer ersten Temperatur oberhalb der minimalen Rekristallisationstemperatur für eine erste Zeitperiode und bei einer zweiten Temperatur oberhalb der minimalen Rekristallisationstemperatur für eine zweite Zeitperiode durchgeführt wird, wobei die erste Temperatur oberhalb der minimalen Rekristallisationstemperatur größer ist als die zweite Temperatur oberhalb der minimalen Rekristallisationstemperatur, und

wobei die Aluminiumlegierung eine Aluminiumlegierung der Serie 7xxx ist.

2. Verfahren nach Anspruch 1, wobei die erste Dicke nicht mehr als 10 mm beträgt und/oder

wobei das Tempern bei einer Temperatur oberhalb der minimalen Rekristallisationstemperatur für nicht mehr als 3,0 Stunden durchgeführt wird und/oder
wobei die zweite Dicke nicht mehr als 4,0 mm beträgt.

3. Verfahren nach einem der Ansprüche 1 oder 2, wobei das zweite gewalzte Aluminiumlegierungsprodukt umfasst:

einen ersten Oberflächenabschnitt, wobei der erste Oberflächenabschnitt eine erste gewalzte Oberfläche umfasst, und wobei der erste Oberflächenabschnitt einen ersten Rekristallisationsquotienten aufweist;
einen zweiten Oberflächenabschnitt, dem ersten Oberflächenabschnitt gegenüberliegend, wobei der zweite Oberflächenabschnitt eine zweite gewalzte Oberfläche umfasst, und wobei der zweite Oberflächenabschnitt einen zweiten Rekristallisationsquotienten aufweist; und
einen intermediären Abschnitt, welcher zwischen dem ersten Oberflächenabschnitt und dem zweiten Oberflächenabschnitt positioniert ist, wobei der intermediäre Abschnitt einen dritten Rekristallisationsquotienten aufweist, und
wobei der dritte Rekristallisationsquotient kleiner ist als mindestens einer von dem ersten Rekristallisationsquotienten oder dem zweiten Rekristallisationsquotienten.

4. Verfahren nach Anspruch 3, wobei der erste Rekristallisationsquotient zwischen 0,50 und 1,0 beträgt, wobei der zweite Rekristallisationsquotient zwischen 0,50 und 1,0 beträgt, oder wobei der dritte Rekristallisationsquotient zwischen 0,01 und 0,65 beträgt und/oder
wobei sich der erste Oberflächenabschnitt von einer ersten Oberfläche des ersten Oberflächenabschnitts zu einer ersten Tiefe von weniger als 40 % einer Dicke des zweiten gewalzten Aluminiumlegierungsprodukts erstreckt, und wobei sich der zweite Oberflächenabschnitt von einer zweiten Oberfläche des zweiten Oberflächenabschnitts zu einer zweiten Tiefe von weniger als 40 % der Dicke des zweiten gewalzten Aluminiumlegierungsprodukts erstreckt.

5. Aluminiumlegierungsgegenstand, umfassend ein Aluminiumlegierungsmaterial, wobei das Aluminiumlegierungsmaterial umfasst:

einen ersten Oberflächenabschnitt, wobei der erste Oberflächenabschnitt eine erste gewalzte Oberfläche umfasst, und wobei der erste Oberflächenabschnitt einen ersten Rekristallisationsquotienten aufweist;
einen zweiten Oberflächenabschnitt, dem ersten Oberflächenabschnitt gegenüberliegend, wobei der zweite Oberflächenabschnitt eine zweite gewalzte Oberfläche umfasst, und wobei der zweite Oberflächenabschnitt einen zweiten Rekristallisationsquotienten aufweist; und
einen intermediären Abschnitt, welcher zwischen dem ersten Oberflächenabschnitt und dem zweiten Oberflächenabschnitt positioniert ist, wobei der intermediäre Abschnitt einen dritten Rekristallisationsquotienten aufweist, und wobei der dritte Rekristallisationsquotient kleiner ist als mindestens einer von dem ersten Rekristallisationsquotienten oder dem zweiten Rekristallisationsquotienten,
wobei ein Rekristallisationsquotient einer prozentualen oder fraktionalen Menge, Volumen oder Masse eines Abschnitts des Aluminiumlegierungsmaterials entspricht, welches im Vergleich zu einer Gesamtmenge, -volumen oder -masse des Abschnitts des Aluminiumlegierungsmaterials rekristallisiert ist,
wobei das Aluminiumlegierungsmaterial eine Aluminiumlegierung der Serie 7xxx ist und
wobei sowohl die erste gewalzte Oberfläche als auch die zweite gewalzte Oberfläche durch einen Prozess gebildet werden, welcher Kaltwalzen umfasst.

6. Aluminiumlegierungsgegenstand nach Anspruch 5, wobei sich der erste Oberflächenabschnitt von einer Oberfläche des ersten Oberflächenabschnitts zu einer ersten Tiefe von nicht mehr als 40,0 % einer Dicke des Aluminiumlegierungsgegenstands erstreckt.

7. Aluminiumlegierungsgegenstand nach Anspruch 6, wobei sich der zweite Oberflächenabschnitt von einer Oberfläche des zweiten Oberflächenabschnitts zu einer zweiten Tiefe von nicht mehr als 40,0 % der Dicke des Aluminiumlegierungsgegenstands erstreckt.

8. Aluminiumlegierungsgegenstand nach einem der Ansprüche 5 bis 7, wobei sich der intermediäre Abschnitt von einer ersten Tiefe des ersten Oberflächenabschnitts zu einer zweiten Tiefe des zweiten Oberflächenabschnitts erstreckt.

9. Aluminiumlegierungsgegenstand nach Anspruch 5, wobei der erste Rekristallisationsquotient mindestens 0,50 beträgt, wobei der zweite Rekristallisationsquotient mindestens 0,50 beträgt, oder wobei der dritte Rekristallisationsquotient nicht mehr als 0,65 beträgt.

10. Aluminiumlegierungsgegenstand nach einem der Ansprüche 5 bis 9 mit einem β-Winkel zwischen 100° und 138° für die Biegbarkeitsprüfung gemäß der Spezifikation VDA 238-100 und/oder
mit einer Bewertung der Abblätterungskorrosion von EA für die Prüfung der Abblätterungskorrosion nach dem ASTM-Test Nr. G34-01.

11. Aluminiumlegierungsgegenstand nach einem der Ansprüche 5 bis 10, wobei sich der erste Oberflächenabschnitt von einer ersten Oberfläche des ersten Oberflächenabschnitts zu einer ersten Tiefe von weniger als 40 % einer Dicke des Aluminiumlegierungsgegenstands erstreckt, und wobei sich der zweite Oberflächenabschnitt von einer zweiten Oberfläche des zweiten Oberflächenabschnitts zu einer zweiten Tiefe von weniger als 40 % der Dicke des Aluminiumlegierungsgegenstands erstreckt.

Revendications

1. Procédé de fabrication d'un article en alliage d'aluminium, le procédé comprenant les étapes consistant à :

couler un alliage d'aluminium pour former un produit coulé en alliage d'aluminium ;
homogénéiser le produit coulé en alliage d'aluminium pour former un produit coulé en alliage d'aluminium homogénéisé ;
soumettre le produit coulé en alliage d'aluminium homogénéisé à un premier processus de laminage pour former un premier produit en alliage d'aluminium laminé ayant une première épaisseur, dans lequel le premier processus de laminage comprend une ou plusieurs passes de laminage à chaud suivies par une plusieurs passes de laminage à froid ;
recuire le premier produit en alliage d'aluminium laminé à une température ne dépassant pas 50 °C au-dessus d'une température de recristallisation minimale de l'alliage d'aluminium pour former un premier produit en alliage d'aluminium recuit ; et
soumettre le premier produit en alliage d'aluminium recuit à un second processus de laminage pour former un second produit en alliage d'aluminium laminé ayant une seconde épaisseur,
dans lequel le recuit est exécuté à une première température supérieure à la température de recristallisation minimale pendant une première période de temps et à une seconde température supérieure à la température de recristallisation minimale pendant une seconde période de temps, dans lequel la première température supérieure à la température de recristallisation minimale est supérieure à la seconde température supérieure à la température de recristallisation minimale, et
dans lequel l'alliage d'aluminium est un alliage d'aluminium de série 7xxx.

2. Procédé selon la revendication 1, dans lequel la première épaisseur est inférieure ou égale à 10 mm et/ou,

dans lequel le recuit est exécuté à la température supérieure à la température de recristallisation minimale pendant un temps ne dépassant pas 3,0 heures et/ou,
dans lequel la seconde épaisseur est inférieure ou égale à 4,0 mm.

3. Procédé selon l'une ou l'autre des revendications 1 et 2, dans lequel le second produit en alliage d'aluminium laminé comprend :

une première partie de surface, dans lequel la première partie de surface comprend une première surface laminée, et dans lequel la première partie de surface a un premier quotient de recristallisation ;
une seconde partie de surface opposée à la première partie de surface, dans lequel la seconde partie de surface comprend une seconde surface laminée, et dans lequel la seconde partie de surface a un deuxième quotient de recristallisation ; et
une partie intermédiaire positionnée entre la première partie de surface et la seconde partie de surface, dans lequel la partie intermédiaire a un troisième quotient de recristallisation, et dans lequel le troisième quotient de recristallisation est inférieur à au moins l'un du premier quotient de recristallisation ou du deuxième quotient de recristallisation.

4. Procédé selon la revendication 3, dans lequel le premier quotient de recristallisation est compris entre 0,50 et 1,0, dans lequel le deuxième quotient de recristallisation est compris entre 0,50 et 1,0, ou dans lequel le troisième quotient de recristallisation est compris entre 0,01 et 0,65 et/ou,
dans lequel la première partie de surface s'étend d'une première surface de la première partie de surface jusqu'à une première profondeur inférieure à 40 % d'une épaisseur du second produit en alliage d'aluminium laminé, et dans lequel la seconde partie de surface s'étend d'une seconde surface de la seconde partie de surface jusqu'à une seconde profondeur inférieure à 40 % de l'épaisseur du second produit en alliage d'aluminium laminé.

