



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
31.03.2021 Bulletin 2021/13

(51) Int Cl.:
C22C 21/00 (2006.01) **C22C 21/02** (2006.01)
C22C 21/06 (2006.01) **C22F 1/043** (2006.01)
C22F 1/047 (2006.01)

(21) Application number: **20195946.7**

(22) Date of filing: **14.09.2020**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

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(30) Priority: **25.09.2019 US 201962905896 P**
02.03.2020 US 202062984054 P

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(54) **COSMETIC ALUMINUM ALLOYS MADE FROM RECYCLED ALUMINUM SCRAP**

(57) The disclosure is directed to aluminum alloys made from recycled components. The alloys have copper (Cu) from 0.051 to 0.10 wt%, chromium (Cr) from 0.01 to 0.10 wt%, zinc (Zn) from 0.02 to 0.20 wt%, manganese (Mn) from 0.03 to 0.10 wt%, iron (Fe) in an amount of at least 0.10 wt%, silicon (Si) in an amount of at least 0.35 wt%, magnesium (Mg) in amount of at least 0.45 wt%, and the remaining wt% being Al and incidental impurities. In other aspects, the disclosure is directed to aluminum

alloys having copper (Cu) from 0.010 to 0.050 wt%, chromium (Cr) from 0.01 to 0.10 wt%, zinc (Zn) from 0.01 to 0.20 wt%, manganese (Mn) from 0.03 to 0.10 wt%, iron (Fe) in an amount of at least 0.10 wt%, silicon (Si) in an amount of at least 0.35 wt%, magnesium (Mg) in amount of at least 0.45 wt%, and the remaining wt% being Al and incidental impurities. The b* color of the alloys ranges from -2 to 2, and the L* color ranges from 70 to 100.

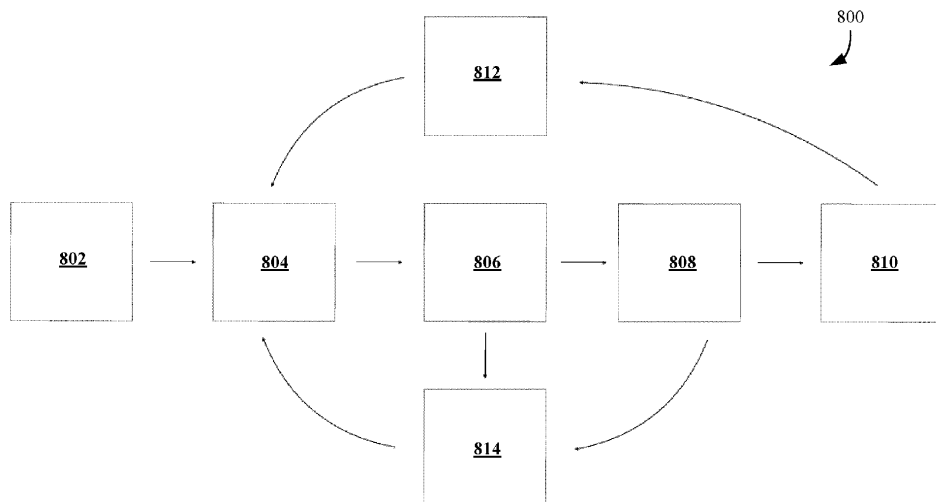


FIG. 8

Description**CROSS-REFERENCES TO RELATED PATENT APPLICATIONS**

[0001] This patent application claims the benefit under 35 U.S.C. § 119(e) of U.S. Patent Application Serial No. 62/905896, entitled "COSMETIC ALUMINUM ALLOYS MADE FROM RECYCLED ALUMINUM SCRAP," filed on September 25, 2019, and U.S. Patent Application Serial No. 62/984054, entitled "COSMETIC ALUMINUM ALLOYS MADE FROM RECYCLED ALUMINUM SCRAP," filed on March 2, 2020, each of which is incorporated herein by reference in its entirety.

FIELD

[0002] The disclosure is directed to recycled aluminum alloys and processes for recycling aluminum alloy scrap with cosmetic appeal and corrosion resistance.

BACKGROUND

[0003] Commercial aluminum alloys, such as the 6063 aluminum (Al) alloys, have been used for fabricating enclosures for electronic devices. Cosmetic appeal is very important for enclosures of electronic devices.

[0004] Conventional recycling of manufacturing scrap (e.g. 6063 Al) is generally associated with downgraded quality. Sometimes, in order to maintain the quality of the recycled product, conventional recycling of manufacturing scrap may be limited to a particular source and a limited amount of scrap in the recycled material. U.S. Patent Application No. 16/530,830, entitled "RECYCLED ALUMINUM ALLOYS FROM MANUFACTURING SCRAP WITH COSMETIC APPEAL," filed on August 2, 2019, discloses recycled aluminum alloys made from manufacturing chip scrap. However, the manufacturing chip scrap are from a known alloy and source and are also limited in supply.

[0005] It is desirable to recycle market scrap of various alloys and from various sources, because this enables a higher volume of market scrap for recycling than just relying on the manufacturing chip scrap. There remains a need for developing alloys and processes for recycling the market scrap from various sources to improve the cosmetic appeal of recycled aluminum alloys.

BRIEF SUMMARY

[0006] In one aspect, the disclosure is directed to an aluminum alloy having copper (Cu) from 0.051 to 0.10 wt%, chromium (Cr) from 0.01 to 0.10 wt%, zinc (Zn) from 0.02 to 0.20 wt%, manganese (Mn) from 0.03 to 0.10 wt%, iron (Fe) in an amount of at least 0.10 wt%, silicon (Si) in an amount of at least 0.35 wt%, magnesium (Mg) in amount of at least 0.45 wt%, and the remaining wt% being Al and incidental impurities. The b* color ranges from -2 to 2, and the L* color ranges from 70 to 100. In some variations, the L*, a*, and b* values may be based on non-dyed anodized aluminum or textured aluminum.

[0007] In another aspect, the disclosure is directed to an aluminum alloy having copper (Cu) from 0.010 to 0.050 wt%, chromium (Cr) from 0.01 to 0.10 wt%, zinc (Zn) from 0.01 to 0.20 wt%, manganese (Mn) from 0.03 to 0.10 wt%, iron (Fe) in an amount of at least 0.10 wt%, silicon (Si) in an amount of at least 0.35 wt%, magnesium (Mg) in amount of at least 0.45 wt%, and the remaining wt% being Al and incidental impurities. The b* color ranges from -2 to 2, and the L* color ranges from 70 to 100.

[0008] In various aspects, the disclosed alloys can include titanium (Ti) from 0 to 0.10 wt%, gallium (Ga) from 0 to 0.20 wt%, tin (Sn) from 0 to 0.20 wt%, vanadium (V) from 0 to 0.20 wt%, calcium (Ca) from 0 to 0.01 wt%, sodium (Na) from 0 to 0.008 wt%, boron (B) from 0 to 0.10 wt%, zirconium (Zr) from 0 to 0.10 wt%, lithium (Li) from 0 to 0.10 wt%, cadmium (Cd) from 0 to 0.10 wt%, lead (Pb) from 0 to 0.10 wt%, nickel (Ni) from 0 to 0.10 wt%, phosphorous (P) from 0 to 0.10 wt%, and combinations thereof.

[0009] Additional embodiments and features are set forth in part in the description that follows, and will become apparent to those skilled in the art upon examination of the specification or may be learned by the practice of the disclosed subject matter. A further understanding of the nature and advantages of the disclosure may be realized by reference to the remaining portions of the specification and the drawings, which forms a part of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The description will be more fully understood with reference to the following figures and data graphs, which are presented as various embodiments of the disclosure and should not be construed as a complete recitation of the scope of the disclosure, wherein:

FIG. 1A illustrates the yield strength for extrusion samples formed of various 6000 series aluminum alloys in accordance with embodiments of the disclosure;

FIG. 1B illustrates the tensile strength for extrusion samples formed of various 6000 series aluminum alloys in accordance with embodiments of the disclosure;

FIG. 1C illustrates the elongation for extrusion samples formed of various 6000 series aluminum alloys in accordance with embodiments of the disclosure;

FIG. 1D illustrates the hardness for extrusion samples formed of various 6000 series aluminum alloys in accordance with embodiments of the disclosure;

FIG. 2A illustrates the average grain size for extrusion samples formed of various 6000 series aluminum alloys in accordance with embodiments of the disclosure;

FIG. 2B illustrates the largest grain size for extrusion samples formed of various 6000 series aluminum alloys in accordance with embodiments of the disclosure;

FIG. 2C illustrates the grain aspect ratio for extrusion samples formed of various 6000 series aluminum alloys in accordance with embodiments of the disclosure;

FIG. 3 illustrates extrusion speed for various market scrap alloys in accordance with embodiments of the disclosure;

FIG. 4A illustrates comparison of electrochemical impedance of the aluminum samples having different total impurities and different elemental compositions for a neutral color aluminum or non-dyed anodized aluminum (NDA);

FIG. 4B illustrates comparison of electrochemical impedance of the aluminum samples having different total impurities and different elemental compositions for a grey color aluminum;

FIG. 5A illustrates comparison of corrosion rate of the aluminum samples having different total impurities and different elemental compositions for a non-anodized alloy;

FIG. 5B illustrates comparison of pitting potential of the aluminum samples having different total impurities and different elemental compositions for a non-anodized alloy;

FIG. 6A illustrates comparison of number of pits of the aluminum samples having different total impurities and different elemental compositions for a non-anodized alloy;

FIG. 6B illustrates comparison of pit radius of the aluminum samples having different total impurities and different elemental compositions for a non-anodized alloy;

FIG. 7 illustrates comparison of salt fog test pass rate of the aluminum samples having different total impurities and different elemental compositions for a neutral color aluminum and a grey color aluminum; and

FIG. 8 illustrates a recycling process from materials including manufacturing scrap in accordance with embodiments of the disclosure.

DETAILED DESCRIPTION

[0011] The disclosure may be understood by reference to the following detailed description, taken in conjunction with the drawings as described below. It is noted that, for purposes of illustrative clarity, certain elements in various drawings may not be drawn to scale.

[0012] The disclosure provides recycled 6000 series aluminum alloys made from scrap. The scrap can be collected from manufacturing processes of conventional aluminum alloys (e.g. 6000 series aluminum alloys or 6063 aluminum). The recycled 6000 series aluminum alloys can surprisingly provide the same or similar cosmetic appeal, mechanical properties, and/or microstructure as aluminum alloys with lower iron, silicon, and magnesium. The recycled 6000 series aluminum alloys can include higher Cu content, higher Mn content, higher Zn content, and/or higher Cr content than would be expected for alloys having cosmetic appeal.

Alloys Made from Market Scrap

[0013] In some variations, the disclosed 6000 series aluminum alloys are designed to be tolerant to include up to 100% recycled 6000 series aluminum, such as market scraps including casting scrap, extrusion scrap, chip scrap from various manufacturing sources, among others. The disclosed 6000 series aluminum alloys may also be tolerant to other series scraps, such as 1000 series scrap. The disclosed 6000 series aluminum alloys, also referred to as recycled 6000 series aluminum alloys, allow the use of market scraps from various sources that can reduce use of virgin aluminum, and result in significant reduction of emissions and related carbon footprint. Conventional 6000 series Al alloys include small amounts of Si and Mg, and may include small amounts of Fe, Mn, Cu, Zr, Pb, Cr, Zn, among others.

[0014] Recycled aluminum alloys from market scrap can contain more copper than is typically present in virgin aluminum alloys or recycled aluminum alloys from a closed loop of manufacturing, such as the recycled aluminum alloys disclosed in U.S. Patent Application No. 16/530,830, entitled "RECYCLED ALUMINUM ALLOYS FROM MANUFACTURING SCRAP WITH COSMETIC APPEAL," filed on August 2, 2019, which is incorporated herein by reference in its entirety. The increase in copper would be expected to have a negative effect on the cosmetic appeal of aluminum alloys, particularly

by resulting in a more yellowish color of the anodized layer. Copper generally cannot be removed from aluminum alloys by conventional industrial methods, and once copper is included in the aluminum alloy, the amount of copper in the alloy cannot be reduced. Because of the number of copper-containing alloys in market scrap, the amount of copper is higher in the disclosed recycled aluminum than in other aluminum alloys, while retaining anodized layer color and other cosmetic properties similar to alloys with lower Cu, Cr, Mn, and/or Zn.

[0015] In some variations, the disclosed aluminum alloys include higher amounts of Cu, Mn, Zn, Fe, and Cr than other aluminum alloys. Various properties of the disclosed recycled aluminum alloys from market scrap have cosmetic properties with high amounts of copper of up to 0.10 wt%, which is significantly higher than other aluminum alloys with cosmetic properties disclosed herein. For example, the disclosed recycled aluminum alloys surprisingly have a less yellow anodized layer color than would be expected for alloys with higher quantities of copper.

[0016] The disclosed recycled 6000 series aluminum alloys allow use of recycled materials, such as market scrap from various sources. The disclosed recycled 6000 series aluminum alloys result in significant reduction of the carbon footprint associated with manufacturing.

[0017] The disclosed alloys can be described by various wt% of elements, as well as specific properties. In all descriptions of the alloys described herein, it will be understood that the wt% balance of alloys is Al and incidental impurities. Impurities can be present, for example, as a byproduct of processing and manufacturing. In various embodiments, an incidental impurity can be no greater than 0.05 wt% of any one additional element (i.e., a single impurity), and no greater than 0.10 wt% total of all additional elements (i.e., total impurities). The impurities can be less than or equal to about 0.1 wt%, alternatively less than or equal about 0.05 wt%, alternatively less than or equal about 0.01 wt%, alternatively less than or equal about 0.001 wt%.

[0018] In some variations, the disclosed alloys have copper (Cu) from 0.051 to 0.10 wt%. In some variations, the disclosed alloys have chromium (Cr) from 0.01 to 0.10 wt%. In some variations, the disclosed alloys have zinc (Zn) from 0.02 to 0.20 wt%. In some variations, the disclosed alloys have manganese (Mn) from 0.03 to 0.10 wt%. In some variations, the disclosed alloys have at least 0.14 wt% Fe. Further, in some variations, the disclosed alloys have at least 0.43 wt% Si and at least 0.56 wt% Mg. In still further variations, the disclosed alloys can have equal to or greater than 0.20 wt% Fe. The disclosed alloys can have equal to or less than 0.62 wt% Mg and equal to or less than 0.49 wt% Si.

Cu Content

[0019] In some variations, the alloys can include Cu. Without wishing to be limited to any particular mechanism, effect, or mode of action, Cu can influence color of the anodized alloy. For example, additional Cu may cause yellowish color to the anodized aluminum alloy. Cu may also affect corrosion resistance.

[0020] In some variations, copper may vary from 0.051 wt% to 0.10 wt%.

[0021] In some variations, copper may be equal to or less than 0.100 wt%. In some variations, copper may be equal to or less than 0.095 wt%. In some variations, copper may be equal to or less than 0.090 wt%. In some variations, copper may be equal to or less than 0.085 wt%. In some variations, copper may be equal to or less than 0.080 wt%. In some variations, copper may be equal to or less than 0.075 wt%. In some variations, copper may be equal to or less than 0.060 wt%. In some variations, copper may be equal to or less than 0.055 wt%.

[0022] In some variations, copper may be equal to or greater than 0.051 wt%. In some variations, copper may be equal to or greater than 0.055 wt%. In some variations, copper may be equal to or greater than 0.060 wt%. In some variations, copper may be equal to or greater than 0.065 wt%. In some variations, copper may be equal to or greater than 0.070 wt%. In some variations, copper may be equal to or greater than 0.075 wt%. In some variations, copper may be equal to or greater than 0.080 wt%. In some variations, copper may be equal to or greater than 0.085 wt%. In some variations, copper may be equal to or greater than 0.090 wt%. In some variations, copper may be equal to or greater than 0.095 wt%.

Mn Content

[0023] In some variations, the alloys can include Mn. Without wishing to be held to a particular mechanism, effect, or mode of action, Mn can result in breaking up coarse Al-Fe-Si particles or AlFeSi particles. When the amount of Mn increases above a higher value, the aspect ratio of the grains may increase such that the grains may be elongated. The control of upper range amount of Mn results in a surprising grain structure control at a low average grain aspect ratio from sample-to-sample, and can have reduced streaky lines in finished and anodized alloys. The elongated grain structure can cause streaky lines.

