US 20150354045A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2015/0354045 A1

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(43) Pub. Date: Dec. 10, 2015

(54) **7XXX SERIES ALLOY WITH CU HAVING HIGH YIELD STRENGTH AND IMPROVED EXTRUDABILITY**

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(21) Appl. No.: **14/736,000**

(22) Filed: **Jun. 10, 2015**

Related U.S. Application Data

(60) Provisional application No. 62/009,991, filed on Jun. 10, 2014.

Publication Classification

(51) **Int. Cl.**

C22F 1/053	(2006.01)
C22C 21/10	(2006.01)
C22F 1/00	(2006.01)

(52) **U.S. Cl.**

CPC ***C22F 1/053*** (2013.01); ***C22F 1/002*** (2013.01); ***C22C 21/10*** (2013.01)

(57) **ABSTRACT**

7000 series aluminum alloys containing copper are provided. The aluminum alloys have high yield strength, and in some aspects allow press quenchability and/or have extrusion speeds more rapid than conventional 7000 series Al alloys.

7XXX SERIES ALLOY WITH CU HAVING HIGH YIELD STRENGTH AND IMPROVED EXTRUDABILITY

[0001] This patent application claims the benefit under 35 U.S.C. §119(e) of U.S. Provisional Patent Application No. 62/009,991, entitled "7XXX Series Alloy (with Cu) Having High Yield Strength and Improved Extrudability," filed on Jun. 10, 2014, which is incorporated herein by reference in its entirety.

FIELD

[0002] Embodiments described herein generally relate to aluminum alloys. More specifically, the embodiments relate to aluminum alloys with high strength and cosmetic appeal for applications including enclosures for electronic devices.

BACKGROUND

[0003] Commercial aluminum alloys, such as the 6063 aluminum (Al) alloy and 7000 series alloys, have been used for fabricating enclosures for electronic devices. However, the 6063 aluminum alloy has relatively low yield strength, for example, about 214 MPa, which may dent easily when used as an enclosure for electronic devices. Similarly, 7000 series aluminum alloys do not provide high yield strength. It may be desirable to produce alloys with high yield strength such that the alloys do not dent easily. The electronic devices may include mobile phones, tablet computers, notebook computers, instrument windows, appliance screens, and the like.

[0004] Many commercial 7000 series aluminum alloys have been developed for aerospace applications. Generally, 7000 series aluminum alloys have higher yield strengths than 6000 series aluminum alloys. However, such alloys still have lower than desired yield strengths. Further, typical commercial 7000 series aluminum alloys cannot be directly press-quenched, and instead must be solution heat treated and quenched, and have low extrusion speed.

[0005] There still remains a need to develop aluminum alloys with high strength, improved processing speed, and lower thermal conductivity.

SUMMARY

[0006] 7000 series aluminum alloys are described herein. The alloys may provide aluminum alloys with high tensile yield strength, high extrusion speed, and/or low thermal conductivity. In certain variations, the alloys are press quenchable, allowing processing without additional subsequent solution heat treatment while not compromising the ability to form an aluminum alloy having a high tensile yield strength as described herein.

[0007] In various embodiments, the aluminum alloy comprises Fe from 0 to 0.50 wt %, Si from 0 to 0.05 wt %, Mg from 1.95 to 2.9 wt %, Zn from 5.1 to 6.3 wt %, and Cu from 1.0 to 2.05 wt %, with the remaining wt % being Al and incidental impurities. In further variations, the aluminum alloy comprises Fe from 0 to 0.08 wt %, Si from 0 to 0.05 wt %, Mg from 1.85 to 3.0 wt %, Zn from 5.0 to 6.3 wt %, and Cu from 0.9 to 2.15 wt %. In further aspects, the aluminum alloy comprises Fe from 0 to 0.08 wt %, Si from 0 to 0.05 wt %, Mg from 1.90 to 2.00 wt %, Zn from 5.4 to 5.6 wt %, and Cu from 0.75 to 1.25 wt %. In additional aspects, the aluminum alloy Mg from 2.25 to 2.35 wt %, Zn from 6.2 to 6.4 wt %, and Cu from 1.80 to 2.30 wt. In some variations, the alloys can include at least 0.01 wt % Fe and at least 0.01 wt % Si.