5. Article en alliage d'aluminium comprenant un matériau d'alliage d'aluminium, le matériau d'alliage d'aluminium comprenant :

une première partie de surface, dans lequel la première partie de surface comprend une première surface laminée, et dans lequel la première partie de surface a un premier quotient de recristallisation ;
une seconde partie de surface opposée à la première partie de surface, dans lequel la seconde partie de surface comprend une seconde surface laminée, et dans lequel la seconde partie de surface a un deuxième quotient de recristallisation ; et
une partie intermédiaire positionnée entre la première partie de surface et la seconde partie de surface, dans lequel la partie intermédiaire a un troisième quotient de recristallisation, et dans lequel le troisième quotient de recristallisation est inférieur à au moins l'un du premier quotient de recristallisation ou du deuxième quotient de recristallisation,
dans lequel un quotient de recristallisation correspond à un pourcentage ou à une quantité, un volume, ou une masse fractionnaire d'une partie du matériau d'alliage d'aluminium qui a été recristallisée par comparaison à une quantité, un volume, ou une masse total de la partie du matériau d'alliage d'aluminium,
dans lequel le matériau d'alliage d'aluminium est un alliage d'aluminium de série 7xxx, et
dans lequel la première surface laminée et la seconde surface laminée sont toutes les deux formées par un processus qui comprend un laminage à froid.

6. Article en alliage d'aluminium selon la revendication 5, dans lequel la première partie de surface s'étend d'une surface de la première partie de surface jusqu'à une première profondeur inférieure ou égale à 40,0 % d'une épaisseur de l'article en alliage d'aluminium.

7. Article en alliage d'aluminium selon la revendication 6, dans lequel la seconde partie de surface s'étend d'une surface de la seconde partie de surface jusqu'à une seconde profondeur inférieure ou égale à 40,0 % de l'épaisseur de l'article en alliage d'aluminium.

8. Article en alliage d'aluminium selon l'une quelconque des revendications 5 à 7, dans lequel la partie intermédiaire s'étend d'une première profondeur de la première partie de surface à une seconde profondeur de la seconde partie de surface.

9. Article en alliage d'aluminium selon la revendication 5, dans lequel le premier quotient de recristallisation est d'au moins 0,50, dans lequel le deuxième quotient de recristallisation est d'au moins 0,50, ou dans lequel le troisième quotient de recristallisation est de 0,65 au maximum.

10. Article en alliage d'aluminium selon l'une quelconque des revendications 5 à 9, ayant un angle β compris entre 100° et 138° en matière d'essai de flexion conformément à la Spécification VDA 238-100 et/ou,
ayant un taux de corrosion par exfoliation d'EA en matière d'essai de corrosion par exfoliation conformément à l'essai ASTM N° G34-01.

11. Article en alliage d'aluminium selon l'une quelconque des revendications 5 à 10, dans lequel la première partie de surface s'étend d'une première surface de la première partie de surface jusqu'à une première profondeur inférieure à 40 % d'une épaisseur de l'article en alliage d'aluminium, et dans lequel la seconde partie de surface s'étend d'une seconde surface de la seconde partie de surface jusqu'à une seconde profondeur inférieure à 40 % de l'épaisseur de l'article en alliage d'aluminium.