[0024] In some variations, manganese may be equal to or less than 0.090 wt%. In some variations, manganese may be equal to or less than 0.085 wt%. In some variations, manganese may be equal to or less than 0.080 wt%. In some variations, manganese may be equal to or less than 0.075 wt%. In some variations, manganese may be equal to or less than 0.070 wt%. In some variations, manganese may be equal to or less than 0.065 wt%. In some variations, manganese

may be equal to or less than 0.060 wt%. In some variations, manganese may be equal to or less than 0.055 wt%. In some variations, manganese may be equal to or less than 0.050 wt%. In some variations, manganese may be equal to or less than 0.045 wt%. In some variations, manganese may be equal to or less than 0.040 wt%. In some variations, manganese may be equal to or less than 0.035 wt%. In some variations, manganese may be equal to or less than 0.030 wt%. In some variations, manganese may be equal to or less than 0.025 wt%. In some variations, manganese may be equal to or less than 0.020 wt%. In some variations, manganese may be equal to or less than 0.015 wt%. In some variations, manganese may be equal to or less than 0.010 wt%. In some variations, manganese may be equal to or less than 0.005 wt%.

[0025] In some variations, manganese may be equal to or greater than 0.005 wt%. In some variations, manganese may be equal to or greater than 0.010 wt%. In some variations, manganese may be equal to or greater than 0.015 wt%. In some variations, manganese may be equal to or greater than 0.020 wt%. In some variations, manganese may be equal to or greater than 0.025 wt%. In some variations, manganese may be equal to or greater than 0.030 wt%. In some variations, manganese may be equal to or greater than 0.035 wt%. In some variations, manganese may be equal to or greater than 0.040 wt%. In some variations, manganese may be equal to or greater than 0.045 wt%. In some variations, manganese may be equal to or greater than 0.050 wt%. In some variations, manganese may be equal to or greater than 0.055 wt%. In some variations, manganese may be equal to or greater than 0.060 wt%. In some variations, manganese may be equal to or greater than 0.065 wt%.

[0026] In some variations, manganese may be equal to or greater than 0.070 wt%. In some variations, manganese may be equal to or greater than 0.075 wt%. In some variations, manganese may be equal to or greater than 0.080 wt%. In some variations, manganese may be equal to or greater than 0.085 wt%.

Cr Content

[0027] In some variations, the alloys can include Cr. Without wishing to be held to a particular mechanism, effect, or mode of action, Cr may affect color and corrosion resistance. When the amount of Cr increases to a higher value, the aspect ratios of the grains may increase such that the grains may be elongated. The control of the upper range amount of Cr may allow surprising grain structure control at a low average grain aspect ratio from sample-to-sample, and can have reduced streaky lines in finished and anodized alloys. The elongated grain structure can cause streaky lines.

[0028] In some variations, chromium may be equal to or less than 0.10 wt%. In some variations, chromium may be equal to or less than 0.08 wt%. In some variations, chromium may be equal to or less than 0.06 wt%. In some variations, chromium may be equal to or less than 0.04 wt%. In some variations, chromium may be equal to or less than 0.03 wt%. In some variations, chromium may be equal to or less than 0.02 wt%. In some variations, chromium may be equal to or less than 0.01 wt%. In some variations, chromium may be equal to or less than 0.008 wt%. In some variations, chromium may be equal to or less than 0.006 wt%. In some variations, chromium may be equal to or less than 0.004 wt%. In some variations, chromium may be equal to or less than 0.002 wt%.

Zn Content

[0029] In some variations, the alloys can include Zn. Without wishing to be held to a particular mechanism, effect, or mode of action, Zn may affect color and corrosion resistance. For example, the anodized alloy may become more bluish. In some variations, zinc may be equal to or less than 0.20 wt%. In some variations, zinc may be equal to or less than 0.15 wt%. In some variations, zinc may be equal to or less than 0.10 wt%. In some variations, zinc may be equal to or less than 0.08 wt%. In some variations, zinc may be equal to or less than 0.06 wt%. In some variations, zinc may be equal to or less than 0.04 wt%. In some variations, zinc may be equal to or less than 0.03 wt%. In some variations, zinc may be equal to or greater than 0.01 wt%. In some variations, zinc may be equal to or greater than 0.02 wt%. In some variations, zinc may be equal to or greater than 0.03 wt%. In some variations, zinc may be equal to or greater than 0.04 wt%. In some variations, zinc may be equal to or greater than 0.05 wt%. In some variations, zinc may be equal to or greater than 0.06 wt%. In some variations, zinc may be equal to or greater than 0.07 wt%. In some variations, zinc may be equal to or greater than 0.08 wt%. In some variations, zinc may be equal to or greater than 0.09 wt%. In some variations, zinc may be equal to or greater than 0.10 wt%. In some variations, zinc may be equal to or greater than 0.15 wt%.

Fe Content

[0030] As described above, the scrap (e.g., market scrap) includes more Fe than the conventional 6000 series aluminum alloys for cosmetic applications. The Fe may be from sources including tooling and fasteners, among others. The disclosed 6000 series aluminum alloy is designed to have more Fe than conventional 6000 series aluminum alloys or virgin aluminum alloys currently used for cosmetic consumer electronic products.

[0031] In some variations, iron may range from 0.10 wt% to 0.50 wt%.

[0032] In some variations, iron may be equal to or greater than 0.10 wt%. In some variations, iron may be equal to or greater than 0.14 wt%. In some variations, iron may be equal to or greater than 0.15 wt%. In some variations, iron may be equal to or greater than 0.16 wt%. In some variations, iron may be equal to or greater than 0.17 wt%. In some variations, iron may be equal to or greater than 0.18 wt%. In some variations, iron may be equal to or greater than 0.19 wt%. In some variations, iron may be equal to or greater than 0.20 wt%. In some variations, iron may be equal to or greater than 0.25 wt%. In some variations, iron may be equal to or greater than 0.30 wt%. In some variations, iron may be equal to or greater than 0.35 wt%. In some variations, iron may be equal to or greater than 0.40 wt%. In some variations, iron may be equal to or greater than 0.45 wt%.

[0033] In some variations, iron may be equal to or less than 0.50 wt%. In some variations, iron may be equal to or less than 0.45 wt%. In some variations, iron may be equal to or less than 0.35 wt%. In some variations, iron may be equal to or less than 0.40 wt%. In some variations, iron may be equal to or less than 0.35 wt%. In some variations, iron may be equal to or less than 0.30 wt%. In some variations, iron may be equal to or less than 0.25 wt%. In some variations, iron may be equal to or less than 0.20 wt%. In some variations, iron may be equal to or less than 0.19 wt%. In some variations, iron may be equal to or less than 0.18 wt%. In some variations, iron may be equal to or less than 0.17 wt%. In some variations, iron may be equal to or less than 0.16 wt%. In some variations, iron may be equal to or less than 0.15 wt%.

Ti Content

[0034] Scrap can include more Ti than the conventional 6000 series aluminum alloys. The Ti can be added as a grain refiner during the casting process. In many instances, the 6000 series aluminum alloy is designed to tolerate more Ti versus conventional aluminum alloys used for cosmetic consumer electronic products.

[0035] In some variations, titanium may equal to or less than 0.10 wt%. In some variations, titanium may equal to or less than 0.09 wt%. In some variations, titanium may equal to or less than 0.08 wt%. In some variations, titanium may equal to or less than 0.07 wt%. In some variations, titanium may equal to or less than 0.06 wt%. In some variations, titanium may equal to or less than 0.05 wt%. In some variations, titanium may equal to or less than 0.04 wt%. In some variations, titanium may equal to or less than 0.03 wt%. In some variations, titanium may equal to or less than 0.025 wt%. In some variations, titanium may be equal to or less than 0.020 wt%. In some variations, titanium may be equal to or less than 0.015 wt%. In some variations, titanium may be equal to or less than 0.010 wt%. In some variations, titanium may be equal to or less than 0.005 wt%.

Si Content and Mg Content

[0036] Additional Si may be added to the disclosed alloys than in some 6000 series alloys, without a resulting loss of mechanical strength by forming Mg-Si particles.

[0037] In some variations, silicon may vary from 0.35 wt% to 0.80 wt%.

[0038] In some variations, silicon may be equal to or less than 0.80 wt%. In some variations, silicon may be equal to or less than 0.75 wt%. In some variations, silicon may be equal to or less than 0.70 wt%. In some variations, silicon may be equal to or less than 0.65 wt%. In some variations, silicon may be equal to or less than 0.60 wt%. In some variations, silicon may be equal to or less than 0.55 wt%. In some variations, silicon may be equal to or less than 0.50 wt%. In some variations, silicon may be equal to or less than 0.49 wt%. In some variations, silicon may be equal to or less than 0.48 wt%. In some variations, silicon may be equal to or less than 0.47 wt%. In some variations, silicon may be equal to or less than 0.46 wt%. In some variations, silicon may be equal to or less than 0.45 wt%. In some variations, silicon may be equal to or less than 0.40 wt%. In some variations, silicon may be equal to or less than 0.39 wt%. In some variations, silicon may be equal to or less than 0.38 wt%. In some variations, silicon may be equal to or less than 0.37 wt%. In some variations, silicon may be equal to or less than 0.36 wt%.

[0039] In some variations, silicon may be equal to or greater than 0.35 wt%. In some variations, silicon may be equal to or greater than 0.36 wt%. In some variations, silicon may be equal to or greater than 0.37 wt%. In some variations, silicon may be equal to or greater than 0.38 wt%. In some variations, silicon may be equal to or greater than 0.39 wt%. In some variations, silicon may be equal to or greater than 0.40 wt%. In some variations, silicon may be equal to or greater than 0.41 wt%. In some variations, silicon may be equal to or greater than 0.42 wt%. In some variations, silicon may be equal to or greater than 0.43 wt%. In some variations, silicon may be equal to or greater than 0.44 wt%. In some variations, silicon may be equal to or greater than 0.45 wt%. In some variations, silicon may be equal to or greater than 0.46 wt%. In some variations, silicon may be equal to or greater than 0.47 wt%. In some variations, silicon may be equal to or greater than 0.48 wt%. In some variations, silicon may be equal to or greater than 0.49 wt%. In some variations, silicon may be equal to or greater than 0.50 wt%. In some variations, silicon may be equal to or greater than 0.55 wt%. In some variations, silicon may be equal to or greater than 0.60 wt%. In some variations, silicon may be equal to or greater than 0.65 wt%. In some variations, silicon may be equal to or greater than 0.70 wt%. In some variations, silicon

may be equal to or greater than 0.75wt%.

[0040] Mg can be designed to have the proper Mg/Si ratio to form Mg-Si precipitates for strengthening purpose. In some variations, the ratio of Mg to Si is typically 2:1, but other variations can be possible.

[0041] In some variations, magnesium may vary from 0.45 wt% to 0.95 wt%.

[0042] In some variations, magnesium may be equal to or less than 0.95 wt%. In some variations, magnesium may be equal to or less than 0.90 wt%. In some variations, magnesium may be equal to or less than 0.85 wt%. In some variations, magnesium may be equal to or less than 0.80 wt%. In some variations, magnesium may be equal to or less than 0.75 wt%. In some variations, magnesium may be equal to or less than 0.70 wt%. In some variations, magnesium may be equal to or less than 0.65 wt%. In some variations, magnesium may be equal to or less than 0.60 wt%. In some variations, magnesium may be equal to or less than 0.55 wt%. In some variations, magnesium may be equal to or less than 0.50 wt

[0043] In some variations, magnesium may be equal to or greater than 0.50 wt%. In some variations, magnesium may be equal to or greater than 0.55 wt%. In some variations, magnesium may be equal to or greater than 0.60 wt%. In some variations, magnesium may be equal to or greater than 0.65 wt%. In some variations, magnesium may be equal to or greater than 0.70 wt%. In some variations, magnesium may be equal to or greater than 0.75 wt%. In some variations, magnesium may be equal to or greater than 0.80 wt%. In some variations, magnesium may be equal to or greater than 0.85 wt%. In some variations, magnesium may be equal to or greater than 0.90 wt%.

Additional Non-Aluminum Elements

[0044] The disclosed 6000 series aluminum alloys may include other elements as disclosed below.

[0045] In some variations, gallium may be equal to or less than 0.20 wt%. In some variations, gallium may be equal to or less than 0.15 wt%. In some variations, gallium may be equal to or less than 0.10 wt%. In some variations, gallium may be equal to or less than 0.08 wt%. In some variations, gallium may be equal to or less than 0.06 wt%. In some variations, gallium may be equal to or less than 0.04 wt%. In some variations, gallium may be equal to or less than 0.03 wt%. In some variations, gallium may be equal to or less than 0.02 wt%. In some variations, gallium may be equal to or less than 0.015 wt%. In some variations, gallium may be equal to or less than 0.01 wt%. In some variations, gallium may be equal to or less than 0.005 wt%. In some variations, gallium may be equal to or less than 0.001 wt%.

[0046] In some variations, tin may be equal to or less than 0.20 wt%. In some variations, tin may be equal to or less than 0.15 wt%. In some variations, tin may be equal to or less than 0.10 wt%. In some variations, tin may be equal to or less than 0.08 wt%. In some variations, tin may be equal to or less than 0.06 wt%. In some variations, tin may be equal to or less than 0.04 wt%. In some variations, tin may be equal to or less than 0.01 wt%. In some variations, tin may be equal to or less than 0.008 wt%. In some variations, tin may be equal to or less than 0.006 wt%. In some variations, tin may be equal to or less than 0.004 wt%. In some variations, tin may be equal to or less than 0.002 wt%.

[0047] In some variations, vanadium may be equal to or less than 0.20 wt%. In some variations, vanadium may be equal to or less than 0.15 wt%. In some variations, vanadium may be equal to or less than 0.10 wt%. In some variations, vanadium may be equal to or less than 0.08 wt%. In some variations, vanadium may be equal to or less than 0.06 wt%. In some variations, vanadium may be equal to or less than 0.04 wt%. In some variations, vanadium may be equal to or less than 0.02 wt%. In some variations, vanadium may be equal to or less than 0.01 wt%. In some variations, vanadium may be equal to or less than 0.005 wt%. In some variations, vanadium may be equal to or less than 0.001 wt%.

[0048] In some variations, calcium may be equal to or less than 0.01 wt%. In some variations, calcium may be equal to or less than 0.008 wt%. In some variations, calcium may be equal to or less than 0.006 wt%. In some variations, calcium may be equal to or less than 0.005 wt%. In some variations, calcium may be equal to or less than 0.003 wt%. In some variations, calcium may be equal to or less than 0.002 wt%. In some variations, calcium may be equal to or less than 0.001 wt%.

[0049] In some variations, sodium may be equal to or less than 0.008 wt%. In some variations, sodium may be equal to or less than 0.006 wt%. In some variations, sodium may be equal to or less than 0.004 wt%. In some variations, sodium may be equal to or less than 0.002 wt%. In some variations, sodium may be equal to or less than 0.001 wt%.

[0050] One or more of other elements, including boron, zirconium, lithium, cadmium, lead, nickel, phosphorous, among others, may be equal to or less than 0.1 wt%. One or more of other elements, including boron, zirconium, lithium, cadmium, lead, nickel, phosphorous, among others, may be equal to or less than 0.08 wt%. One or more of these other elements may be equal to or less than 0.06 wt%. One or more of these other elements may be equal to or less than 0.04 wt%. One or more of other elements may be equal to or less than 0.02 wt%.

[0051] In some variations, a total of other elements may not exceed 0.20 wt%. In some variations, a total of other elements may not exceed 0.10 wt%. In some variations, a total of other elements may not exceed 0.08 wt%. In some variations, a total of other elements may not exceed 0.06 wt%. In some variations, a total of other elements may not exceed 0.04 wt%.