[0008] In additional aspects, the aluminum alloy comprises Fe from 0 to 0.08 wt %, Si from 0 to 0.05 wt %, Mg from 2.30 wt %, Zn of 6.3 wt %, and Cu of 2.05 wt %, with the remaining wt % being Al and incidental impurities. In further aspects, the aluminum alloy comprises Fe from 0 to 0.50 wt %, Si from 0 to 0.40 wt %, Mg from 2.1 to 2.9 wt %, Zn from 5.1 to 6.1 wt %, and Cu from 1.2 to 2.0 wt %, with the remaining wt % being Al and incidental impurities.

[0009] Such alloys can have tensile strengths greater than 450 MPa. Further, such alloys can have thermal conductivity less than 150 W/mK.

[0010] Additional embodiments and features are set forth in part in the description that follows, and in part will become apparent to those skilled in the art upon examination of the specification, or may be learned by the practice of the embodiments discussed herein. A further understanding of the nature and advantages of certain embodiments may be realized by reference to the remaining portions of the specification and the drawings, which forms a part of this disclosure.

DETAILED DESCRIPTION

[0011] The present 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, may be represented schematically or conceptually, or otherwise may not correspond exactly to certain physical configurations of embodiments.

Alloys

[0012] The present disclosure is directed to 7000 series aluminum alloys. The aluminum alloys have high yield strength, and in some aspects press quenchability and/or extrusion speeds more rapid than conventional 7000 series Al alloys. The 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. The impurities can be less than or equal to about 2 wt %, alternatively less than or equal about 1 wt %, alternatively less than or equal about 0.5 wt %, alternatively less than or equal about 0.1 wt %.

[0013] The alloys can comprise Fe from 0 to 0.80 wt %, Si from 0 to 0.50 wt %, Mg from 1.85 to 3.0 wt %, Zn from 5.0 to 6.5 wt %, Cu from 0.75 to 2.50 wt %, and Al at least 92.40 wt %. In certain variations, the non-Fe, Si, Mg, Zn, and Cu alloys are Al and incidental impurities. In some variations, the alloys comprise at least 0.01 wt % Fe and at least 0.01 wt % Si.

[0014] In certain embodiments, the aluminum alloy comprises Fe from 0 to 0.60 wt %, Si from 0 to 0.50 wt %, Mg from 1.85 to 3.0 wt %, Zn from 5.0 to 6.3 wt %, and Cu from 0.9 to 2.15 wt %, with the remaining wt % being Al and incidental impurities. In further embodiments, the aluminum alloy comprises Fe from 0 to 0.50 wt %, Si from 0 to 0.05 wt %, Mg from 1.95 to 2.9 wt %, Zn from 5.1 to 6.3 wt %, and Cu from 1.0 to 2.05 wt %, with the remaining wt % being Al and incidental impurities. The tensile yield strength of such alloys can be greater than 450 MPa. The thermal conductivity of such alloys can be less than 150 W/mK.

[0015] In further embodiments, the aluminum alloy comprises Fe from 0 to 0.08 wt %, Si from 0 to 0.05 wt %, Mg from 1.70 to 2.55 wt %, Zn from 5.25 to 6.55 wt %, and Cu from 0.75 to 2.30 wt %, with the remaining wt % being Al and incidental impurities. In certain embodiments, the aluminum alloy comprises Fe from 0 to 0.10 wt %, Si from 0 to 0.07 wt %, Mg from 1.90 to 2.35 wt %, Zn from 5.4 to 6.4 wt %, and Cu from 0.9 to 2.25 wt %, with the remaining wt % being Al and incidental impurities. In certain embodiments, the aluminum alloy comprises Fe from 0 to 0.08 wt %, Si from 0 to 0.05 wt %, Mg from 1.90 to 2.35 wt %, Zn from 5.4 to 6.4 wt %, and Cu from 0.90 to 2.25 wt %, with the remaining wt % being Al and incidental impurities. In further embodiments, the aluminum alloy comprises Fe from 0 to 0.08 wt %, Si from 0 to 0.05 wt %, Mg from 1.95 to 2.30 wt %, Zn from 5.5 to 6.3 wt %, and Cu from 1.0 to 2.05 wt %, with the remaining wt % being Al and incidental impurities. In certain variations, the alloy comprises at least 0.01 wt % Fe and at least 0.01 wt % Si.

[0016] The tensile yield strength of such alloys can be greater than 450 MPa. The extrusion speed of such alloys can be less than 10 m/min. The thermal conductivity of such alloys can be less than 150 W/mK.