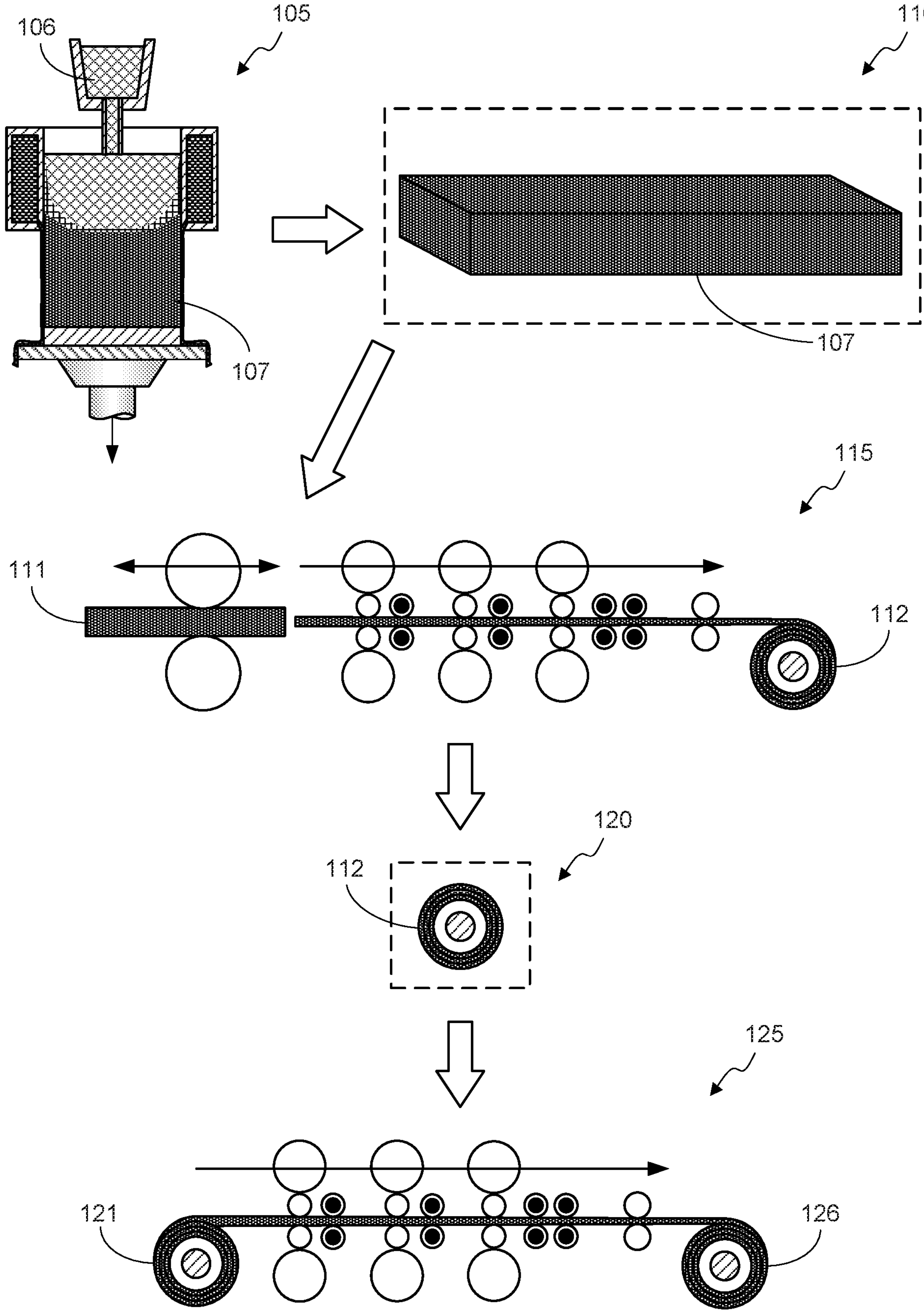


FIG. 1

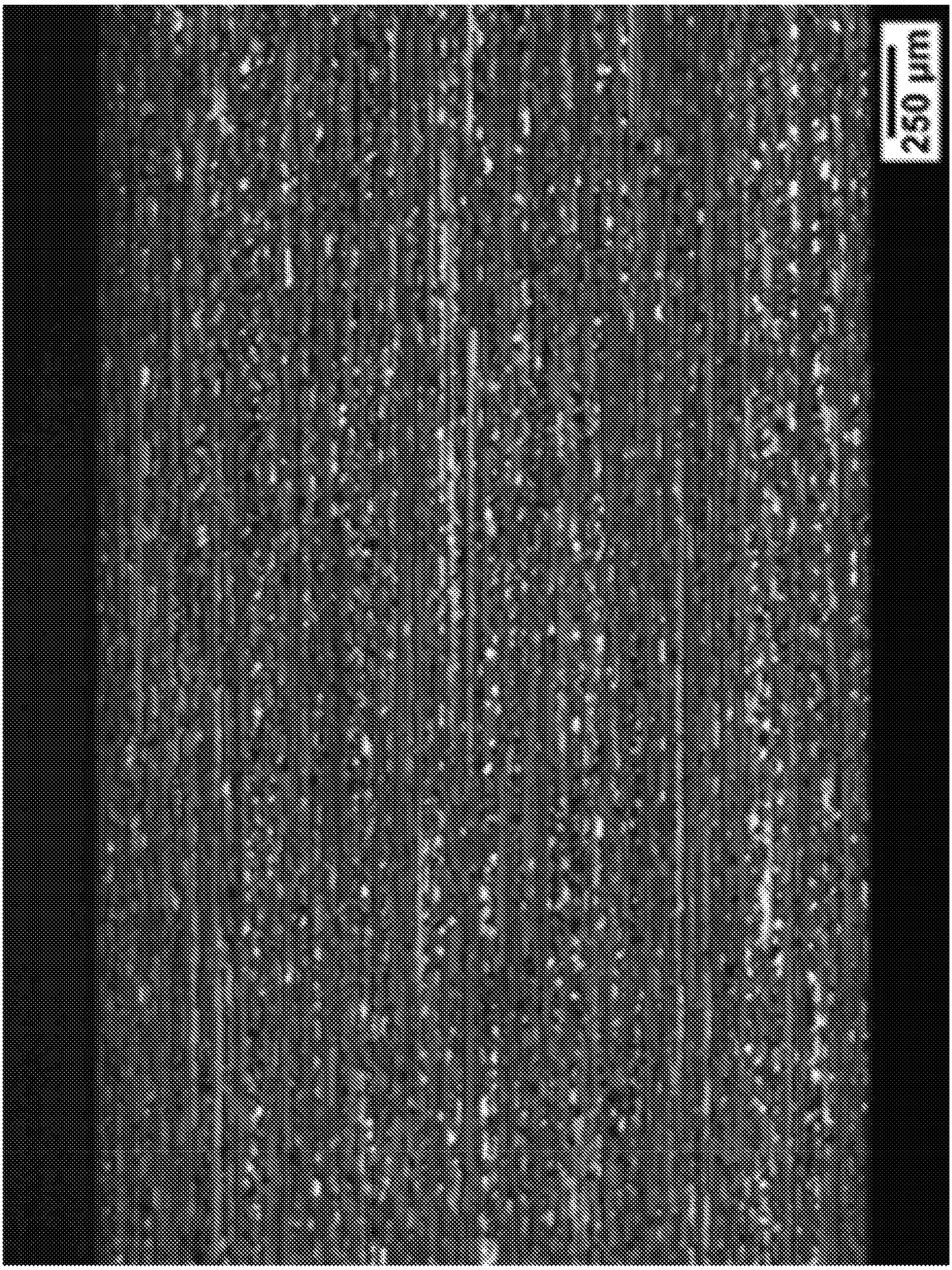


FIG. 2

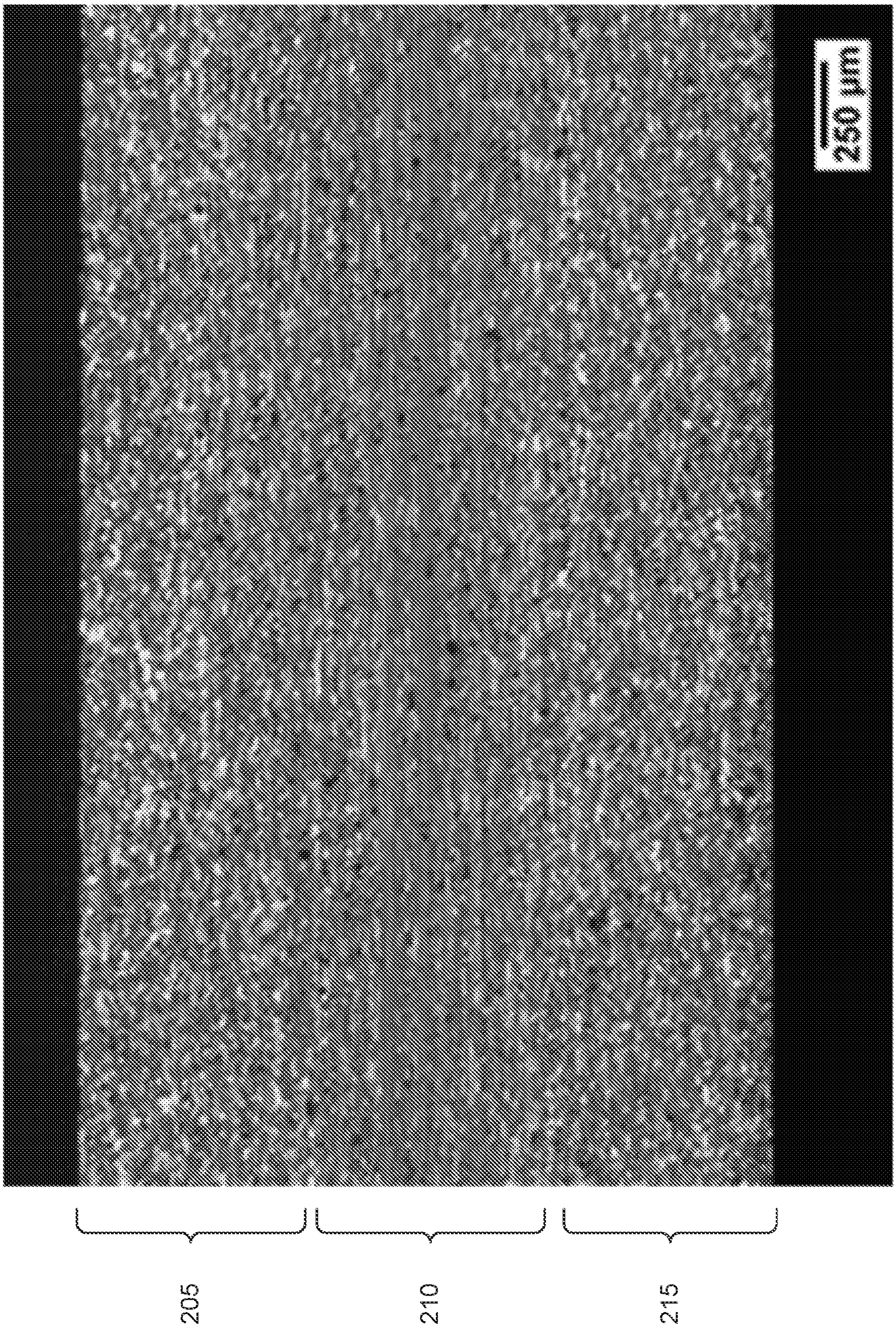


FIG. 3A