Cosmetic Appeal

[0052] The aluminum alloys disclosed herein typically have more Fe than in conventional aluminum alloys. Anodized aluminum alloys having higher amounts of Fe typically have a more gray color. Market scrap can include more Fe than the conventional 6000 series aluminum alloys. As described above, the recycled aluminum alloys described herein can have more Fe than that is typically present in aluminum alloys with cosmetic appeal.

[0053] Fe has negative effects on the cosmetic appeal by creating an unattractive gray color. In addition to having a negative effect on cosmetics, Fe contributes to the formation of iron-aluminum-silicon particles during processing. The acquisition of Si by the Fe particles can reduce the amount of Si available for strengthening. As such, more Si may be added to the alloys disclosed herein. The presently disclosed alloys have increased Si and increased Fe. Contrary to expectations, the properties of the alloy are consistent or better than alloys with such undesirable amounts of Fe.

[0054] In some embodiments, the disclosed 6000 series aluminum alloys can be anodized. Anodizing is a surface treatment process for metal, most commonly used to protect aluminum alloys. Anodizing uses electrolytic passivation to increase the thickness of the natural oxide layer on the surface of metal parts. Anodizing may increase corrosion resistance and wear resistance, and may also provide better adhesion for paint primers and glues than bare metal. Anodized films may also be used for cosmetic effects, for example, it may add interference effects to reflected light.

[0055] Surprisingly, the disclosed recycled 6000 series aluminum alloys have the same or improved cosmetic appeal as those with lower Fe, Si, and Mg. In particular, after anodizing they do not have a yellowish or gray color, and do not have increased cosmetic defects such as mottling, grain lines, black lines, discoloration, white dots, oxidation, and line mark, among others.

[0056] In some embodiments, the disclosed 6000 series aluminum alloys can form enclosures for electronic devices. The enclosures may be designed to have a blasted surface finish absent of streaky lines. Blasting is a surface finishing process, for example, smoothing a rough surface or roughening a smooth surface. Blasting may texture surface material by forcibly propelling a stream of abrasive media against a surface under high pressure.

[0057] Standard methods may be used for evaluation of cosmetics including color, gloss and haze. The color of objects may be determined by the wavelength of light that is reflected or transmitted without being absorbed, assuming incident light is white light. The visual appearance of objects may vary with light reflection or transmission. Additional appearance attributes may be based on the directional brightness distribution of reflected light or transmitted light, commonly referred to as glossy, shiny, dull, clear, hazy, among others. The quantitative evaluation may be performed based on ASTM Standards on Color & Appearance Measurement or ASTM E-430 Standard Test Methods for Measurement of Gloss of High-Gloss Surfaces, including ASTM D523 (Gloss), ASTM D2457 (Gloss on plastics), ASTM E430 (Gloss on high-gloss surfaces, haze), and ASTM D5767 (DOI), among others. The measurements of gloss, haze, and DOI (distinctness of image) may be performed by testing equipment, such as Rhopoint IQ.

[0058] In some embodiments, color may be quantified by parameters L^* , a^* , and b^* , where L^* stands for light brightness, a^* stands for color between red and green, and b^* stands for color between blue and yellow. For example, high b^* values suggest an unappealing yellowish color, not a gold yellow color. Nearly zero parameters a^* and b^* suggest a neutral color. Low L^* values suggest dark brightness, while high L^* value suggests great brightness. For color measurement, testing equipment, such as X-Rite ColorEye XTH, X-Rite Coloreye 7000 may be used. These measurements are according to CIE/ISO standards for illuminants, observers, and the L^* , a^* , and b^* color scale. For example, the standards include: (a) ISO 11664-1:2007(E)/CIE S 014-1/E:2006: Joint ISO/CIE Standard: Colorimetry - Part 1: CIE Standard Colorimetric Observers; (b) ISO 11664-2:2007(E)/CIE S 014-2/E:2006: Joint ISO/CIE Standard: Colorimetry - Part 2: CIE Standard Illuminants for Colorimetry, (c) ISO 11664-3:2012(E)/CIE S 014-3/E:2011: Joint ISO/CIE Standard: Colorimetry - Part 3: CIE Tristimulus Values; and (d) ISO 11664-4:2008(E)/CIE S 014-4/E:2007: Joint ISO/CIE Standard: Colorimetry - Part 4: CIE 1976 L^* , a^* , and b^* Color Space.

[0059] In some variations, b^* is from -2 to 2. In some variations, b^* is equal to or greater than -1.9. In some variations, b^* is equal to or greater than -1.8. In some variations, b^* is equal to or greater than -1.7. In some variations, b^* is equal to or greater than -1.6. In some variations, b^* is equal to or greater than -1.5. In some variations, b^* is equal to or greater than -1.4. In some variations, b^* is equal to or greater than -1.3. In some variations, b^* is equal to or greater than -1.2. In some variations, b^* is equal to or greater than -1.1. In some variations, b^* is equal to or greater than -1.0. In some variations, b^* is equal to or greater than -0.9. In some variations, b^* is equal to or greater than -0.8. In some variations, b^* is equal to or greater than -0.7. In some variations, b^* is equal to or greater than -0.6. In some variations, b^* is equal to or greater than -0.5. In some variations, b^* is equal to or greater than -0.4. In some variations, b^* is equal to or greater than -0.3. In some variations, b^* is equal to or greater than -0.2. In some variations, b^* is equal to or greater than -0.1. In some variations, b^* is equal to or greater than 0. In some variations, b^* is equal to or greater than 0.1. In some variations, b^* is greater than or equal to 0.2. In some variations, b^* is greater than or equal to 0.3. In some variations, b^* is greater than or equal to 0.4. In some variations, b^* is greater than or equal to 0.5. In some variations, b^* is greater than or equal to 0.6. In some variations, b^* is greater than or equal to 0.7. In some variations, b^* is greater than or equal to 0.8. In some variations, b^* is greater than or equal to 0.9. In some variations, b^* is equal to or greater than 1.0. In

some variations, b^* is equal to or greater than 1.1. In some variations, b^* is greater than or equal to 1.2. In some variations, b^* is greater than or equal to 1.3. In some variations, b^* is greater than or equal to 1.4. In some variations, b^* is greater than or equal to 1.5. In some variations, b^* is greater than or equal to 1.6. In some variations, b^* is greater than or equal to 1.7. In some variations, b^* is greater than or equal to 1.8. In some variations, b^* is greater than or equal to 1.9.

[0060] In some variations, b^* is equal to or less than -1.9. In some variations, b^* is equal to or less than -1.8. In some variations, b^* is equal to or less than -1.7. In some variations, b^* is equal to or less than -1.6. In some variations, b^* is equal to or less than -1.5. In some variations, b^* is equal to or less than -1.4. In some variations, b^* is equal to or less than -1.3. In some variations, b^* is equal to or less than -1.2. In some variations, b^* is equal to or less than -1.1. In some variations, b^* is equal to or less than -1.0. In some variations, b^* is equal to or less than -0.9. In some variations, b^* is equal to or less than -0.8. In some variations, b^* is equal to or less than -0.7. In some variations, b^* is equal to or less than -0.6. In some variations, b^* is equal to or less than -0.5. In some variations, b^* is equal to or less than -0.4. In some variations, b^* is equal to or less than -0.3. In some variations, b^* is equal to or less than -0.2. In some variations, b^* is equal to or less than -0.1. In some variations, b^* is equal to or less than 0. In some variations, b^* is equal to or less than 0.1. In some variations, b^* is less than or equal to 0.2. In some variations, b^* is less than or equal to 0.3. In some variations, b^* is less than or equal to 0.4. In some variations, b^* is less than or equal to 0.5. In some variations, b^* is less than or equal to 0.6. In some variations, b^* is less than or equal to 0.7. In some variations, b^* is less than or equal to 0.8. In some variations, b^* is less than or equal to 0.9. In some variations, b^* is less than or equal to 1.0. In some variations, b^* is less than or equal to 1.1. In some variations, b^* is less than or equal to 1.2. In some variations, b^* is less than or equal to 1.3. In some variations, b^* is less than or equal to 1.4. In some variations, b^* is less than or equal to 1.5. In some variations, b^* is less than or equal to 1.6. In some variations, b^* is less than or equal to 1.7. In some variations, b^* is less than or equal to 1.8. In some variations, b^* is less than or equal to 1.9. In some variations, b^* is less than or equal to 2.0.

[0061] In some variations, L^* is from 70 to 100. In some variations, L^* is equal to or greater than 70. In some variations, L^* is equal to or greater than 75. In some variations, L^* is equal to or greater than 80. In some variations, L^* is equal to or greater than 85. In some variations, L^* is equal to or greater than 90. In some variations, L^* is equal to or greater than 95. In some variations, L^* is less than or equal to 100. In some variations, L^* is less than or equal to 95. In some variations, L^* is less than or equal to 90. In some variations, L^* is less than or equal to 85. In some variations, L^* is less than or equal to 80. In some variations, L^* is less than or equal to 75.

[0062] In some variations, a^* is from -2 to 2. In some variations, a^* is equal to or greater than -2. In some variations, a^* is equal to or greater than -1.5. In some variations, a^* is equal to or greater than -1.0. In some variations, a^* is equal to or greater than -0.5. In some variations, a^* is equal to or greater than 0.0. In some variations, a^* is equal to or greater than 0.5. In some variations, a^* is equal to or greater than -0.5. In some variations, a^* is equal to or greater than 1.0. In some variations, a^* is equal to or greater than 1.5. In some variations, a^* is less than or equal to 2.0. In some variations, a^* is less than or equal to 1.5. In some variations, a^* is less than or equal to 1.0. In some variations, a^* is less than or equal to 0.5. In some variations, a^* is less than or equal to 0.0. In some variations, a^* is less than or equal to 2.0. In some variations, a^* is less than or equal to -0.5. In some variations, a^* is less than or equal to -1.0. In some variations, a^* is less than or equal to -1.5.

Mechanical Properties

[0063] Yield strengths of the alloys may be determined via ASTM B557, which covers the testing apparatus, test specimens, and testing procedure for tensile testing.

[0064] The 6000 series aluminum alloys can be extruded or rolled with the conventional process for aluminum alloys to have the mechanical properties, including yield strength, tensile strength, elongation, and hardness, to be the same as the aluminum alloy without any scrap.

Grain Aspect Ratio

[0065] In some variations, the disclosed alloys have a grain aspect ratio from 0.7 to 1.45. Assuming that the grain is in an ellipse shape. The grain shape aspect ratio is defined as the length of the minor axis divided by the length of the major axis of the ellipse.

[0066] In some variations, the alloys have an average grain aspect ratio greater than or equal to 0.7:1.0. In some variations, the alloys have an average grain aspect ratio less than or equal to 0.8:1.0. In some variations, the alloys have an average grain aspect ratio greater than or equal to 0.9:1.0. In some variations, the alloys have an average grain aspect ratio greater than or equal to 1.0:1.0.

[0067] In some variations, the alloys have an average grain aspect ratio greater than or equal to 1:1.45. In some variations, the alloys have an average grain aspect ratio greater than or equal to 1:1.40. In some variations, the alloys have an average grain aspect ratio greater than or equal to 1:1.35. In some variations, the alloys have an average grain

aspect ratio greater than or equal to 1:1.30. In some variations, the alloys have an average grain aspect ratio greater than or equal to 1:1.25. In some variations, the alloys have an average grain aspect ratio greater than or equal to 1:1.20. In some variations, the alloys have an average grain aspect ratio greater than or equal to 1:1.15. In some variations, the alloys have an average grain aspect ratio greater than or equal to 1:1.10. In some variations, the alloys have an average grain aspect ratio greater than or equal to 1:1.05.

[0068] In some variations, the alloys have an average grain aspect ratio less than or equal to 0.8:1.0. In some variations, the alloys have an average grain aspect ratio less than or equal to 0.9:1.0. In some variations, the alloys have an average grain aspect ratio less than or equal to 1.0:1.0. In some variations, the alloys have an average grain aspect ratio less than or equal to 1:1.45. In some variations, the alloys have an average grain aspect ratio less than or equal to 1:1.40. In some variations, the alloys have an average grain aspect ratio less than or equal to 1:1.35. In some variations, the alloys have an average grain aspect ratio less than or equal to 1:1.30. In some variations, the alloys have an average grain aspect ratio less than or equal to 1:1.25. In some variations, the alloys have an average grain aspect ratio less than or equal to 1:1.20. In some variations, the alloys have an average grain aspect ratio less than or equal to 1:1.15. In some variations, the alloys have an average grain aspect ratio less than or equal to 1:1.10. In some variations, the alloys have an average grain aspect ratio less than or equal to 1:1.05.

Corrosion Resistance

[0069] The recycled alloys that include higher Fe and Zn content than other alloys would be expected to reduce corrosion resistance. Various corrosion tests were performed to evaluate corrosion resistance or corrosion susceptibility of the sample alloys A0, A1, A2, A3, and/or A4.

Cyclic Polarization Test

[0070] Cyclic polarization was performed per ASTM G5 to evaluate the general corrosion properties of various materials. For example, the cyclic polarization helps understand whether the material would undergo active, passive, or localized corrosion. It also provides measurements of corrosion rates and pitting potential.

[0071] Cyclic polarization is a short-term exposure test. It provides information on both corrosion characteristics and corrosion mechanisms. Cyclic polarization measurements are typically used to characterize metals and alloys that derive their corrosion resistance from the formation of a thin passive film.

[0072] The aluminum samples were exposed to 0.35% NaCl solution for the duration of the test (approximately 45 minutes). The corrosion susceptibility of the samples was evaluated by cyclic polarization.

Metastable Pitting

[0073] Metastable pit testing was performed to gain an understanding of susceptibility of a material to localized corrosion, in particular, metastable pitting. This metastable pitting test was run by placing the material at a constant potential where metastable pitting would occur. The constant potential used in the metastable pitting tests was determined from the cyclic polarization test described above. The electric current was recorded during the metastable pitting test and analyzed to identify current transients, such as small spikes in the current. Each current transient was associated with a metastable pitting event. The data were analyzed for a number of metastable pitting events, the magnitudes of these current spikes, and the time interval for each event. The values of the number of metastable pitting events, the magnitudes of these current spikes, and the time interval for each event were compared to rank the susceptibility of the material to metastable pitting. Metastable pitting can be characterized by current fluctuations or current transients when an alloy is held below E_{pit} (pitting potential). These current transients correspond to the nucleation, growth and repassivation of metastable pits.

[0074] The aluminum samples were exposed to a 0.35% NaCl solution for the duration of the test (approximately 15 minutes). The corrosion susceptibility of the samples was evaluated by metastable pitting test results.

Salt Fog Testing

[0075] Salt Fog Testing was performed per ASTM B117 to provide a controlled corrosive environment that can be used to compare the relative corrosion susceptibility between different materials or coatings. In the salt spray test, a standardized solution of 5% NaCl (sodium chloride) was aerosolized to create a highly corrosive atmosphere. The aluminum samples were exposed to the salt fog for 24 hours.

Electrical Impedance Spectroscopy (EIS) Tests

[0076] Electrical Impedance Spectroscopy (EIS) was used to evaluate the corrosion performance of the seal of the anodized aluminum. One of the most useful attributes of anodizing in the cosmetic finishing of aluminum alloys is that anodizing can generate highly porous, optically transparent oxides which can be dyed to a particular color, and then sealed to permanently fix this color. This is particularly true of sulfuric acid anodizing performed in accordance with the "Type II" category of Mil A 8625. Such anodic aluminum oxides are mesoporous, for example, with pores of about 20 nm diameter of good wettability and very high aspect ratio.

[0077] A wide spectrum of color is achievable through organic dyeing of anodic oxides, with organic dyes offering all colors but white. Color can be tuned by adjusting the composition of the dye bath (e.g. concentration of colorants, and pH), and by adjusting the time and temperature of the dye bath. By maintaining a constant bath composition, pH and temperature, time may be used to fine-tune the color to any given color target during production.

[0078] The dye is locked into the pores by a subsequent "sealing" process, which also serves to protect the porosity against staining and any uptake of dirt in service.