[0017] In certain embodiments, the aluminum alloy comprises Fe from 0 to 0.08 wt %, Si from 0 to 0.05 wt %, Mg from 1.90 to 2.00 wt %, Zn from 5.4 to 5.6 wt %, and Cu from 0.75 to 1.25 wt %, with the remaining wt % being Al and incidental impurities. In some additional variations, the aluminum alloy comprises Fe from 0 to 0.08 wt %, Si from 0 to 0.05 wt %, Mg of 1.95 wt %, Zn of 5.5 wt %, and Cu of 1.0 wt %, with the remaining wt % being Al and incidental impurities. The tensile yield strength of such alloys is greater than 450. In further variations, the tensile yield strength of the alloy is greater than 470. In still further variations, the tensile yield strength of the alloy is about 478.

[0018] Such alloys can have an extrusion speed of less than 15 m/min, less than 12 m/min, or about 10 m/min as described below. These extrusion speeds are comparable to the 7000 series comparison alloy, and faster than conventional commercial 8000 series aluminum alloys. In various additional embodiments, the thermal conductivity of such alloys is less than 150 W/mK.

[0019] In certain variations, the alloys can be press quenchable, unlike conventional commercial 7000 series alloys. Such alloys can be press quenched directly following extrusion, instead of performing a separate solution heat treatment before quenching.

[0020] In certain embodiments, the aluminum alloy comprises Fe from 0 to 0.08 wt %, Si from 0 to 0.05 wt %, Mg from 2.25 to 2.35 wt %, Zn from 6.2 to 6.4 wt %, and Cu from 1.80 to 2.30 wt %, with the remaining wt % being Al and incidental impurities. In additional variations, the aluminum alloy comprises Fe from 0 to 0.08 wt %, Si from 0 to 0.05 wt %, Mg of 2.30 wt %, Zn of 6.3 wt %, and Cu of 2.05 wt %, with the remaining wt % being Al and incidental impurities. In certain additional variations, the tensile yield strength of the alloy is greater than 500 MPa. In further embodiments, the tensile yield strength of the alloy is greater than 525 MPa. In still further embodiments, the tensile yield strength is greater than 545 MPa. In further embodiments, the tensile yield strength of the alloy is about 552 MPa. The alloys can have an extrusion speed of less than 10 m/min, less than 5 m/min, less than 2 m/min, or less than 1.5 m/min. In certain variations, the thermal conductivity of the alloy can be less than 150 W/mK.

[0021] In additional variations, the aluminum alloy can comprise Fe from 0 to 0.50 wt %, Si from 0 to 0.40 wt %, Mg from 2.0 to 3.0 wt %, Zn from 5.0 to 6.2 wt %, and Cu from 1.0 to 2.25 wt %, with the remaining wt % being Al and incidental impurities. In further variations, the aluminum alloy can comprise Fe from 0 to 0.50 wt %, Si from 0 to 0.40 wt %, Mg from 2.1 to 2.9 wt %, Zn from 5.1 to 6.1 wt %, and Cu from 1.2 to 2.0 wt %, with the remaining wt % being Al and incidental impurities. In certain additional variations, the tensile yield strength of the alloy is greater than 450 MPa. In further embodiments, the tensile yield strength of the alloy is greater than 475 MPa. In still further embodiments, the tensile yield strength is greater than 500 MPa. In further embodiments, the tensile yield strength of the alloy is about 503 MPa.

[0022] The compositions, elemental compositions, yield strength, press quenchability, and extrusion speed for examples of alloys and aluminum alloys of the present disclosure are depicted in Table 1 below. Table 1 lists example alloy compositions, tensile yield strengths, press quenchability, and extrusion speeds for examples of aluminum alloys in comparison to a 7003 alloy disclosed in U.S. Provisional Patent Application No. 61/884,860 (which is incorporated herein by reference in its entirety), and an example commercial 6063 Al alloy. The alloys have increased tensile yield strength, high extrusion speed, and can be press quenchable.

TABLE 1

Yield Strengths and Compositions of Aluminum Alloys

	Fe	Si	Mg	Zn	Cu	Tensile Yield Strength (MPa)	Elongation (%)	Thermal Conductivity (W/mK)	Press Quenchable	Extrusion Speed (m/min)
6063	0.12 (maximum)	0.37-0.44	0.47-0.55	<0.01	<0.01	214 MPa	18	200	Yes	~20
7003*	0.08 (maximum)	0.05 (maximum)	1.0	5.5	<0.02	350 MPa	21	180	Yes	~10
Sample alloy 1	0.08 (maximum)	0.05 (maximum)	1.95	5.5	1.0	478 MPa	17	<150	Yes	~10
Sample alloy 2	0.08 (maximum)	0.05 (maximum)	2.30	6.3	2.05	552 MPa	16	<150	No	<1.5
Sample alloy 3	0.50 (maximum)	0.40 (maximum)	2.1-2.9	5.1-6.1	1.2-2.0	503 MPa			No	

*Disclosed in U.S. Provisional Pat. application No. 61/884,860.