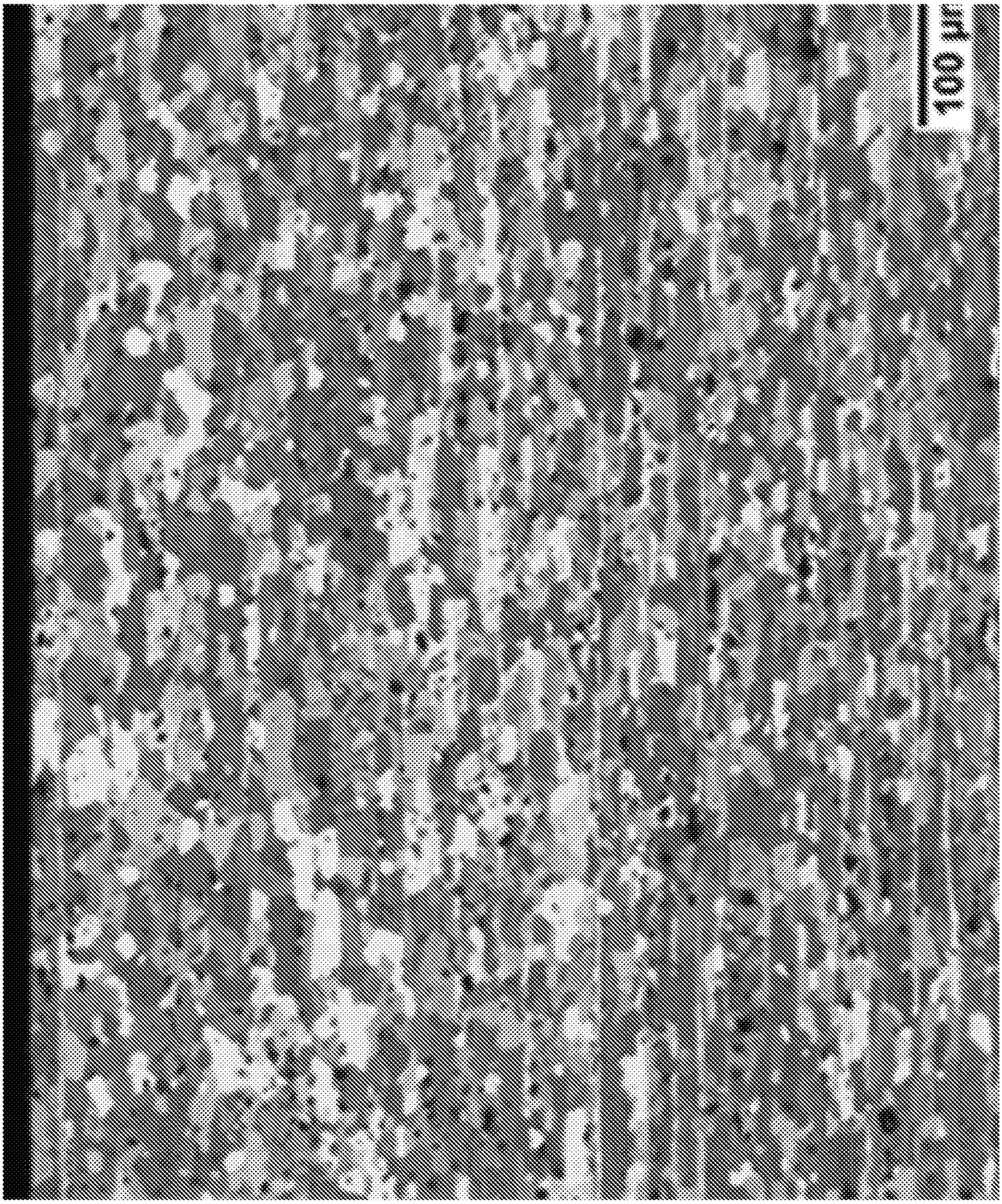


FIG. 3B

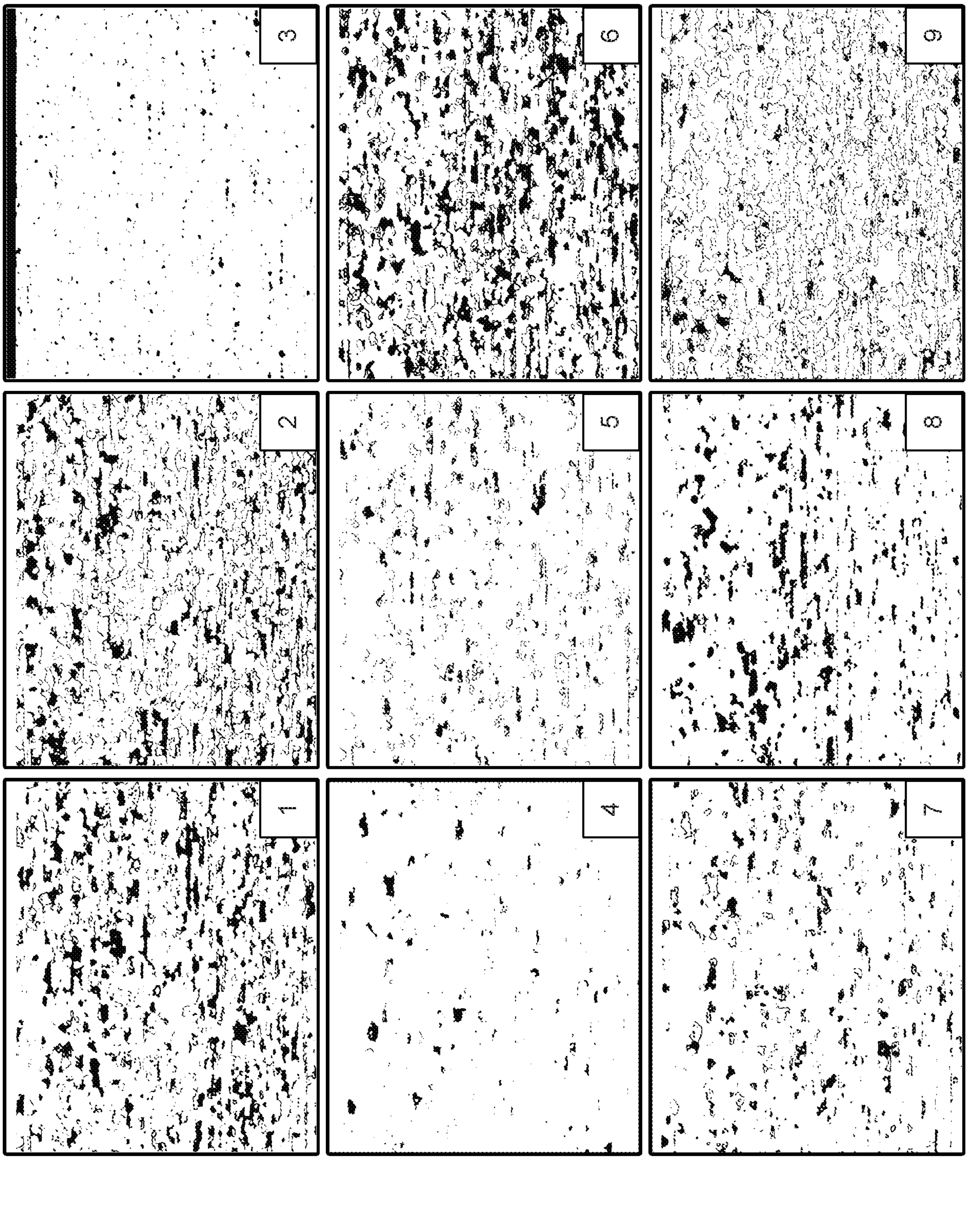


FIG. 3C

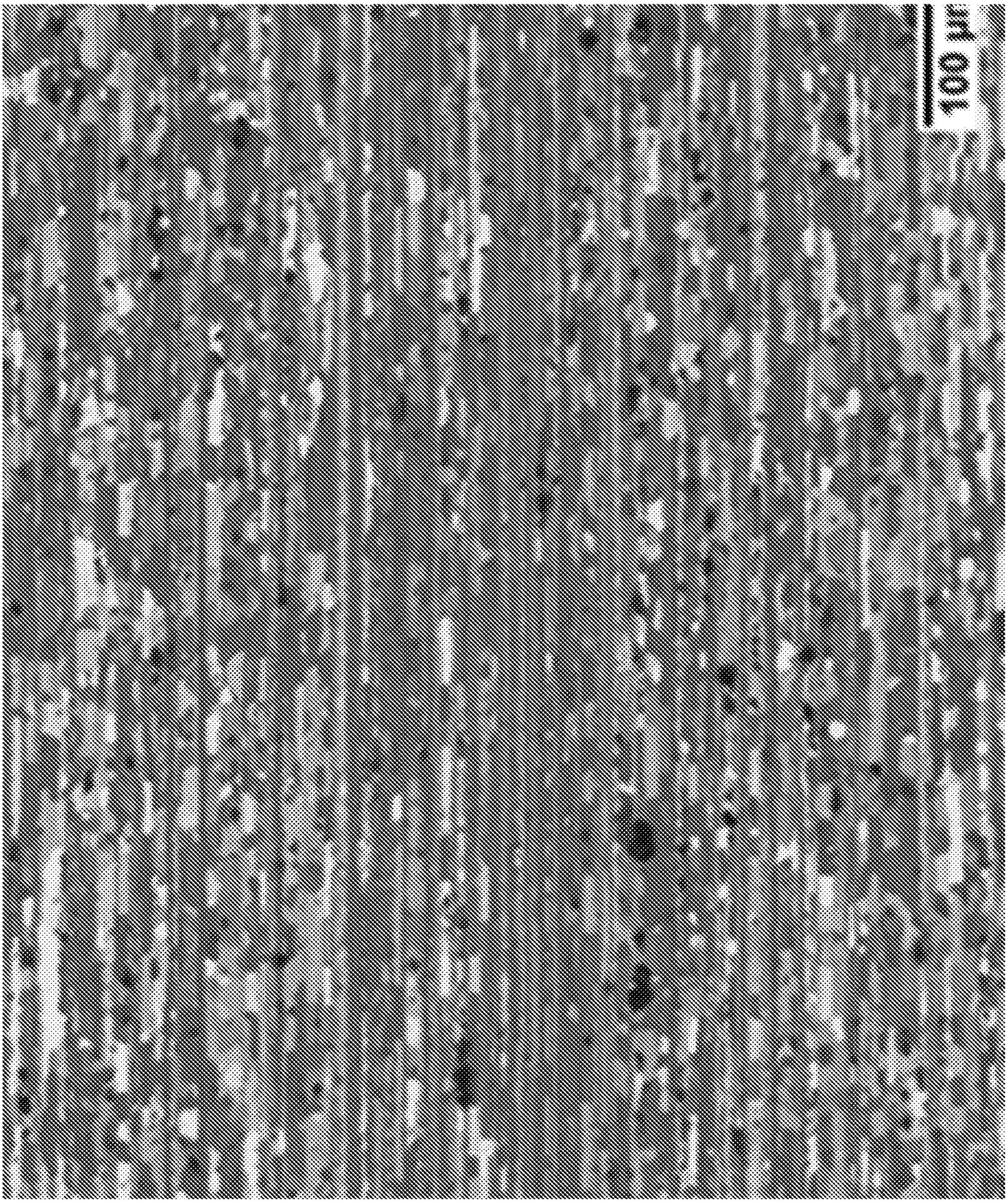