[0079] Hydrothermal sealing can be used to fill the pores by hydrating the amorphous alumina of the cell walls to a gel of Boehmite ($\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$) and/or Bayerite ($\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$), such that the gel swells and closes the open volume. This may be performed in steam, in hot water (typically at or near boiling, and usually with additives to minimize smutting), or at temperatures as low as 70°C. It is greatly enhanced (possibly catalyzed) by using chemistries such as nickel acetate which additionally precipitate metal hydroxides in the pores. After sealing, parts are protected against absorption of material into their pore structure, and are thus insensitive to staining or dirt. Indeed, one of the simpler test of seal quality is a "dye spot test" wherein the inability of a sealed surface to absorb dye is measured. Other tests of seal quality include the quantitative measures of electrochemical impedance spectroscopy (EIS), a simplified variant of EIS performed at a fixed frequency (typically 1 kHz) called "admittance" testing, and acid dissolution testing (ADT).

[0080] Quantitative measures of seal quality reveal a sensitivity to time after sealing - sometimes referred to as ageing or "natural ageing". Older parts generally show better seal quality than freshly sealed parts and this is attributed to a continued hydration, occurring over weeks and even months or years. It has also been observed, however, that parts which are thoroughly dried before sealing cannot seal naturally by this process.

[0081] A good seal (e.g. one with a 1 kHz admittance value (measured in microSiemens in accordance with ISO 2931) of less than 400 times the reciprocal of its thickness (measured in microns) - when measured within 48 h of sealing - a specification set by Qualanod standard) may be achieved in production by immersion in an aqueous solution of nickel acetate at 5-10 g/l and at temperatures of 96 degrees C or more, for a period of 15 minutes or more in the case of a Type II anodic oxide film with a film thickness of 10 to 15 microns.

[0082] The EIS tests were performed per ASTM G106. The EIS technique can be used to evaluate materials and their coatings in corrosive environments. The EIS measures impedance of the materials and their coatings at different frequencies. Changes in electrical properties determined by EIS experiments have been found to closely relate to long-term performance of the materials and their coatings. This EIS method can detect deterioration of the materials and their coatings well before defects become visible and is more quantifiable than with other accelerated corrosion testing methods such as salt spray.

[0083] For EIS tests, a measuring cell was placed on an anodized panel, filled with a 3.5% NaCl solution. A platinum electrode was used as a counter electrode, and a standard Ag/AgCl cell as reference electrode. Measurements were carried out over a broad frequency range from 100 kHz to 10 mHz, using a 10 mV amplitude sinusoidal voltage.

[0084] The seal quality of the anodized aluminum was determined after 48 hours exposure to 3.5% NaCl.

Examples

[0085] The following examples are for illustration purposes only. It will be apparent to those skilled in the art that many modifications, both to materials and methods, may be practiced without departing from the scope of the disclosure.

Samples

[0086] Table 1 lists the compositions for samples alloys A0, A1, A2, A3, and A4 with different total impurities and elemental compositions. A0, A1, and A4 were cosmetic aluminum alloys. Alloys A2 and A3 were recycled aluminum alloys from market scrap. Alloy A0 has less than 0.02 wt% Mn, less than 0.01 wt% Cr, less than 0.01 wt% Cu, and less than 0.01 wt% Zn. Alloys A1 and A4 have less than 0.03 wt% Mn, less than 0.01 wt % Cr, less than 0.02 wt% Cu, and less than 0.02 wt % Zn. Alloy A0 had a low total impurity of 0.195 wt%, including Fe, Cu, Mn, Zn, Ti, and Cr. Alloy A1 had a slightly higher total impurity of 0.3 wt%, including Fe, Cu, Mn, Zn, Ti than alloy A0, and Cr. Alloy A3 had a higher total impurity of 0.45 wt%, including Fe, Cu, Mn, Zn, Ti, and Cr than A0 and A1. Alloy A2 had a higher total impurity of 0.68 wt%, including Fe, Cu, Mn, Zn, Ti, and Cr. Alloy A4 had a total impurity of 0.35%.

[0087] Table 1 lists the composition in wt% for various alloys of the disclosure. Surprisingly, increased amounts of one or more of Mn, Cr, Cu, and Zn in the Al alloys result in aluminum alloys having a neutral color, smaller grain aspect ratio, and/or smaller grain size as described herein.

[0088] Alloy A2 had Fe greater than 0.20, which was higher than alloys A0, A1, and A4. Alloys A2 and A3 had Zn from 0.020 to 0.20, which was higher than alloys A0, A1, and A4.

Table 1: Composition in wt% for Various Al Alloys

Sample	A0	A1	A2	A3	A4
Total impurity	0.20	0.30	0.69	0.45	0.35
Mg	at least 0.45	at least 0.45	at least 0.45	at least 0.45	at least 0.45
Fe	up to 0.20	at least 0.10	greater than 0.20	up to 0.20	up to 0.20
Si	at least 0.30	at least 0.35	at least 0.35	at least 0.35	at least 0.35
Mn	less than 0.05	0.03-0.10	0.03-0.10	0.03-0.10	0.03-0.10
Cr	less than 0.05	0.01 -0.10	0.01 -0.10	0.01 -0.10	0.01 - 0.10
Cu	less than 0.05	0.010-0.050	0.051-0.10	0.051-0.10	0.010-0.050
Ni	less than 0.05	less than 0.05	less than 0.05	less than 0.05	less than 0.05
Zn	less than 0.05	0.01 to 0.020	0.020 to 0.20	0.020 to 0.20	0.01 to 0.020
Ti	less than 0.05	less than 0.10	less than 0.10	less than 0.10	less than 0.10

[0089] The data corresponding to different preparations were presented in box plots, as shown in FIGs. 1A-1D, 2A-2C, 4A-4B, 5A-5B, and 6A-6B.

[0090] FIG. 1A illustrates the yield strength for extrusion samples formed of various 6000 series aluminum alloys in accordance with an embodiment of the disclosure. As shown in FIG. 1A, the yield strength was above 200 MPa for recycled alloys A2 and A3, similar to that of alloys A0, A1, and A4.

[0091] FIG. 1B illustrates the tensile strength for extrusion samples formed of various 6000 series aluminum alloys in accordance with an embodiment of the disclosure. As shown in FIG. 1B, the ultimate tensile strength was above 235 MPa for recycled alloys A2 and A3, similar to that of alloys A0, A1, and A4.

[0092] FIG. 1C illustrates the elongation for extrusion samples formed of various 6000 series aluminum alloys in accordance with an embodiment of the disclosure. As shown in FIG. 1C, the elongation was mostly above 5% for recycled alloys A2 and A3, similar to that of alloys A0, A1, and A4.

[0093] FIG. 1D illustrates the hardness for extrusion samples formed of various 6000 series aluminum alloys in accordance with an embodiment of the disclosure. As shown in FIG. 1D, the hardness was above 75 Hv for recycled alloys A2 and A3, similar to that of alloys A0, A1, and A4.

[0094] Microstructure can be characterized by average grain size, largest grain size, and grain aspect ratio.

[0095] FIG. 2A illustrates the average grain size for extrusion samples formed of various 6000 series aluminum alloys. As shown in FIG. 2A, the average grain size was below 240 μm for recycled alloys A2 and A3, similar to that of alloys A0, A1, and A4.

[0096] FIG. 2B illustrates the largest grain size for extrusion samples formed of various 6000 series aluminum alloys in accordance with an embodiment of the disclosure. As shown in FIG. 2B, the as-large-as grain size was below 650 μm for recycled alloys A2 and A3, similar to that of alloys A0, A1, and A4.

[0097] FIG. 2C illustrates the grain aspect ratio for extrusion samples formed of various 6000 series aluminum alloys in accordance with an embodiment of the disclosure. As shown in FIG. 2C, the aspect ratio of the grain was between a lower limit value of 0.7 and a higher limit value of 1.45 for recycled alloys A2 and A3, and similar to that of alloys A0, A1, and A4.

[0098] FIG. 3 illustrates extrusion speed for various 6000 series aluminum alloys in accordance with embodiments of the disclosure. The extrusion speeds of A2-A4 were normalized to typical extrusion speed of A0 or A1. Product 1 includes A2, A3, and A4. Product 2 includes A2 and A3. Product 3 includes A2 and A3. Band 1 is the typical extrusion speed. As shown in FIG. 3, recycled alloys A2, A3, had similar extrusion speeds to Alloys A1 and A4.

[0099] Four different corrosion tests were performed on alloys A0, A1, A2, A3, and/or A4. Surprisingly, the corrosion resistance in each corrosion test was found to be maintained for the recycled aluminum alloys, although the impurity contents in the recycled aluminum alloys were increased. Four different corrosion tests were performed.

[0100] The quality of the seal of the anodized aluminum was determined after 48 hours exposure to 3.5% NaCl.

Electrochemical impedances were determined by using electrochemical impedance spectroscopy per ASTM G106. FIG. 4A illustrates comparison of electrochemical impedance of the aluminum samples having different total impurities and different elemental compositions for a neutral color aluminum or non-dyed anodized aluminum (NDA).

[0101] As shown in FIG. 4A, the average impedance was about 290,000 ohms-cm² for alloy A1 and was above 290,000 ohms-cm² for recycled alloys A2 and A3. The recycled alloys A2 and A3 with higher total impurities revealed that the impedance was comparable with the alloy A1 with lower total impurities. The alloys with higher impurities (such as Fe and/or Zn) may be expected to have poorer corrosion resistance compared to alloys with lower impurities because higher amounts of impurities may compromise the anodized coating. Y. Ma et al. "Corrosion Behavior of Anodized Al-Cu-Li Alloy: The Role of Intermetallic Particle-Introduced Film Defects," Corrosion Science, 158 (2019) 108110, and C. Blocking et al. "Mechanism of Adhesion Failure of Anodised Coatings on 7075 Aluminum Alloy," disclose the anodized coatings, both of which are herein incorporated by reference. Transactions of the Institute of Metal Finishing, 2011, vol. 89 No.6, pages 298-302). As such, the results of comparable impedances of the recycled alloys to the alloys with low impurities exceeded the expectations.

[0102] FIG. 4B illustrates comparison of electrochemical impedance of the aluminum samples having different total impurities and different elemental compositions for a grey color of anodized aluminum.

[0103] Note that raw material composition is the largest contributor to the NDA color. The grey color of anodized aluminum alloy can have the same alloy composition. The grey color can be predominately affected by the dye and process and can be tuned toward a desired color.

[0104] As shown in FIG. 4B, the average impedance was about 210,000 ohms-cm² for alloy A1, and was above 210,000 ohms-cm² for recycled alloys A2 and A3. The corrosion resistance of the recycled alloy A2 and A3 with higher total impurities revealed that the impedance was comparable with the alloy A1 with lower total impurities. This result suggested that the color, either neutral or grey color, did not affect the electrochemical impedance or corrosion resistance.

[0105] The corrosion susceptibility to 0.35% NaCl solution of the sample alloys was determined. Corrosion rates and pitting potentials were determined by using cyclic polarization per ASTM G5. FIG. 5A illustrates comparison of corrosion rate of the aluminum samples having different total impurities and different elemental compositions for a non-anodized alloy. The non-anodized alloy was a bare metal and was not colored with dye. As shown in FIG. 5A, the average corrosion rate was 150 $\mu\text{A}/\text{CM}^2$ for alloy A1, and was less than 150 $\mu\text{A}/\text{cM}^2$ for recycled alloys A2 and A3. The recycled alloys A2 and A3 with higher total impurities revealed that the corrosion rates were worse than the alloy A0 with lower total impurities, but were not worse than the alloy A1 with lower total impurities. Generally, the alloys with higher impurities (i.e. Fe and/or Zn) may be expected to have higher corrosion rates compared to alloys with lower impurities. As such, the results of comparable corrosion rates of the recycled alloys to the alloys with low impurities corrosion rates exceeded expectations.

[0106] FIG. 5B illustrates comparison of pitting potential of the aluminum samples having different total impurities and different elemental compositions for a non-anodized alloy. The non-anodized alloy was a bare metal and was not colored with dye. As shown in FIG. 5B, the average pitting potential was below -675 mVSCE for alloys A0 and A1, and was higher than 675 mVSCE for recycled alloys A2 and A3. The recycled alloy A2 and A3 with higher Zn and/or Fe impurities revealed that the pitting potential was not worse than the alloys A0 and A1 with lower Zn and/or Fe impurities. Generally, the alloys with higher impurities (e.g. Zn and/or Fe) may be expected to have lower pitting potential compared to alloys with lower impurities. As such, the results of comparable pitting potential of the recycled alloys to the alloys with low impurities exceeded expectations.

[0107] The metastable pitting, i.e. corrosion susceptibility to 0.35% NaCl solution, was determined. FIG. 6A illustrates comparison of the number of pits of the aluminum samples having different total impurities and different elemental compositions for a non-anodized alloy. The non-anodized alloy was a bare metal and was not colored with dye. As shown in FIG. 6A, the average number of pits per test was about 2000 for alloy A1, and was higher than about 1500 for recycled alloy A2. The recycled alloy A2 with higher Zn and Fe impurities revealed that the number of pits per test was not worse than the alloy A1 with lower Zn and Fe impurities. Generally, the alloys with higher impurities (e.g. Fe and/or Zn) may be expected to have higher number of pits per test compared to alloys with lower impurities. As such, the results of comparable number of pits per test of the recycled alloys to the alloys with low impurities number of pits exceeded expectations.

[0108] FIG. 6B illustrates comparison of pit radius of the aluminum samples having different total impurities and different elemental compositions for a non-anodized alloy. The non-anodized alloy was a bare metal and was not colored with dye. As shown in FIG. 6B, the average pit radius was about 0.4 μm for all alloys A0, A1, A2, and A3. Surprisingly, the higher impurities in recycled alloys A2 and A3 did not seem to worsen the pit radius compared to the alloys A0 and A1 with lower impurities.

[0109] Salt fog test pass rate was determined per ASTM B117. FIG. 7 illustrates comparison of salt fog test pass rate of the aluminum samples having different total impurities and different elemental compositions for a neutral color aluminum or NDA and a grey color aluminum. As shown in FIG. 7, the recycled samples A2 and A3 having higher total impurities revealed the same salt fog pass rates as the alloys A0, A1, and A4 having lower total impurities. The alloys with higher

impurities (e.g. Fe and/or Zn) may be expected to have lower pass rate compared to alloys with lower impurities. As such, the results of comparable pass rate of the recycled alloys to the alloys having lower impurities exceeded expectations.

5 **Process for Cleaning and Removing Oxides from Scrap**

[0110] Scrap can have a large surface area/volume ratio compared to virgin material. The large surface area of the scrap can include a substantial quantity of oxides, such as aluminum oxides. Scrap may also include impurities, such as Cu, Zn, Mn, Cr, Fe, among others, compared to conventional 6000 series aluminum alloys or 1000 series alloys.

[0111] The cleaning process may include removing oxides by re-melting scrap and flowing oxides and skim off the oxides. The cleaning process may also include removing organic contaminants by chemical solvent or solution or heating.

[0112] FIG. 8 depicts a recycling process 800 of materials including manufacturing scrap in accordance with embodiments of the disclosure. Aluminum scrap 802 is sourced and sent to an alloy processor 804. Additional aluminum scrap can be obtained from post-consumer scrap source 812 or process scrap source 814. The alloy can be processed during aluminum manufacturing 806. The manufactured product can proceed to final assembly 808, and then to the customer 810. Processed scrap can be obtained from multiple different sources in the supply chain, and the amount of different elements can be adjusted to form the alloys of the disclosure.

[0113] The disclosed recycled 6000 series aluminum alloys can be made from up to 100% Al scrap, and can be used to form a part by extrusion or sheet rolling. The disclosed recycled 6000 series aluminum alloys can also include scrap from the extrusion or sheet fabrication process. In some variations, the disclosed methods can include or exclude primary aluminum or virgin aluminum.

[0114] The disclosed aluminum alloys and methods of making the alloys can be used in the fabrication of electronic devices. An electronic device herein can refer to any electronic device known in the art. For example, such devices can include wearable devices such as a watch (e.g., an AppleWatch®). Devices can also be a telephone such a mobile phone (e.g., an iPhone®) a land-line phone, or any communication device (e.g., an electronic email sending/receiving device). The alloys can be a part of a display, such as a digital display, a TV monitor, an electronic-book reader, a portable web-browser (e.g., iPad®), and a computer monitor. The alloys can also be an entertainment device, including a portable DVD player, conventional DVD player, Blue-Ray disk player, video game console, music player, such as a portable music player (e.g., iPod®), etc. The alloys can also be a part of a device that provides control, such as controlling the streaming of images, videos, sounds (e.g., Apple TV®), or can be a remote control for an electronic device. The alloys can be a part of a computer or its accessories, such as the hard drive tower housing or casing for MacBook Air or Mac Mini.