[0023] As depicted in Table 1, sample alloys 1, 2, and 3 have various amounts of elements including Fe, Si, Mg, Zn, Cu, and Al, along with an increased tensile strength of at least 450 MPa. Comparative alloys 6063 and 7003 have lower tensile yield strength than the presently disclosed alloys.

[0024] Sample alloys 1-3 have a yellow color due to the presence of Cu. Cu alloys have a yellow color that can be used to match existing dye colors. In various embodiments, the amount of Cu can be altered to match a desired dye color.

Processing Methods

[0025] In some embodiments, a melt for an alloy can be prepared by heating the alloy including the composition. After the melt is cooled to room temperature, the alloys may go through various heat treatments, such homogenization, extruding, forging, aging, and/or other forming or solution heat treatment techniques.

[0026] In some embodiments, the cooled alloy can be homogenized by heating to an elevated temperature and holding at the elevated temperature for a period of time, such as at 500° C. for about 8 hours. Homogenization refers to a process in which high-temperature soaking is used at an elevated temperature for a period of time. Homogenization can reduce chemical or metallurgical segregation, which may occur as a natural result of solidification in some alloys. It will be appreciated by those skilled in the art that the heat treatment conditions (e.g. temperature and time) may vary. For example, the homogenization temperature may be greater than 400° C., 450° C., 500° C., or 550° C., and/or may bets than 600° C., 550° C., 500° C., or 450° C. In some embodiments, the high-temperature soaking is conducted for a dwell time of about 4 hours to about 48 hours.

[0027] The homogenized alloy maybe hot-worked, e.g., extruded. Extrusion is a process for converting a metal ingot or billet into lengths of uniform cross section by forcing the metal to flow plastically through a die orifice.

[0028] In some embodiments, the hot-worked alloys can be solution heat-treated at elevated temperatures for 450° C. for 2 hours. The solution heat treatments can alter the strength of the alloy.

[0029] After the solution treatment, the alloy can be aged at a first temperature of 100° C. for about 5 hours, then heated to a second temperature of 150° C. and held at the second temperature for about 9 hours, and then quenched with water. Aging is a heat treatment at an elevated temperature, and may induce a precipitation reaction to form precipitates $MgZn_2$. In some embodiments, aging may be conducted at a first temperature for a first period of time and followed at a second temperature for a second period of time. Single temperature heat treatments may also be used, for example, at 120° C. for 24 hours. (e.g. temperature and time) Again, it will be appreciated by those skilled in the art that the heat treatment condition (e.g. temperature and time) may vary.

[0030] Various alloys can be press quenched by rapid cooling from a high extrusion temperature without any separate hot-working or heat treatment step. In various embodiments, the press quenching occurs while the alloy is within 100° C. of the extrusion temperature. In such methods, the alloys are quenched by immersion in a liquid bath directly after the extrusion step. By removing subsequent heat treating steps, the alloy can be produced at a lower alloy production cost. Further, unlike conventional 7000 series alloys that require a second solution phase heat treatment step, the absence of a quenching step results in an alloys having high tensile yield strength and/or low thermal conductivity without additional processing required for conventional 7000 series alloys.

[0031] In further embodiments, the alloy may be optionally subjected to a stress-relief treatment between the solution heat-treatment and the aging heat-treatment. The stress-relief treatment can include stretching the alloy, compressing the alloy, or combinations thereof.

[0032] In some embodiments, the present 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.

[0033] In some embodiments, the present alloys can form enclosures for the electronic devices. The enclosures may be designed to have a blasted surface finish, or absence of streaky lines. Blasting is a surface finishing process, for example, smoothing a rough surface or roughening a smooth surface. Blasting may remove surface materials by forcibly propelling a stream of abrasive material against a surface under high pressure.

[0034] 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, haze, 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 may be performed by testing equipment, such as Rhopoint IQ.

[0035] 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*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*b* Colour Space.

[0036] Yield strengths of the alloys may be determined via ASTM E8, which covers the testing apparatus, test specimens, and testing procedure for tensile testing.

[0037] Stress corrosion tests may be performed on the alloys via ASTM G47, which covers the test method of sampling, type of specimen, specimen preparation, test environment, and method of exposure for determining the susceptibility to SCC of aluminum alloys.