FIG. 3D

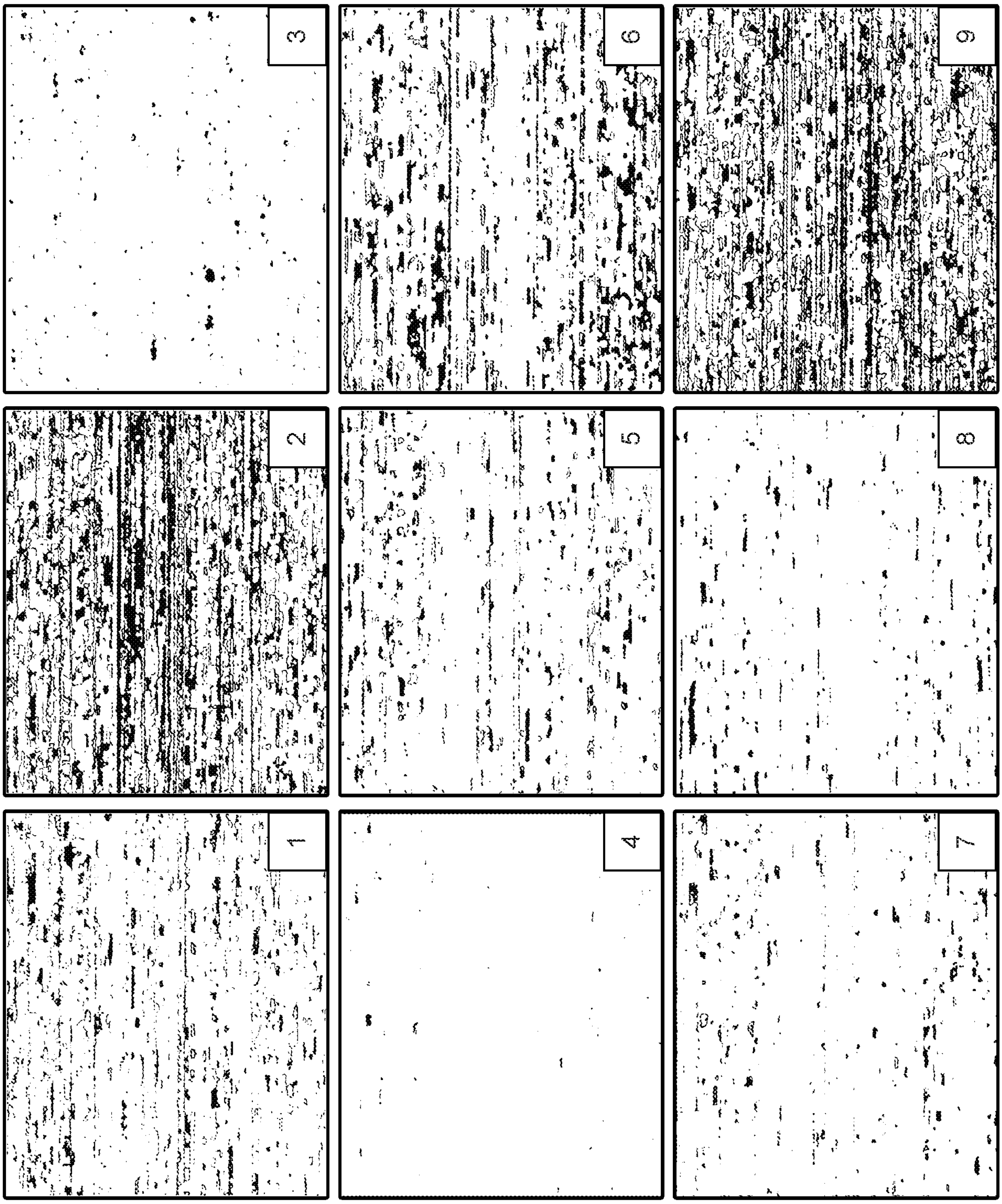


FIG. 3E

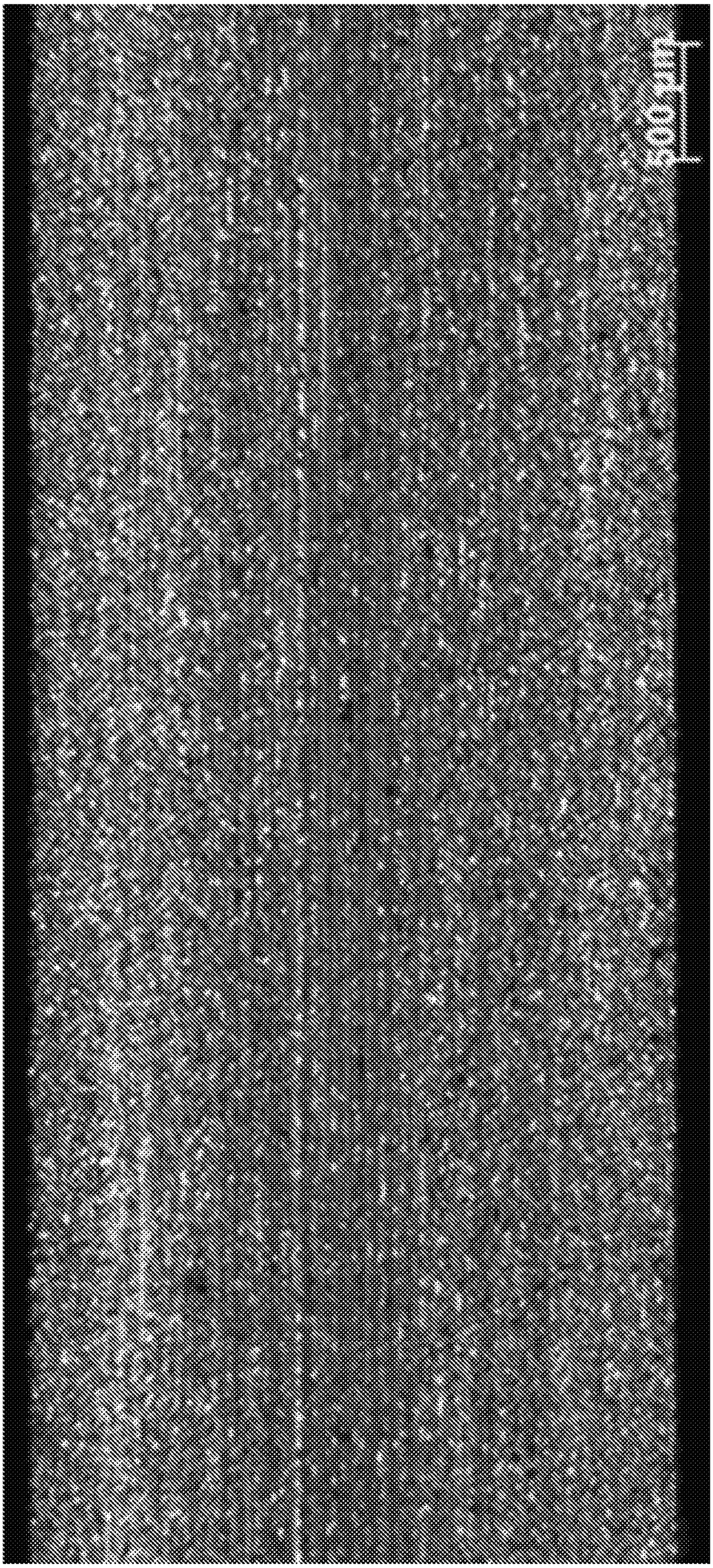


FIG. 4A

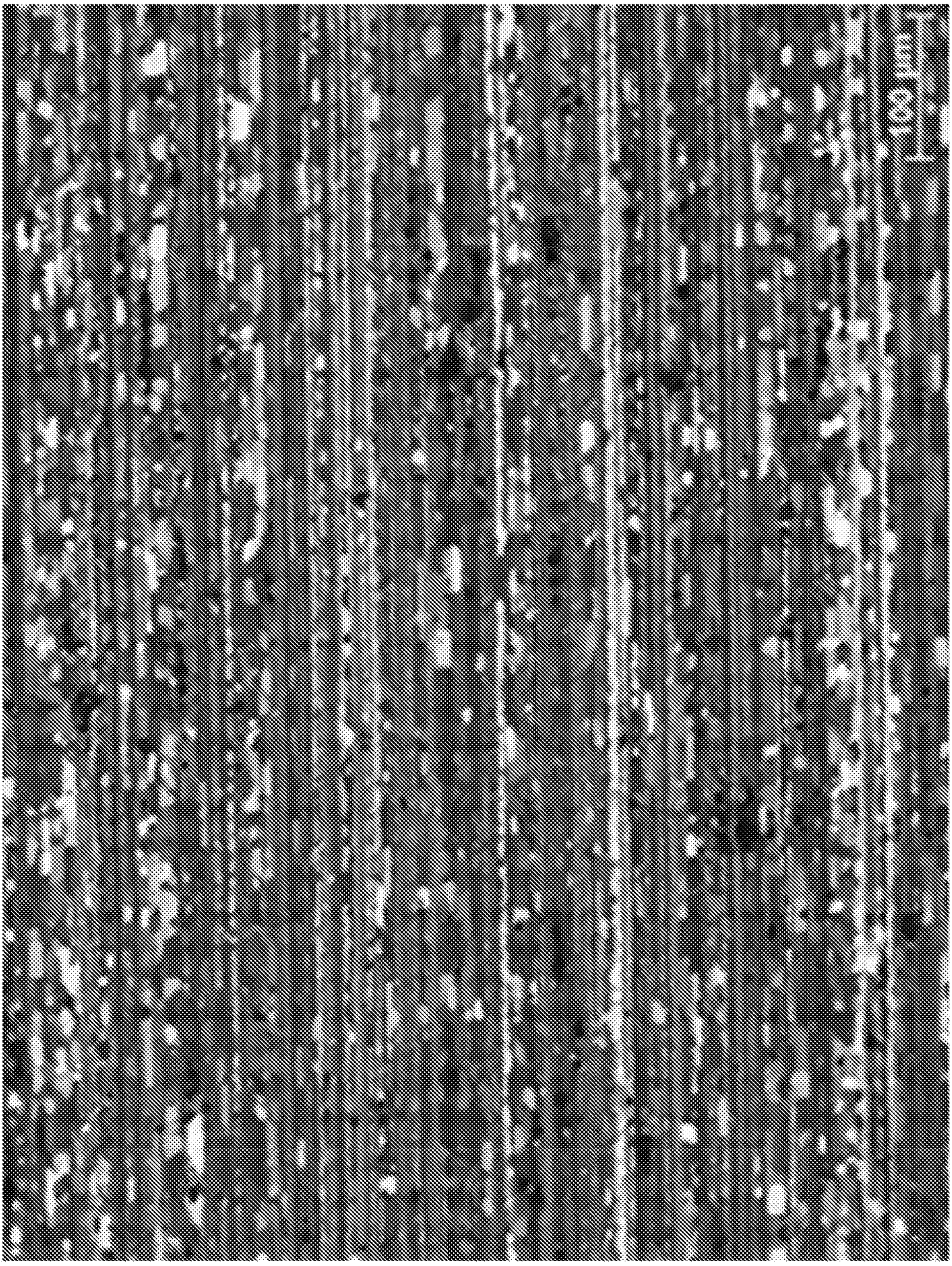