[0115] Any ranges cited herein are inclusive. The terms "substantially" and "about" used throughout this Specification are used to describe and account for small fluctuations. For example, they can refer to less than or equal to $\pm 5\%$, such as less than or equal to $\pm 2\%$, such as less than or equal to $\pm 1\%$, such as less than or equal to $\pm 0.5\%$, such as less than or equal to $\pm 0.2\%$, such as less than or equal to $\pm 0.1\%$, such as less than or equal to $\pm 0.05\%$.

[0116] Having described several embodiments, it will be recognized by those skilled in the art that various modifications, alternative constructions, and equivalents may be used without departing from the spirit of the invention. Additionally, a number of well-known processes and elements have not been described in order to avoid unnecessarily obscuring the invention. Accordingly, the above description should not be taken as limiting the scope of the invention.

[0117] Those skilled in the art will appreciate that the disclosed embodiments teach by way of example and not by limitation. Therefore, the matter contained in the above description or shown in the accompanying drawings should be interpreted as illustrative and not in a limiting sense. The following claims are intended to cover all generic and specific features described herein, as well as all statements of the scope of the method and system, which, as a matter of language, might be said to fall there between.

Claims

1. An aluminum alloy comprising:

copper (Cu) from 0.051 to 0.10 wt%;
chromium (Cr) from 0.01 to 0.10 wt%;
zinc (Zn) from 0.02 to 0.20 wt%;
manganese (Mn) from 0.03 to 0.10 wt%;
iron (Fe) in an amount of at least 0.10 wt%;
silicon (Si) in an amount of at least 0.35 wt%;
magnesium (Mg) in an amount of at least 0.45 wt%; and

remaining wt% being Al and incidental impurities,

wherein b^* ranges from -2 to 2, and L^* ranges from 70 to 100.

2. The aluminum alloy of claim 1, further comprising elements selected from:

titanium (Ti) from 0 to 0.10 wt%;
gallium (Ga) from 0 to 0.20 wt%;
tin (Sn) from 0 to 0.20 wt%;
vanadium (V) from 0 to 0.20 wt%;
calcium (Ca) from 0 to 0.01 wt%;
sodium (Na) from 0 to 0.008 wt%;
boron (B) from 0 to 0.10 wt%;
zirconium (Zr) from 0 to 0.10 wt%;
lithium (Li) from 0 to 0.10 wt%;
cadmium (Cd) from 0 to 0.10 wt%;
lead (Pb) from 0 to 0.10 wt%;
nickel (Ni) from 0 to 0.10 wt%;
phosphorous (P) from 0 to 0.10 wt%; and
combinations thereof.

3. The aluminum alloy of one of claims 1-3, wherein b^* ranges from -1.5 to 1.5.

4. The aluminum alloy of one of claims 1-3, wherein b^* ranges from 0 to 1.0.

5. The aluminum alloy of one of claims 1-3, wherein b^* ranges from -1.0 to 0.

6. The aluminum alloy of one of claims 1-3, wherein b^* ranges from -0.5 to 0.5.

7. The aluminum alloy of one of claims 1-3, wherein b^* ranges from 0 to 0.5.

8. The aluminum alloy of one of claims 1-3, wherein b^* ranges from -0.5 to 0.

9. The aluminum alloy of one of claims 1-3, wherein b^* ranges from 0 to 1.5.

10. The aluminum alloy of one of claims 1-3, wherein b^* ranges from -1.5 to 0.

11. The aluminum alloy of any one preceding claim, wherein the aluminum alloy has an average grain ratio from 0.7 to 1.45.

12. The aluminum alloy of any one preceding claim, wherein the aluminum alloy has average grain ratio from 1.0 to 1.2.

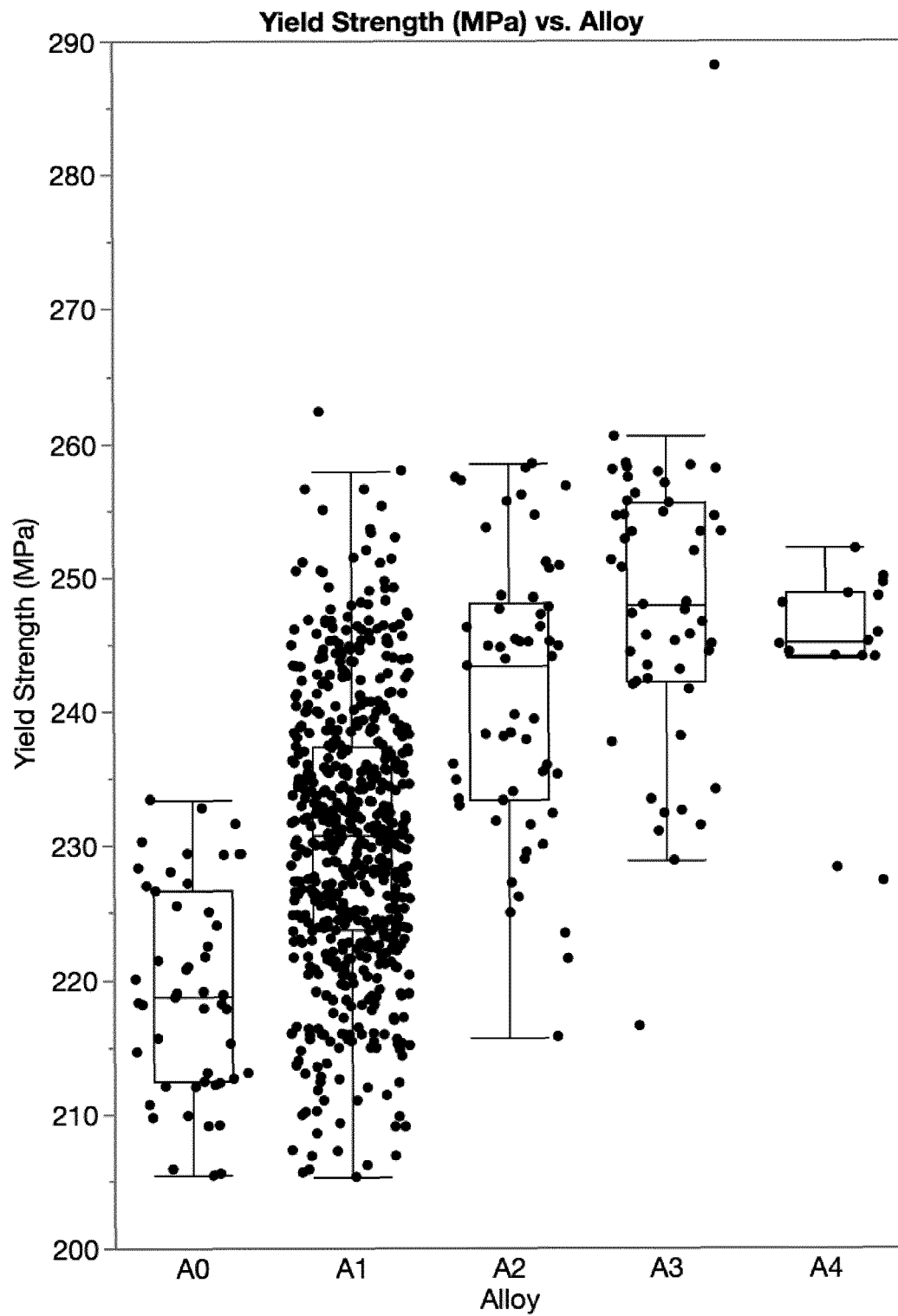
13. The aluminum alloy of any one preceding claim, wherein the aluminum alloy is in the form of an extruded part and has a yield strength of at least 200 MPa and a tensile strength of at least 235 MPa.

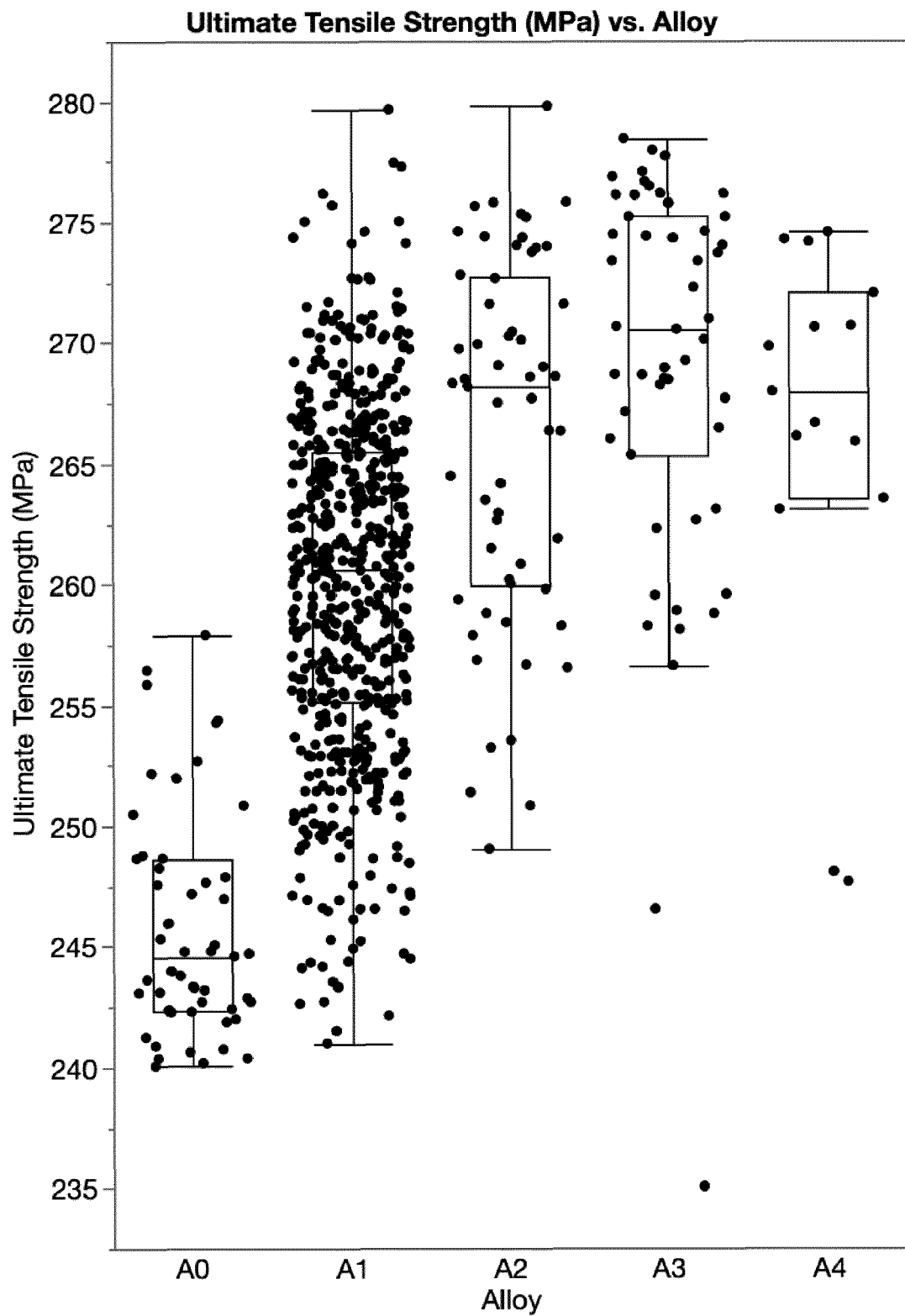
14. The aluminum alloy of any one preceding claim, wherein the aluminum alloy is in the form of an extruded part and has a hardness of at least 75 Vickers.

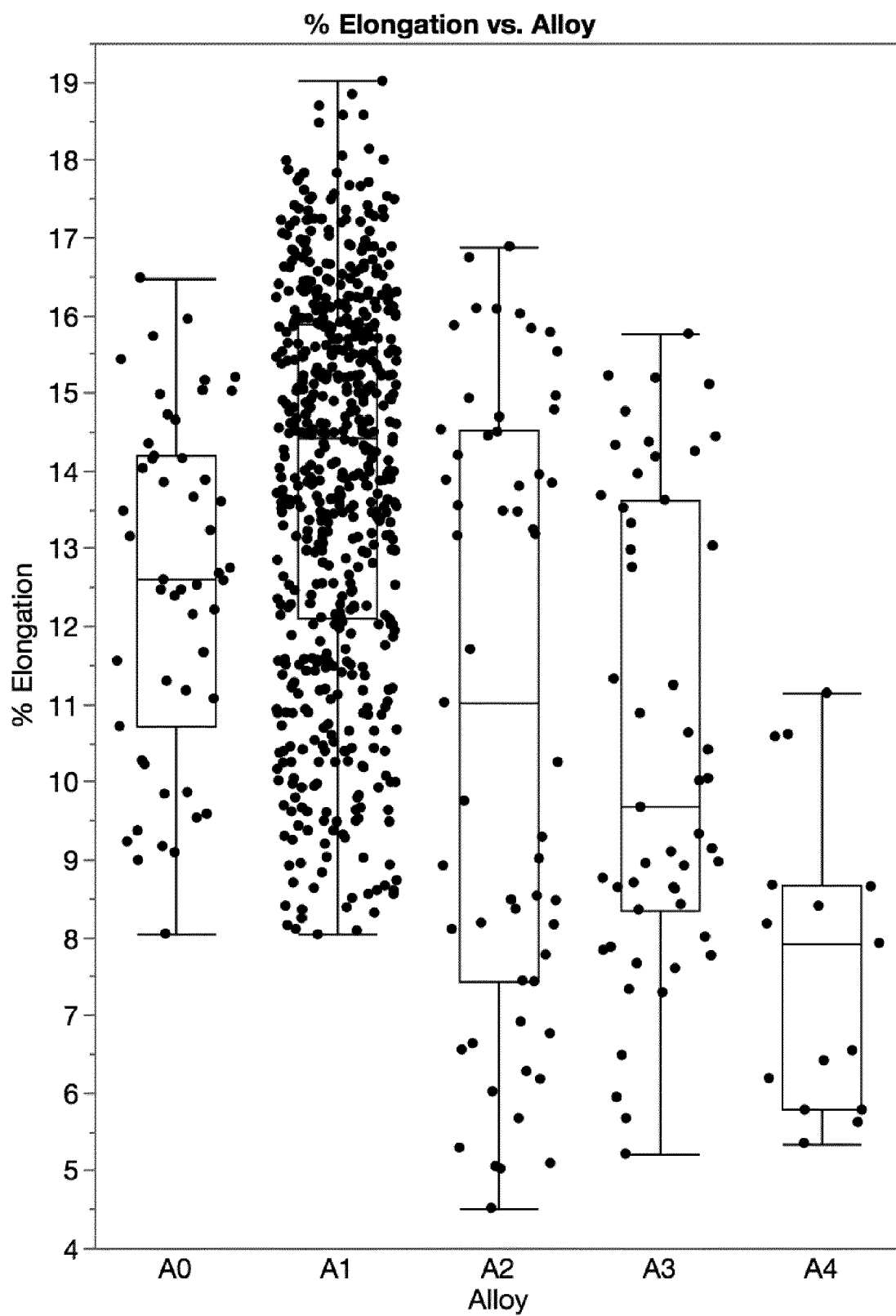
15. A process of making the aluminum alloy of any one preceding claim comprising:

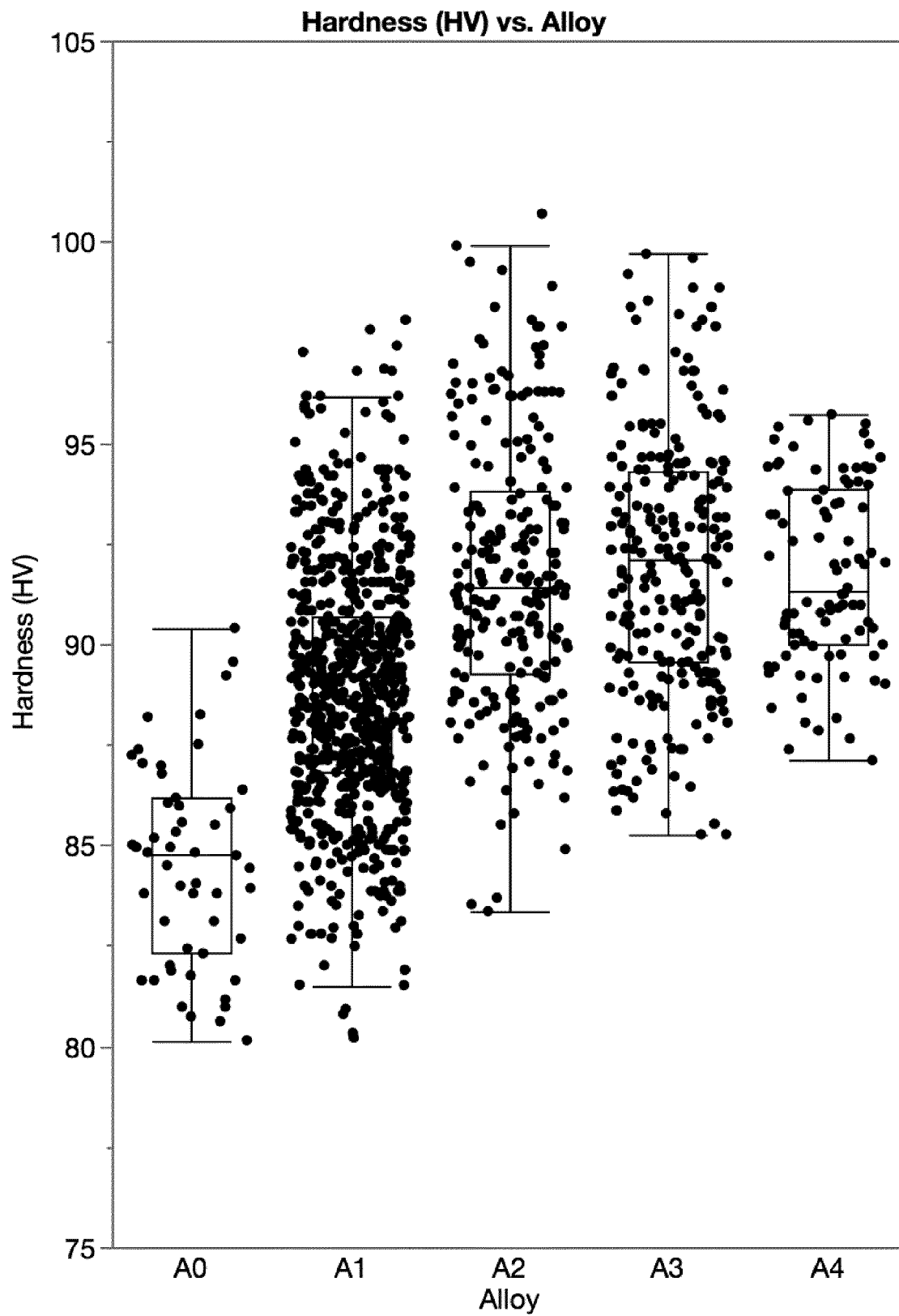
(a) obtaining an aluminum scrap from one or more sources;
(b) melting the aluminum scrap to form a melted aluminum alloy;
(c) casting the melted aluminum alloy to form a cast alloy;
(d) rolling the casted alloy to form a sheet, or extruding the casted alloy to form an extrusion; and
(e) fabricating the sheet or extrusion to produce an aluminum part.

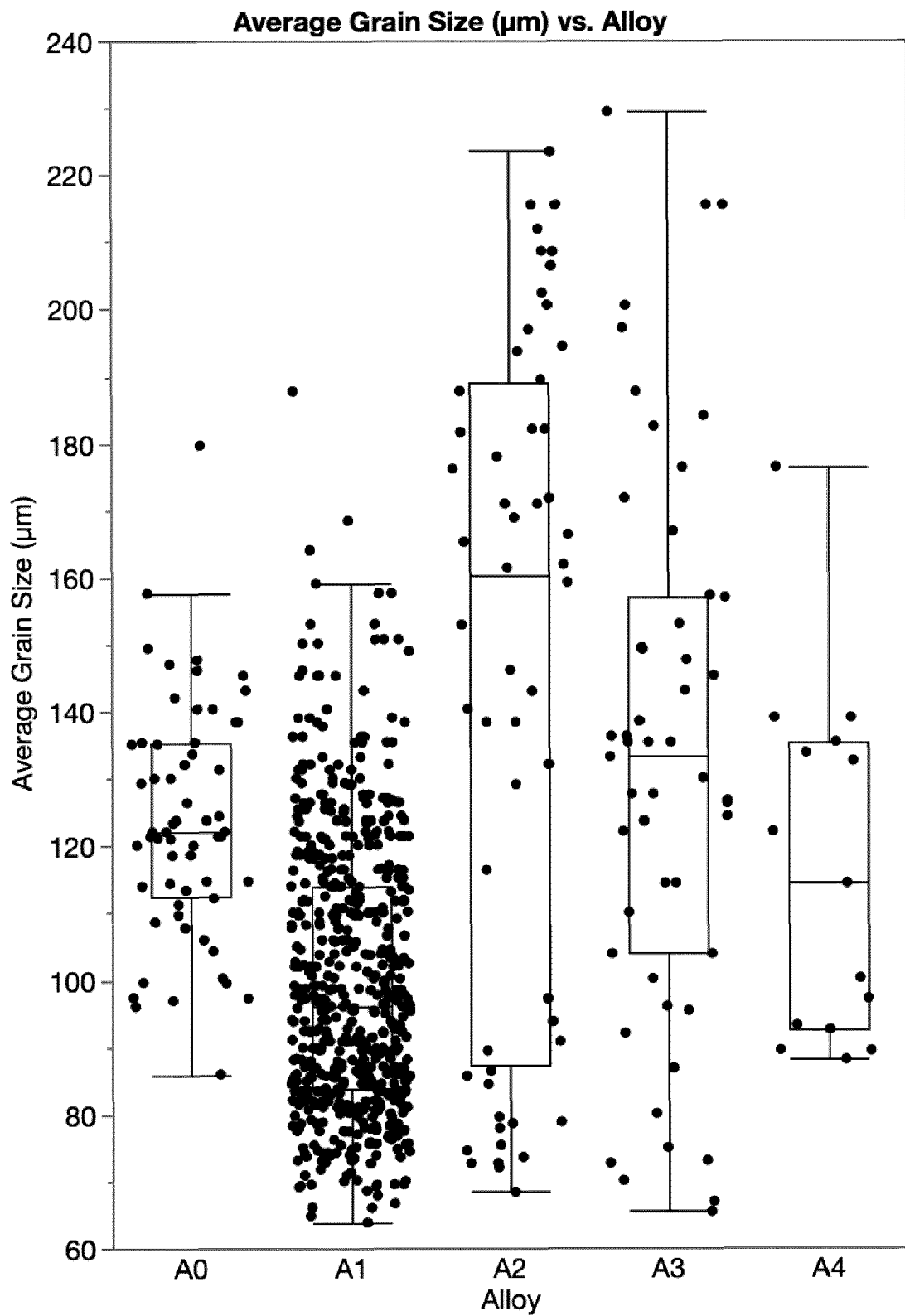
16. The process of claim 15, wherein the step of melting comprises removing oxides from the aluminum scrap.