[0038] The alloys as described herein can be included in various products. Such products can be any product known in the art. The products can be a device, such as an electronic device. For example, the device can be a telephone, such as a mobile phone, and a land-line phone, or any communication device, such as a smart phone, including, for example an iPhone®, and/or an electronic email sending/receiving device. The alloys, metallic glasses, and various non-limiting embodiments can be used in conjunction with a display, such as a digital display, a TV monitor, an electronic-book reader, a portable web-browser (e.g., iPad®), a watch (e.g., Apple Watch™), and/or a computer monitor. The device 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. Devices include control devices, such as those that control the streaming of images, videos, sounds (e.g., Apple TV®), or a remote control for a separate electronic device. The device can be a part of a computer or its accessories, laptop keyboard, laptop track pad, desktop keyboard, mouse, and speaker. The alloys can be in any component of such products, such as housings.

[0039] 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 disclosure. Additionally, a number of well-known processes and elements have not been described in order to avoid unnecessarily obscuring the embodiments disclosed herein. Accordingly, the above description should not be taken as limiting the scope of the document.

[0040] Those skilled in the art will appreciate that the presently 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 present method and system, which, as a matter of language, might be said to fall there between.

What is claimed is:

1. An alloy comprising Fe from 0 to 0.08 wt %, Si from 0 to 0.05 wt %, Mg from 1.85 to 3.0 wt %, Zn from 5.0 to 6.3 wt %, and Cu from 0.9 to 2.15 wt %, the remaining wt % being Al and incidental impurities.

2. The alloy of claim **1**, comprising Mg from 1.95 to 2.9 wt %, Zn from 5.1 to 6.3 wt %, and Cu from 1.0 to 2.05 wt %.

3. The alloy of claim **1**, comprising at least 0.01 wt % Fe and at least 0.01 wt % Si.

4. The alloy of claim **1**, wherein the tensile yield strength of the alloy is greater than 450 MPa.

5. The alloy of claim **1**, wherein the thermal conductivity of the alloy is less than 150 W/mK.

6. The alloy of claim **1**, comprising Mg from 1.90 to 2.00 wt %, Zn from 5.4 to 5.6 wt %, and Cu from 0.75 to 1.25 wt %.

7. The alloy of claim **6**, comprising at least 0.01 wt % Fe and at least 0.01 wt % Si.

8. The alloy of claim **6**, wherein the tensile yield strength is greater than 450 MPa.

9. The alloy of claim **10**, wherein the tensile yield strength of the alloy is greater than 500 MPa.

10. The alloy of claim **10**, wherein the tensile yield strength of the alloy is greater than 525 MPa.

11. The alloy of claim **1**, comprising Mg from 2.25 to 2.35 wt %, Zn from 6.2 to 6.4 wt %, and Cu from 1.80 to 2.30 wt %.

12. The alloy of claim **10**, comprising at least 0.01 wt % Fe and at least 0.01 wt % Si.

13. An alloy comprising Fe from 0 to 0.50 wt %, Si from 0 to 0.40 wt %, Mg from 2.0 to 3.0 wt %, Zn from 5.0 to 6.2 wt %, and Cu from 1.0 to 2.25 wt %, the remaining wt % being Al and incidental impurities.

14. The alloy of claim **15**, comprising Fe from 0 to 0.50 wt %, Si from 0 to 0.40 wt %, Mg from 2.1 to 2.9 wt %, Zn from 5.1 to 6.1 wt %, and Cu from 1.2 to 2.0 wt %.

15. The alloy of claim **10**, comprising at least 0.01 wt % Fe and at least 0.01 wt % Si.

16. A method of making an aluminum alloy of claim **1**, comprising:

homogenizing the alloy to form a homogeneous alloy;

extruding the homogenized alloy to form an extruded alloy at an extrusion temperature; and

press quenching the extruded alloy before the temperature of the extruded alloy changes by 100 degrees ° C. to form the aluminum alloy having a tensile yield strength greater than 450 MPa.

17. The method of claim **16**, wherein the alloy comprises Mg from 1.90 to 2.00 wt %, Zn from 5.4 to 5.6 wt %, and Cu from 0.75 to 1.25 wt %, the remaining wt % being Al and incidental impurities.

18. The method of claim **17**, wherein the alloy comprises at least 0.01 wt % Fe and at least 0.01 wt % Si.

19. The method of claim **16**, wherein the extrusion speed is less than 5 m/min.

20. The method of claim **16**, wherein the extrusion speed is less than 2 m/min.

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