FIG. 4B

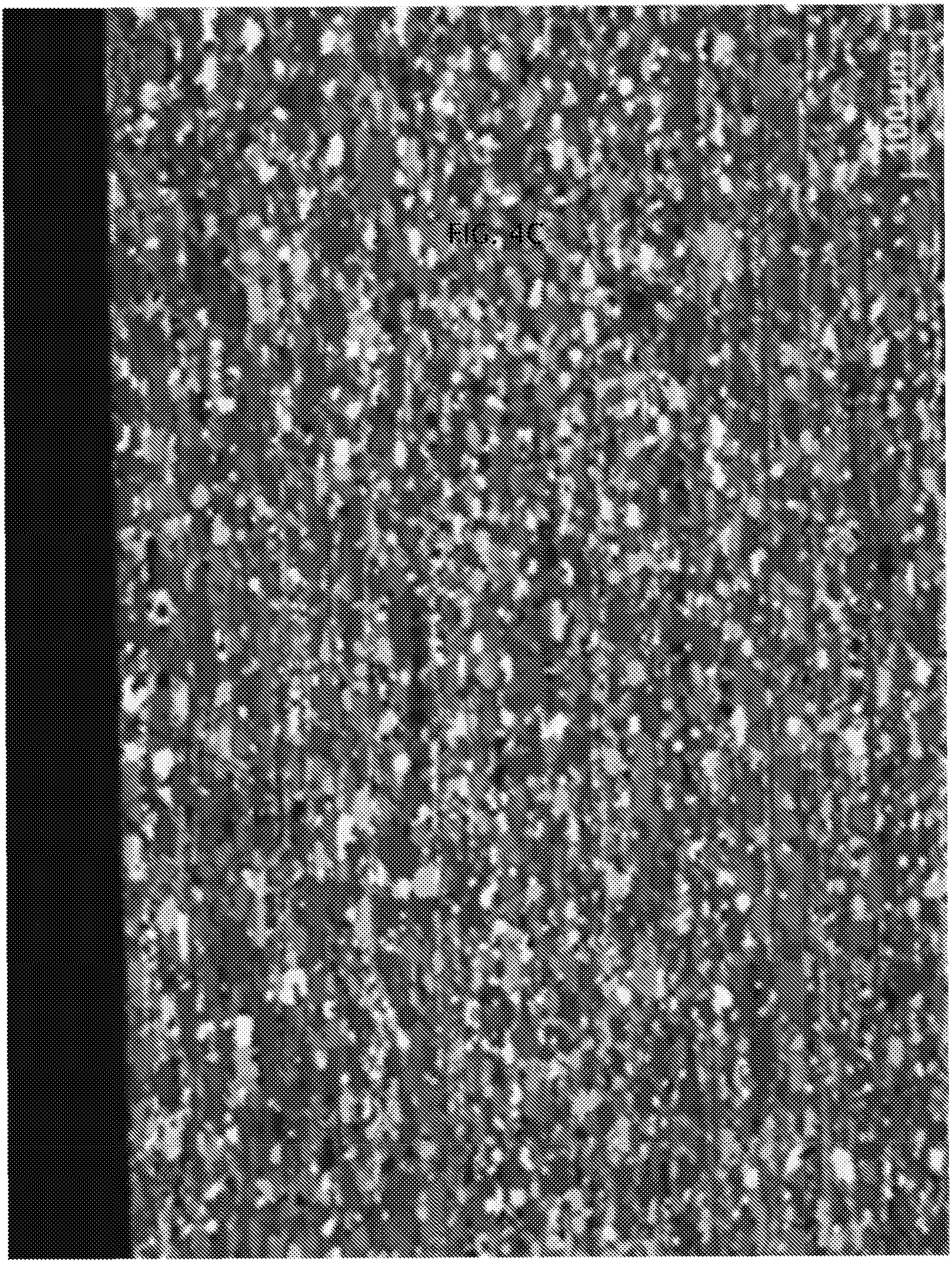


FIG. 4C

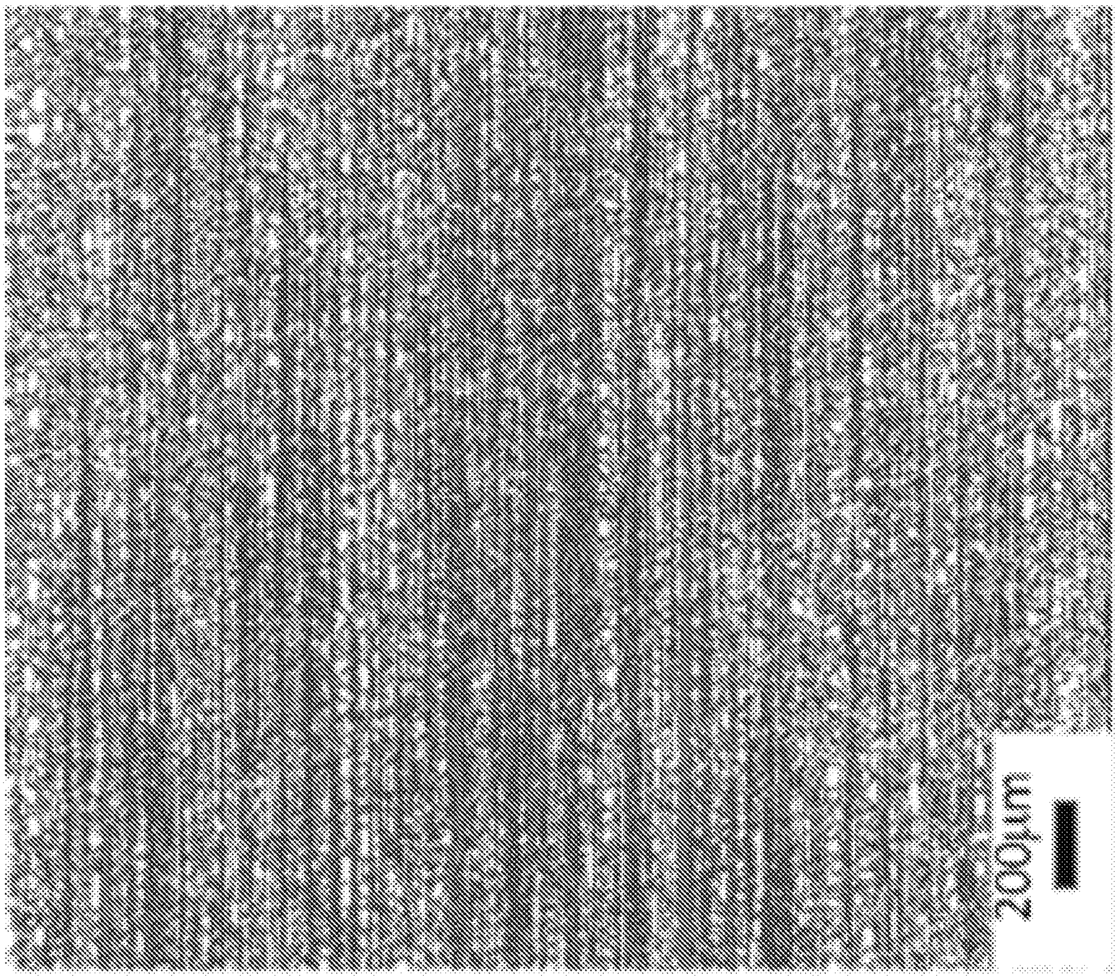
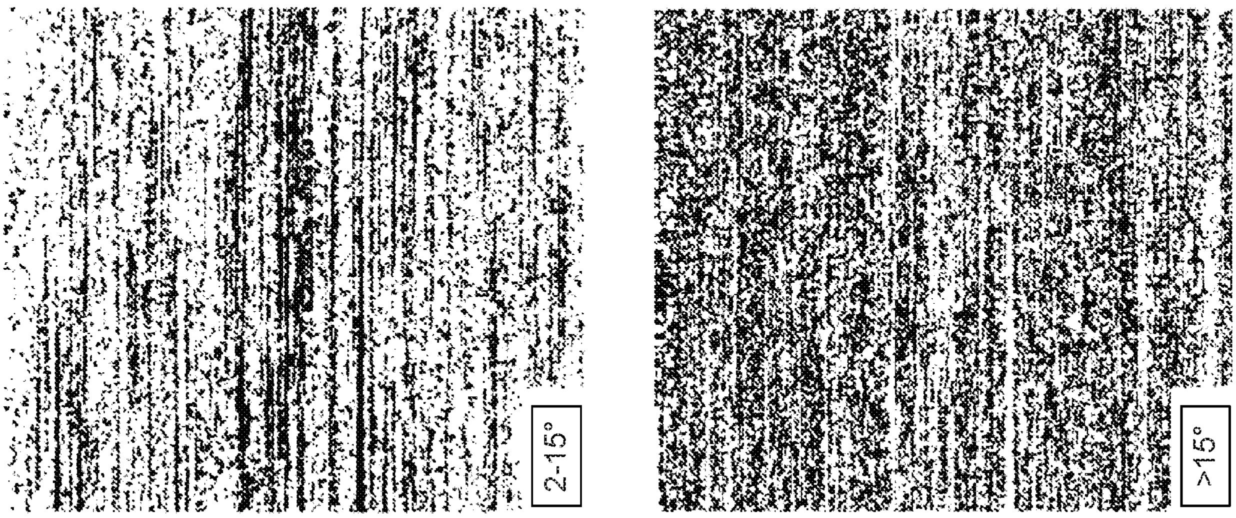