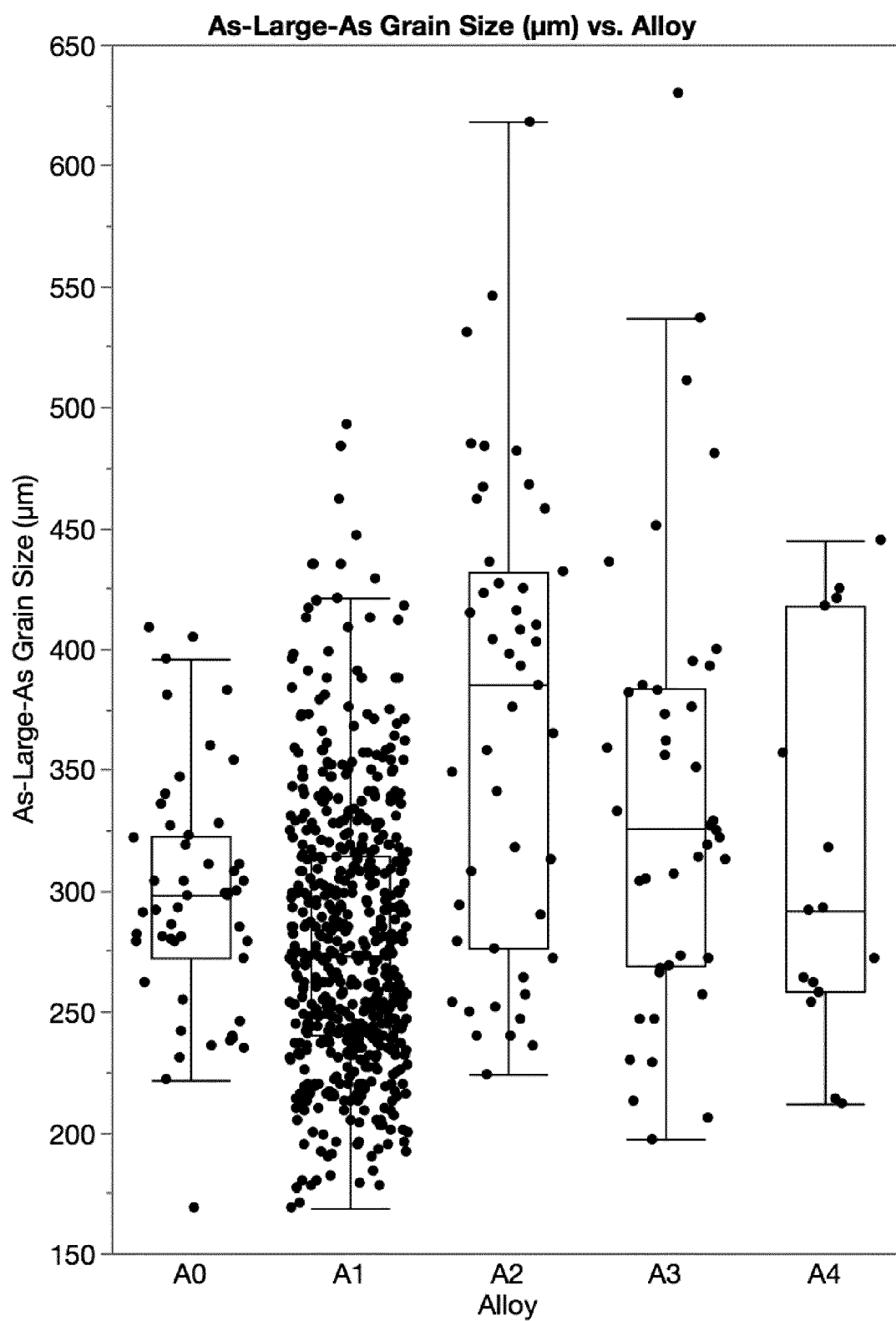
*FIG. 1A*

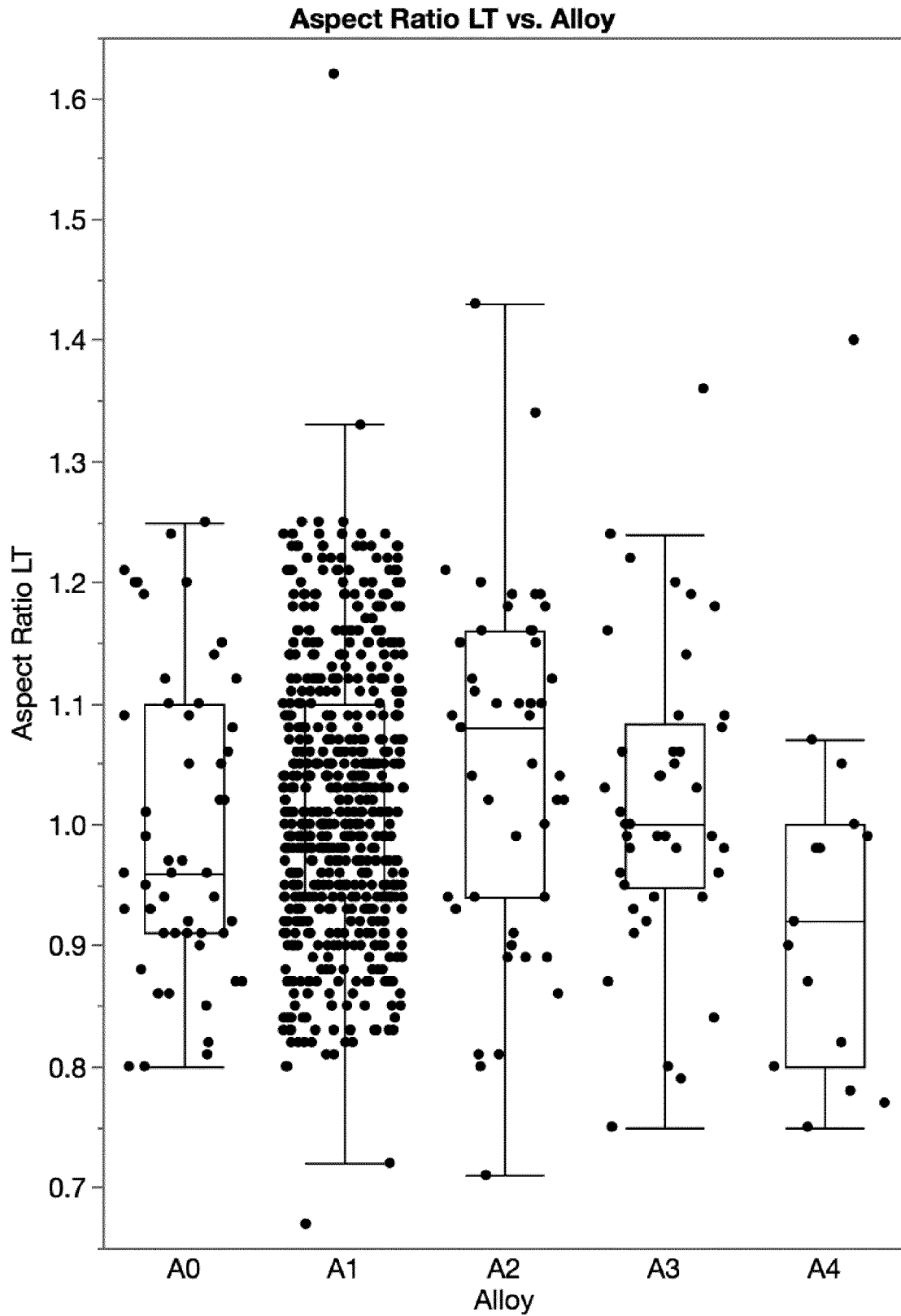
*FIG. 1B*

*FIG. 1C*

*FIG. 1D*

*FIG. 2A*

*FIG. 2B*

*FIG. 2C*

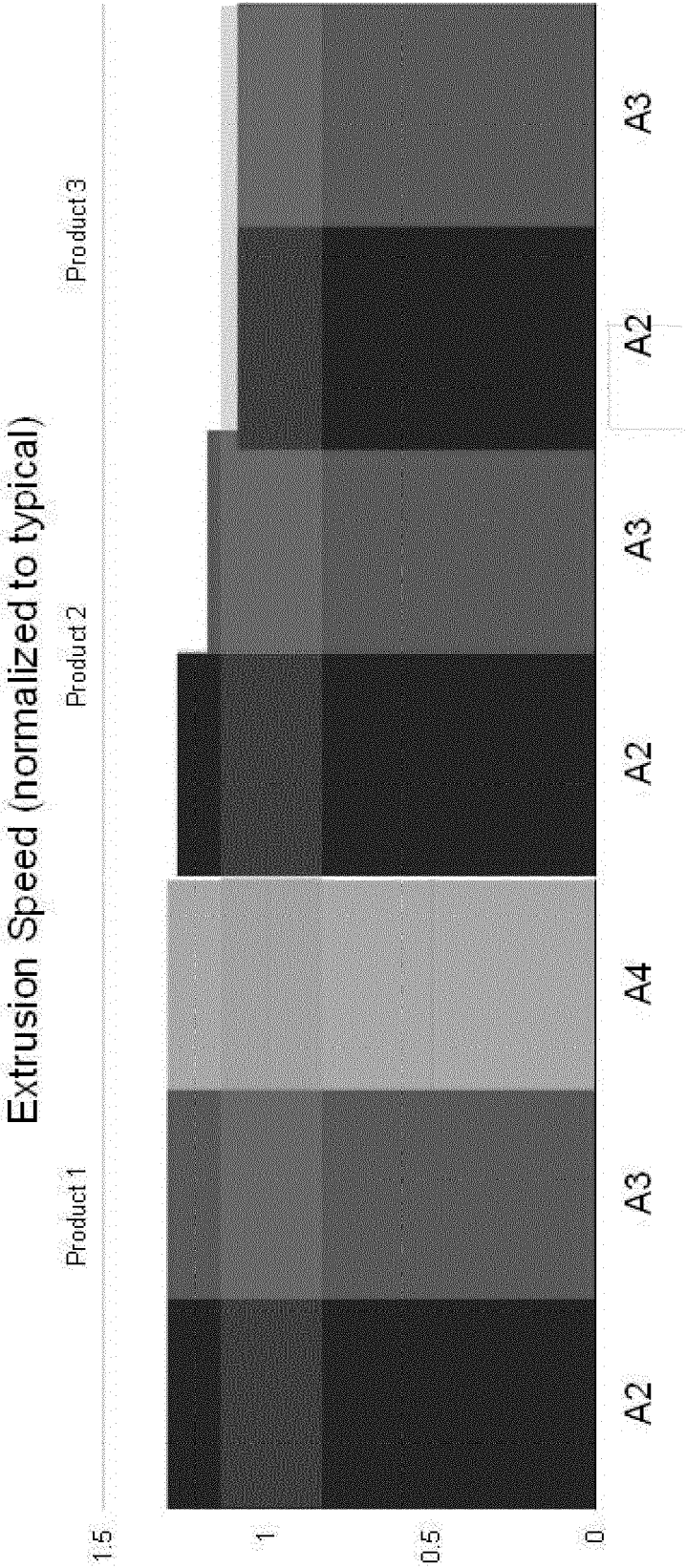


FIG. 3

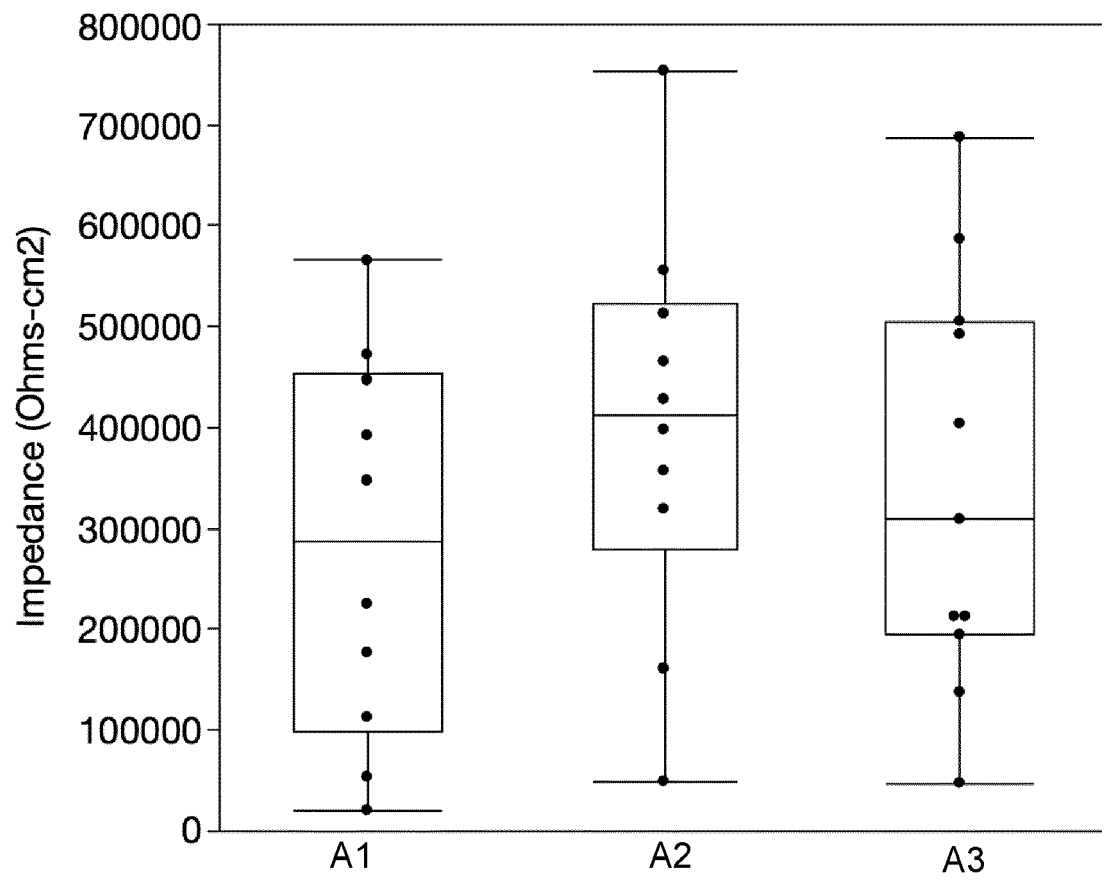
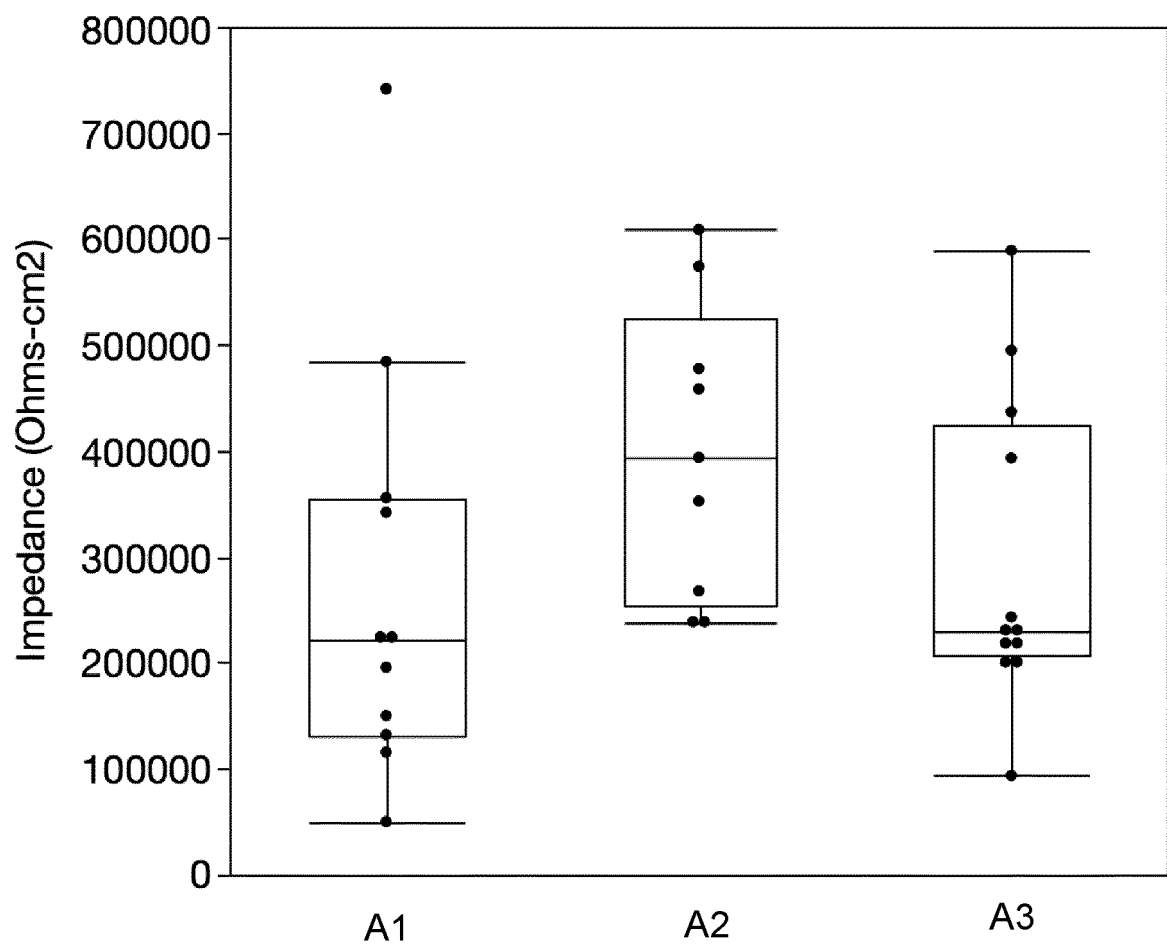
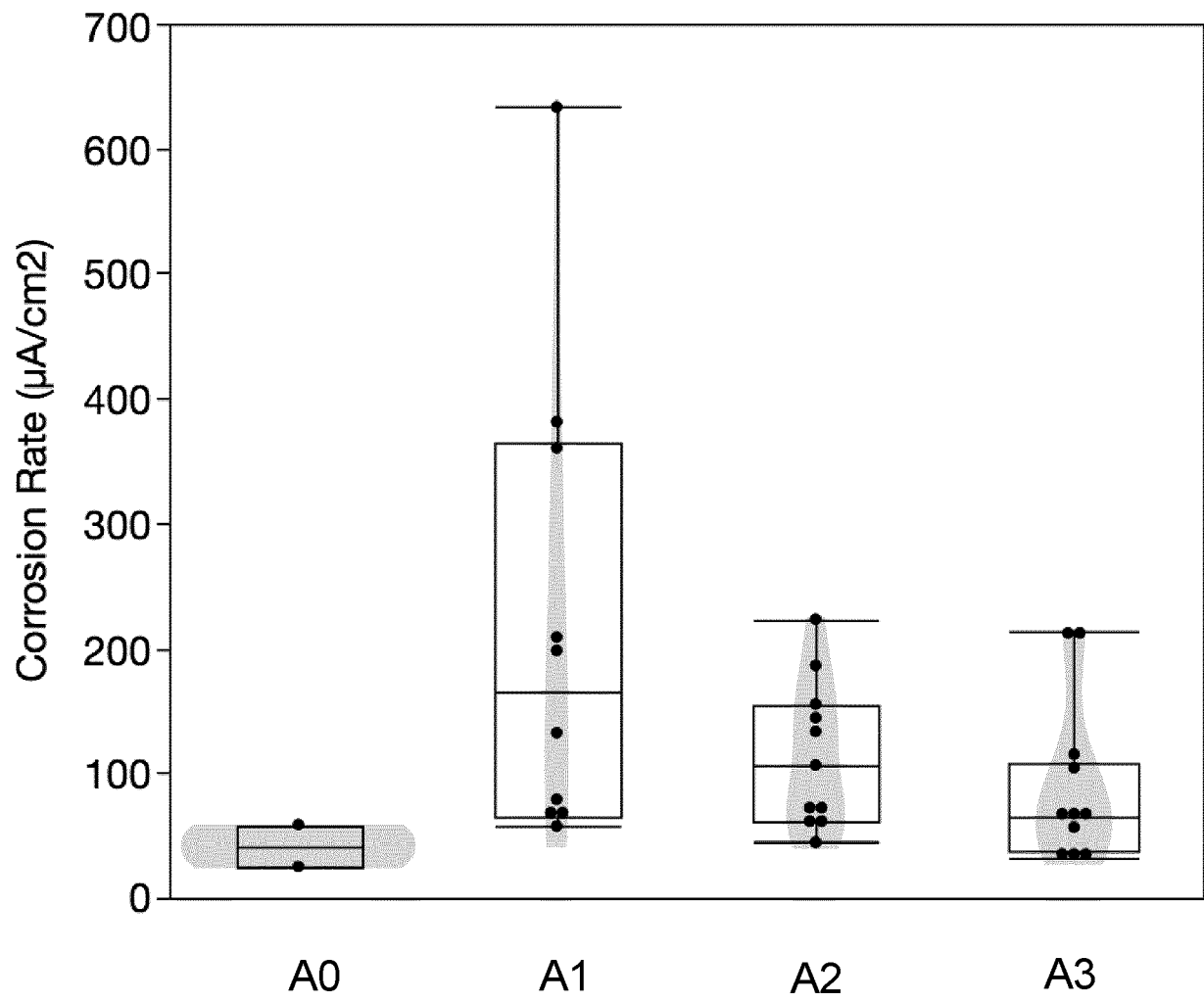
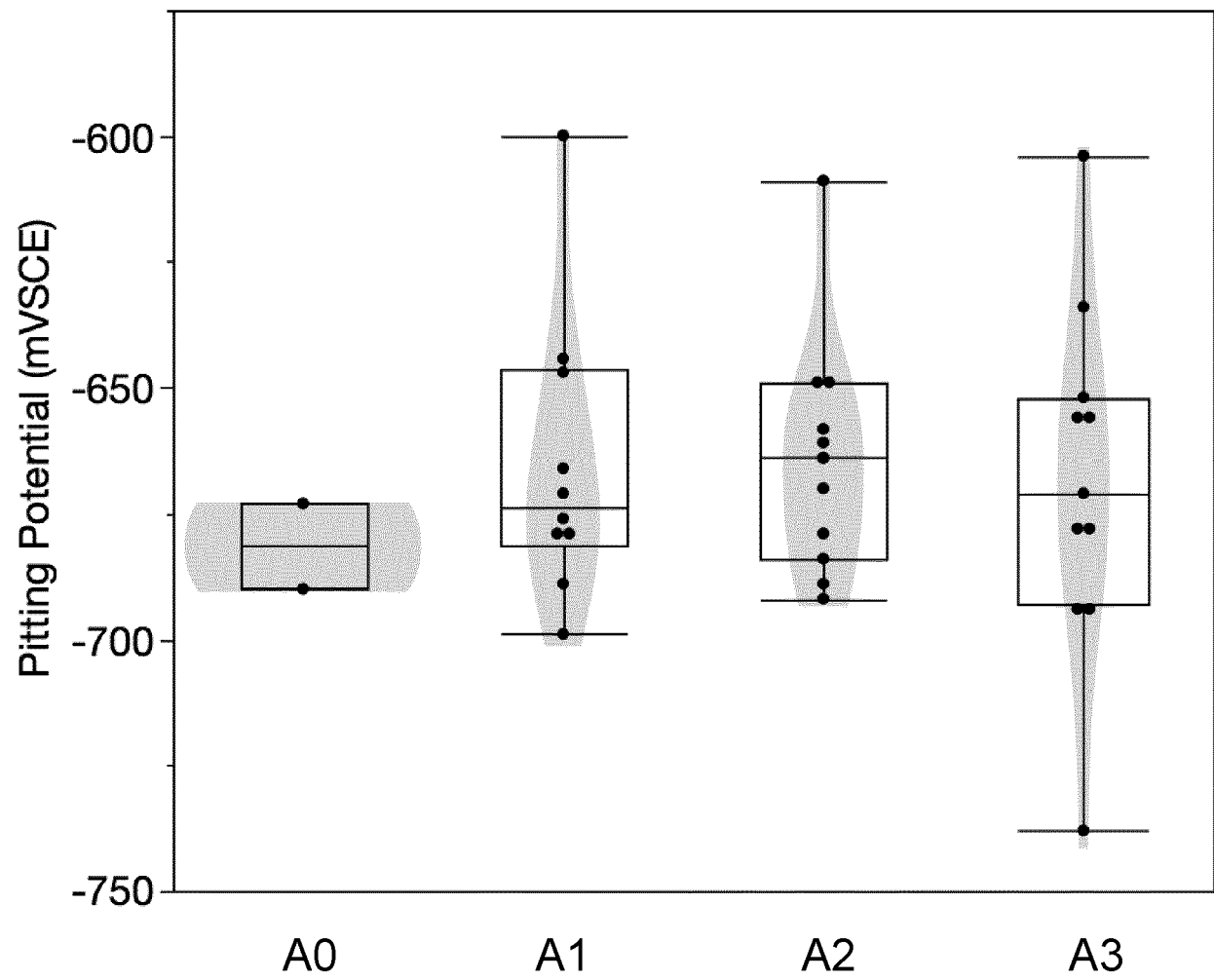