FIG. 5A



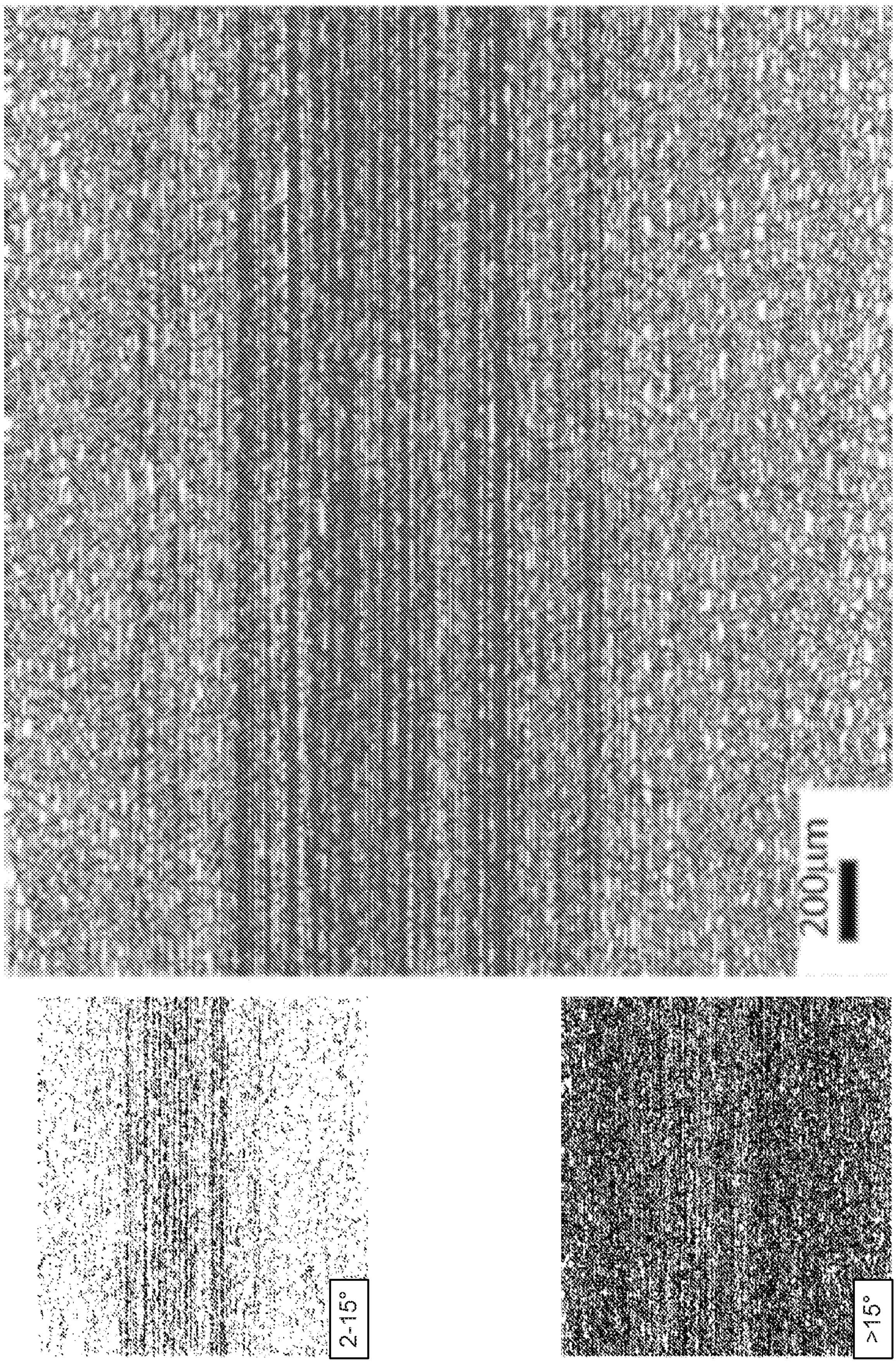


FIG. 5B

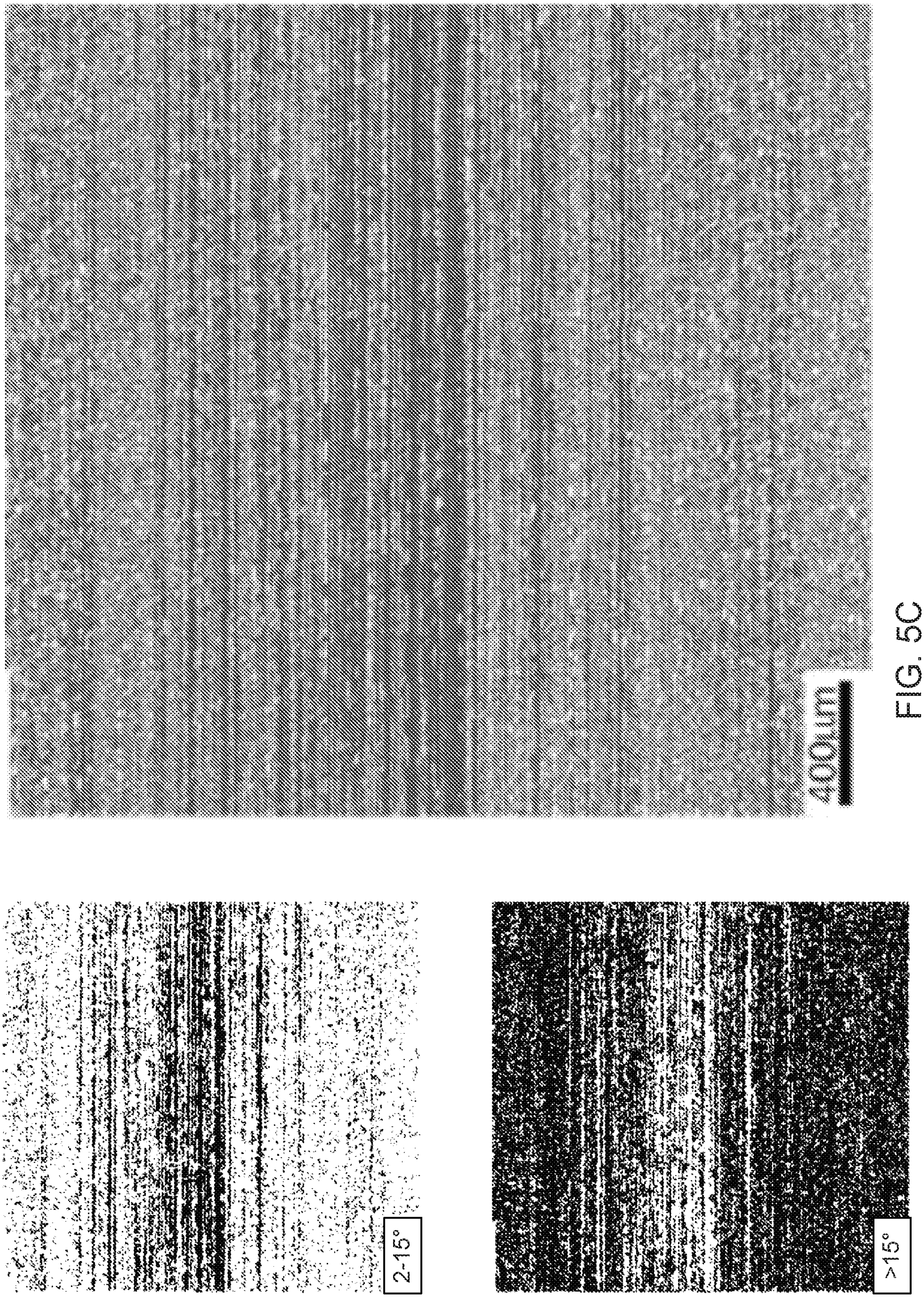


FIG. 5C

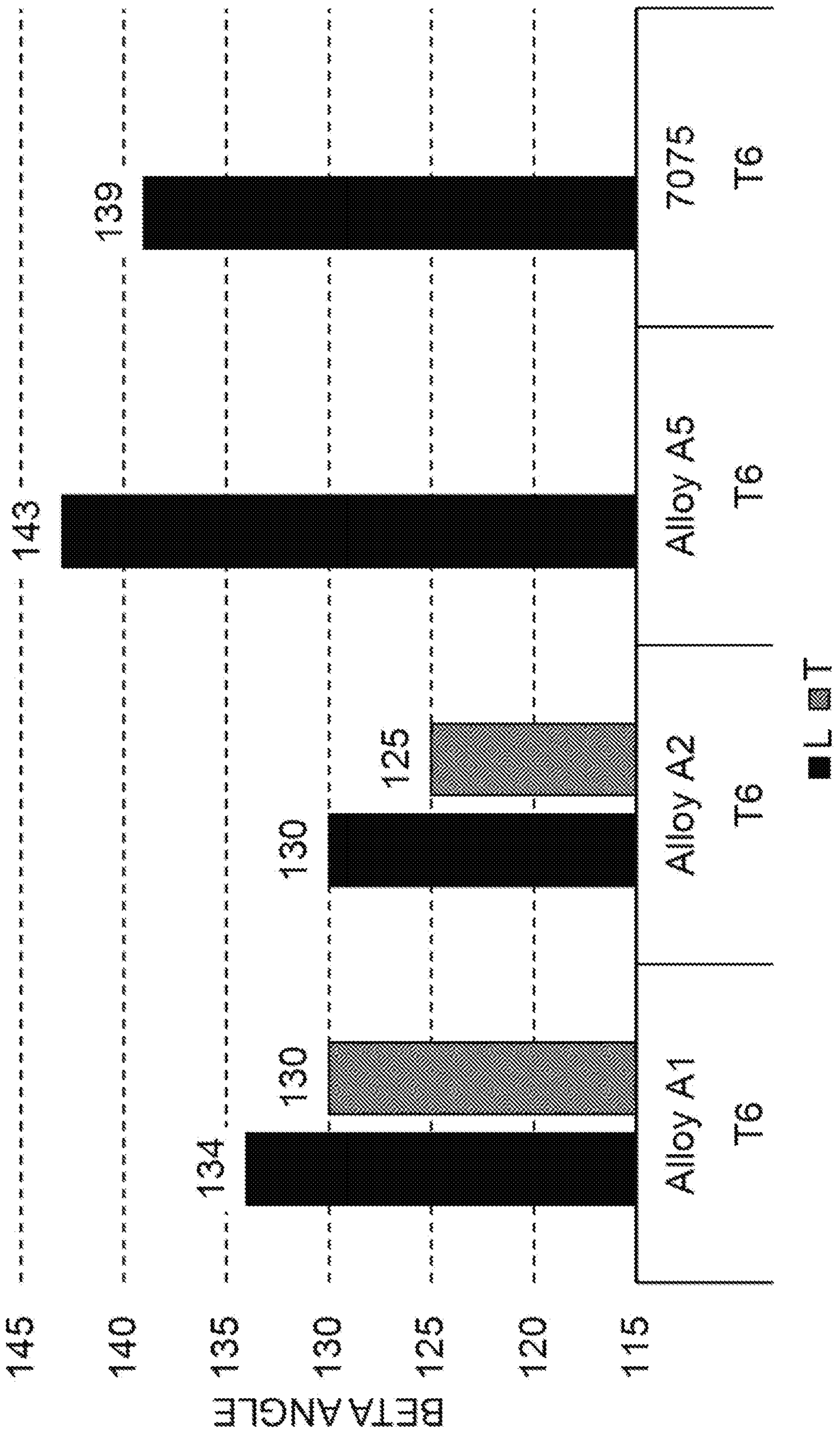

BETA ANGLE
145
140
135
130
125
120
115
134
130
130
125
143
139
Alloy A1
T6
Alloy A2
T6
Alloy A5
T6
7075
T6
L
T