FIG. 4A

*FIG. 4B*

*FIG. 5A*

*FIG. 5B*

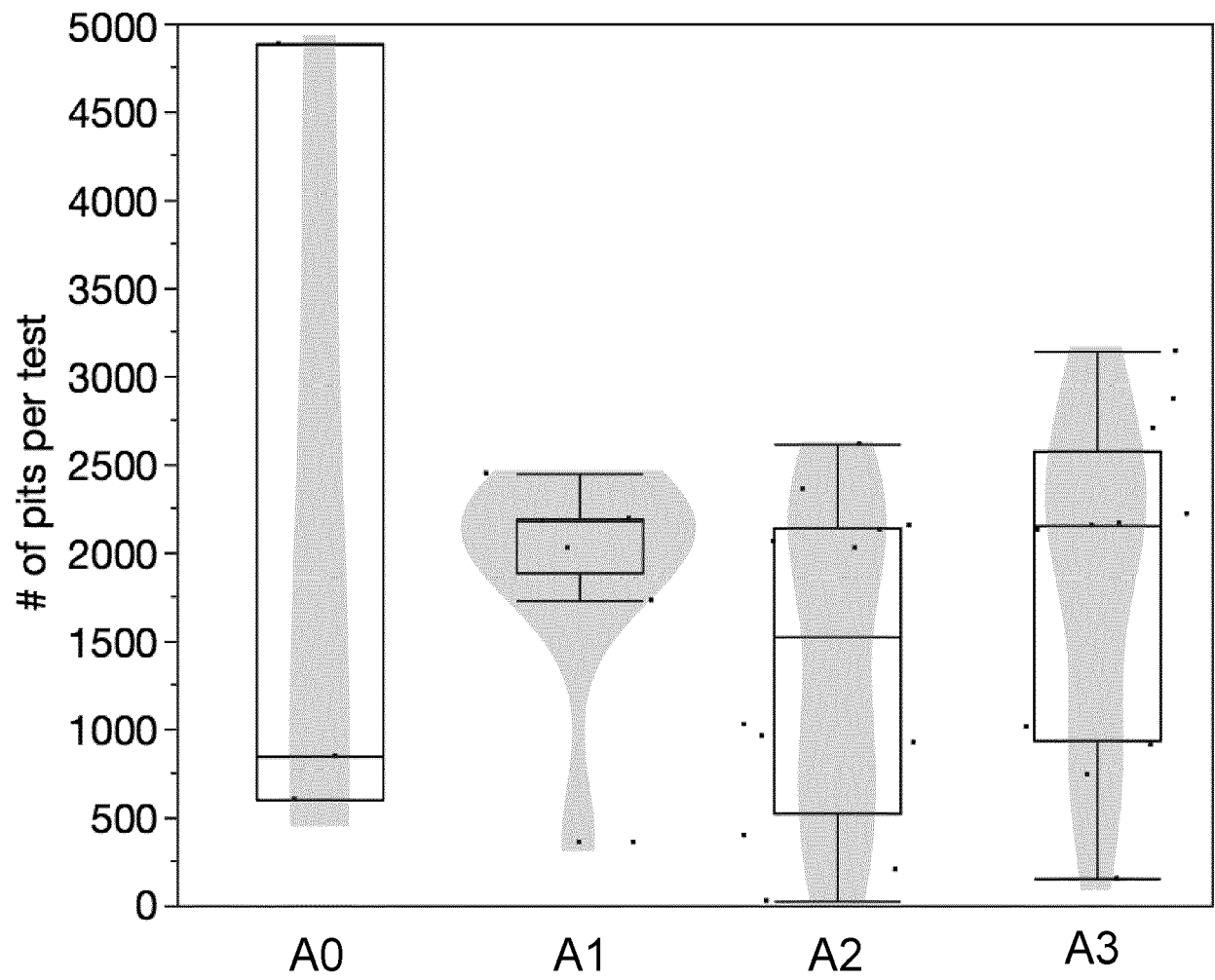
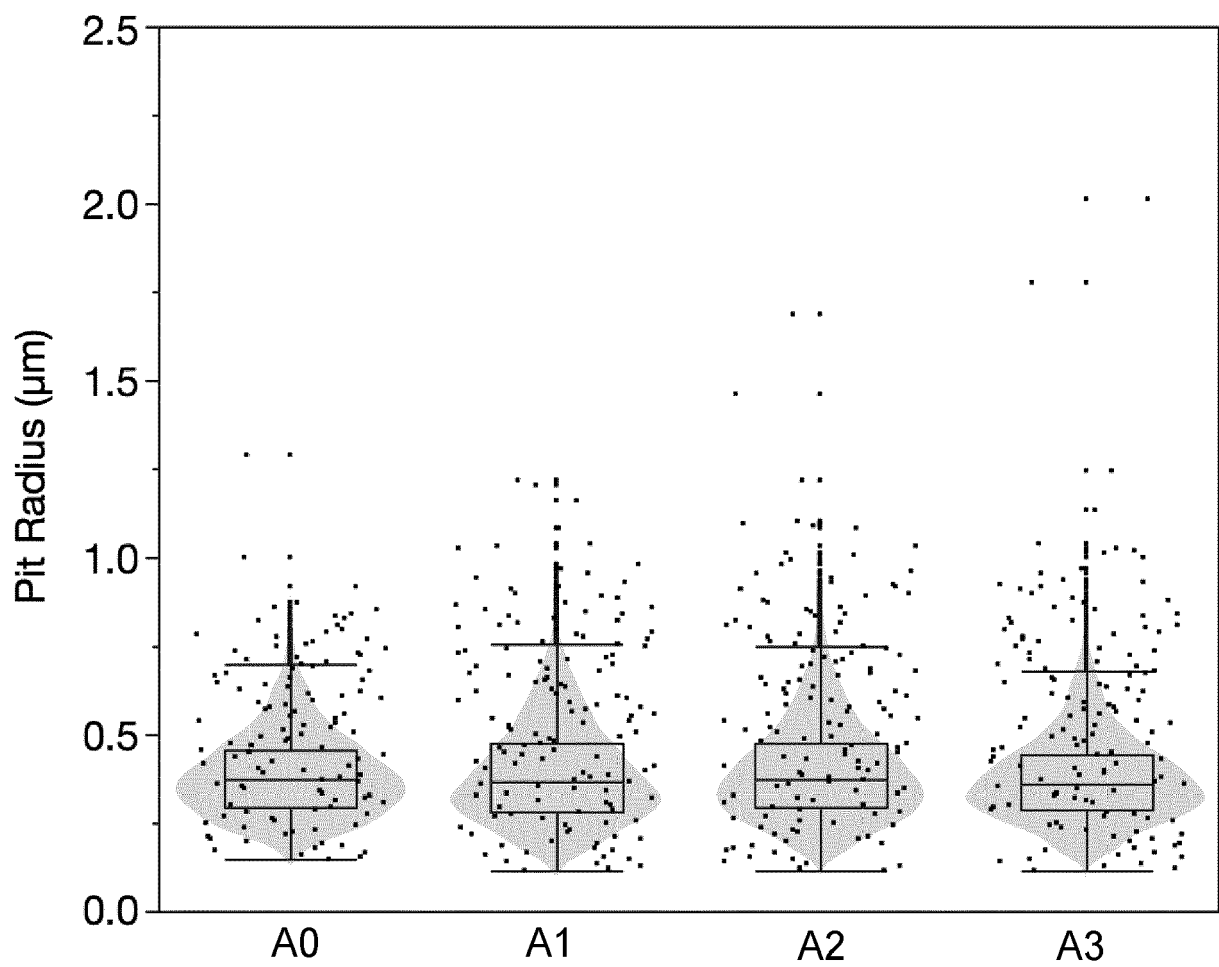


FIG. 6A

*FIG. 6B*

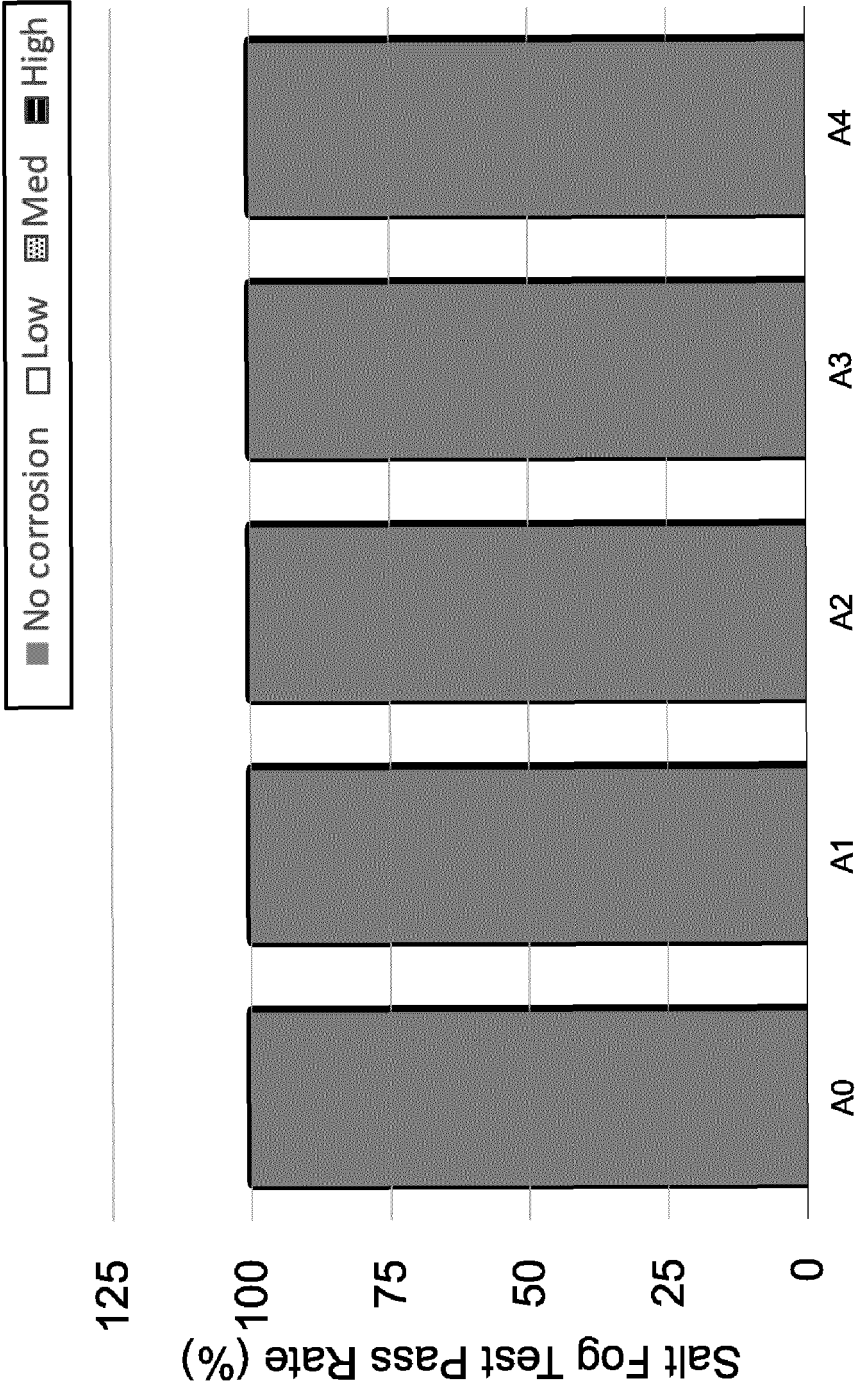


FIG. 7

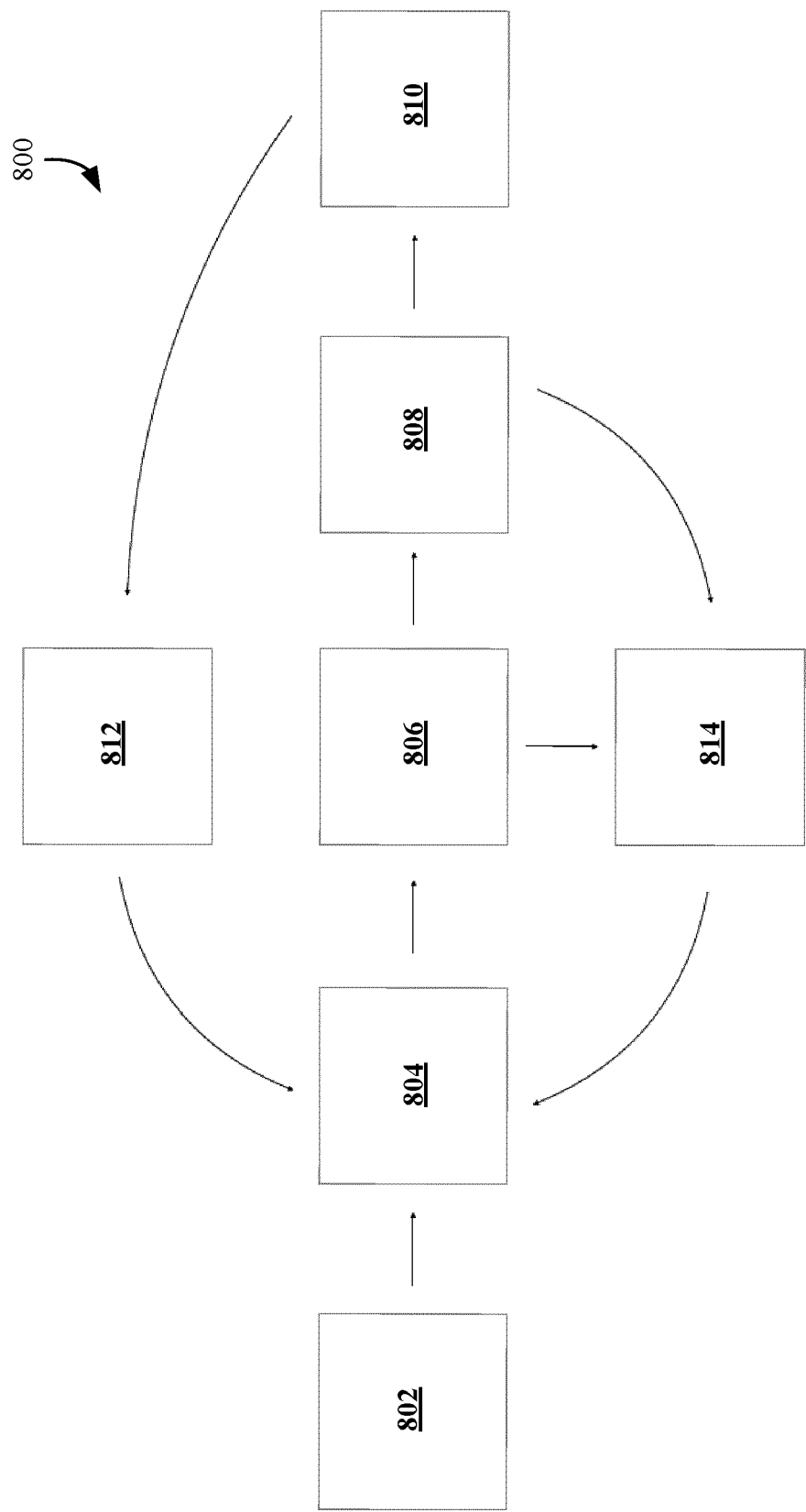


FIG. 8



EUROPEAN SEARCH REPORT

 Application Number
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			C22C C22F
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Place of search Munich		Date of completion of the search 18 January 2021	Examiner Brown, Andrew
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