FIG. 6

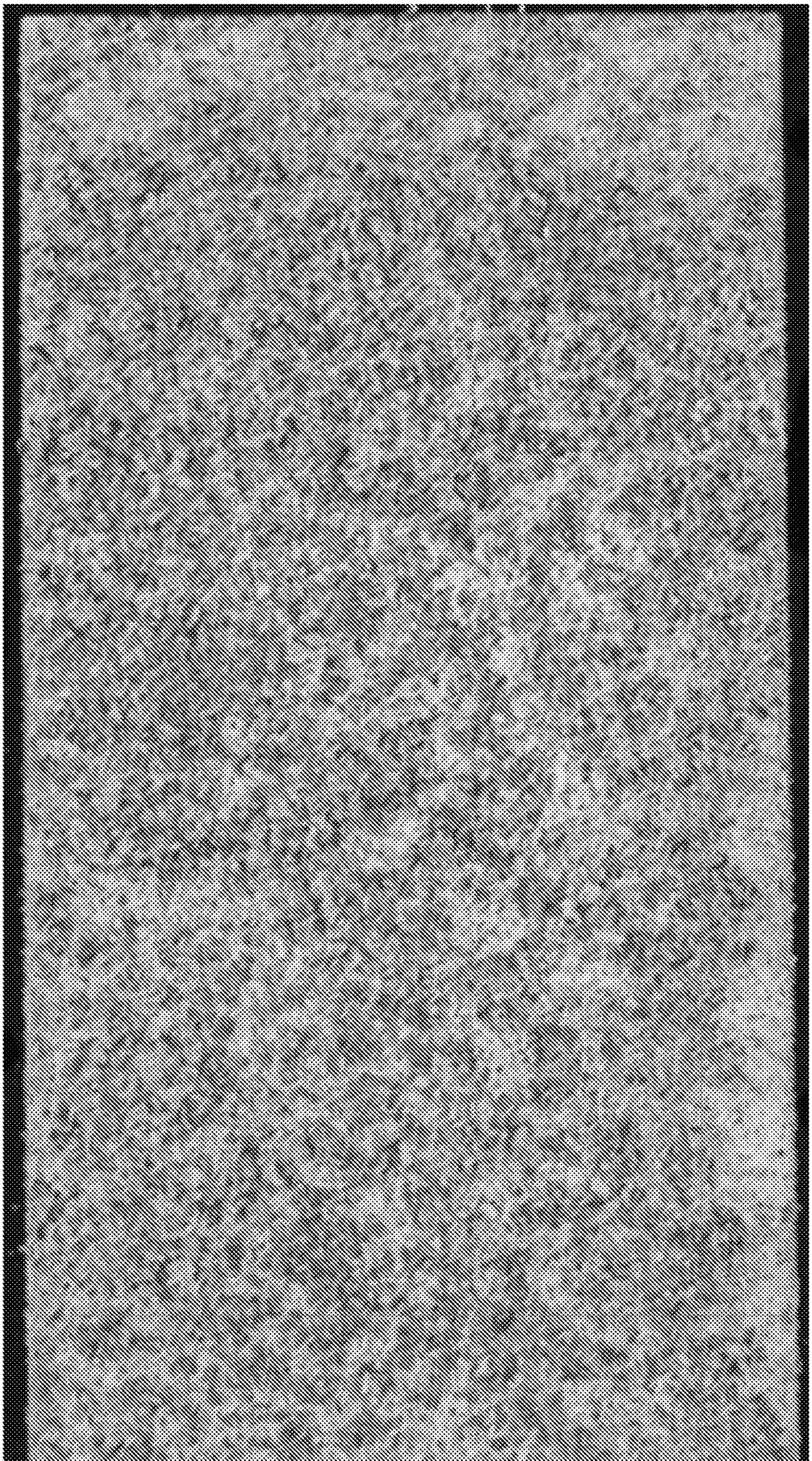


FIG. 7A

FIG. 7B

FIG. 7C

FIG. 7D

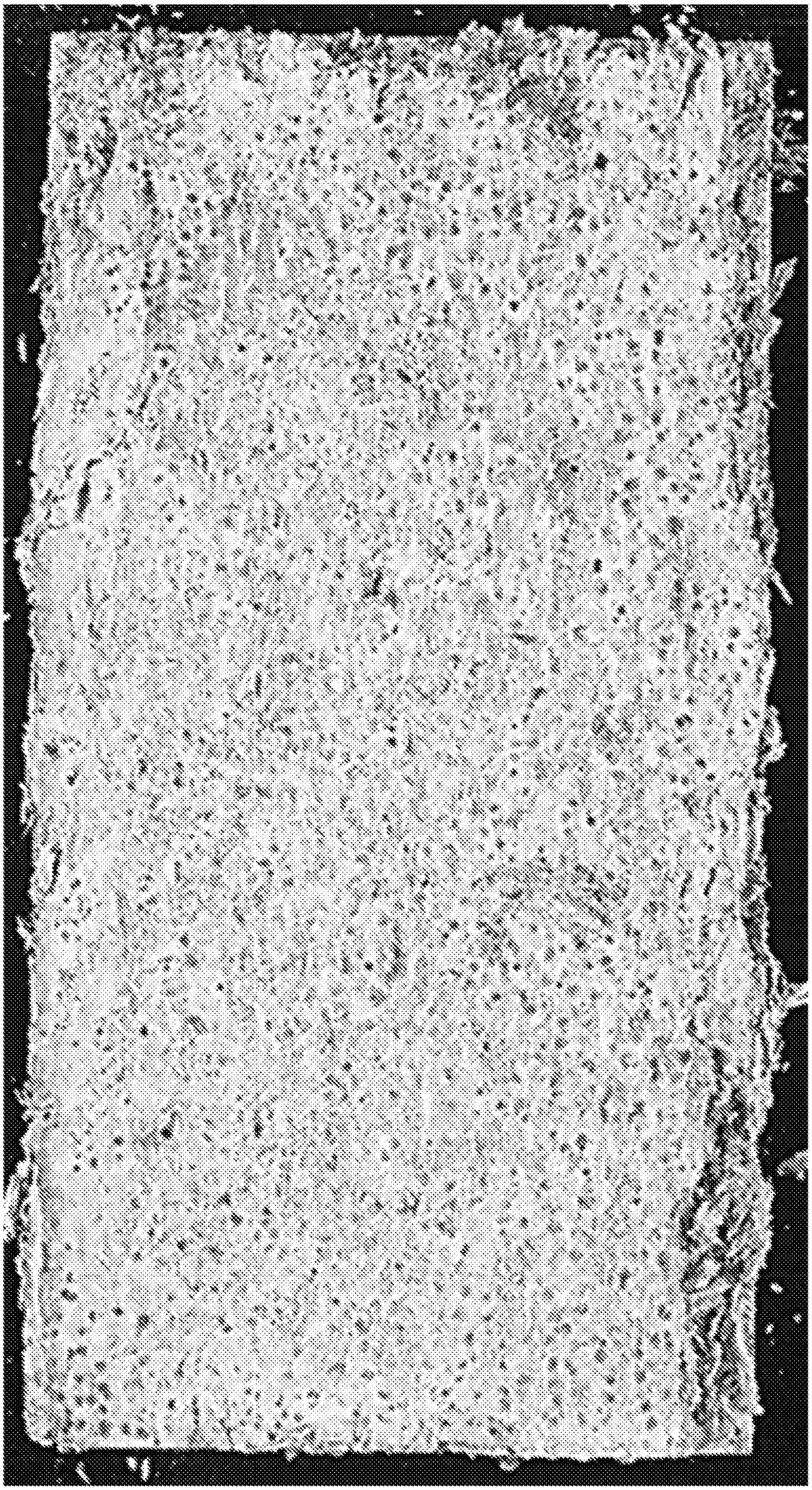


FIG. 7E

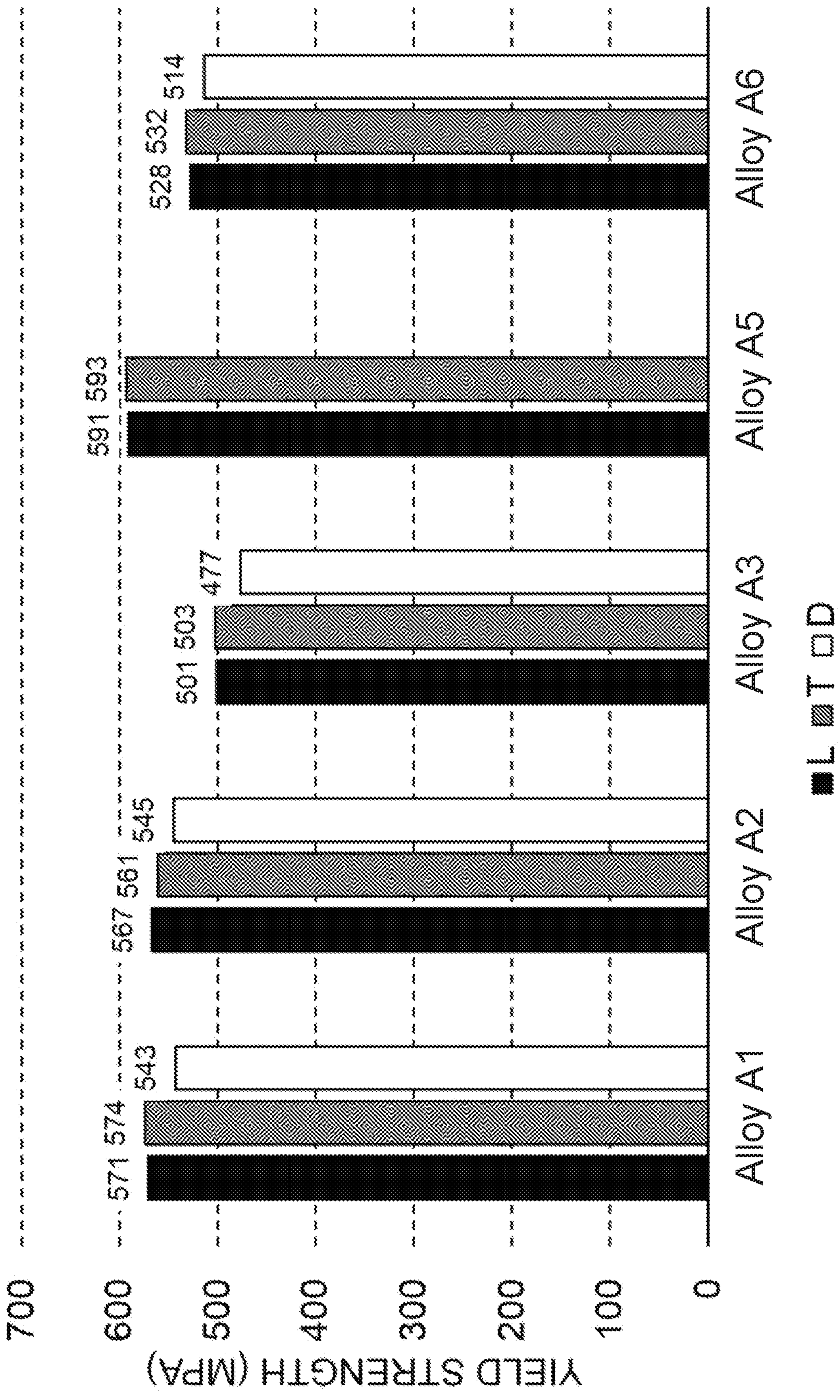

YIELD STRENGTH (MPA)
0
100
200
300
400
500
600
700
571 574 543
567 561 545
501 503 477
591 593
528 532 514
Alloy A1
Alloy A2
Alloy A3
Alloy A5
Alloy A6
L T D

FIG. 8

REFERENCES CITED IN THE DESCRIPTION

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