



- (51) International Patent Classification:
C22C 21/08 (2006.01) C22F 1/06 (2006.01)
- (21) International Application Number:
PCT/US2018/020899
- (22) International Filing Date:
05 March 2018 (05.03.2018)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
62/468,467 08 March 2017 (08.03.2017) US

(71) Applicant: NANOAL LLC [US/US]; 8025 Lamon Avenue, Suite 446, Skokie, IL 60077 (US).

(72) Inventors: VO, Nhon, Q.; 8025 Lamon Avenue, Suite 446, Skokie, IL 60077 (US). RAMOS, Evander; 8025 Lamon Avenue, Suite 446, Skokie, IL 60077 (US). BAYANSAN, Davaadorj; 8025 Lamon Avenue, Suite 446, Skokie, IL 60077 (US). FLORES, Francisco; 8025 Lamon Avenue, Suite 446, Skokie, IL 60077 (US).

(74) Agent: FRIEDMAN, L.; Hahn Loeser & Parks, LLP, 125 South Wacker Drive, Suite 2900, Chicago, IL 60606 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,

OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— of inventorship (Rule 4.17(iv))

Published:
— with international search report (Art. 21(3))



WO 2018/165012 A1

(54) Title: HIGH-PERFORMANCE 5000-SERIES ALUMINUM ALLOYS

(57) Abstract: Aluminum-magnesium-manganese-zirconium-inoculant alloys that exhibit high strength, good ductility, high creep resistance, high thermal stability and durability.

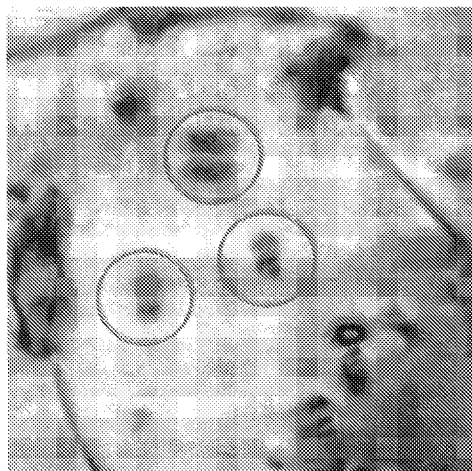


FIG. 2B

HIGH-PERFORMANCE 5000-SERIES ALUMINUM ALLOYS

[0001] The present application claims the benefit of the filing date of US Ser. No. 62/468,467, filed 8 March 2017 and
5 titled High-Performance 5000-Series Aluminum Alloys, the contents of which are incorporated herein by reference. This invention was made with government support under Federal Award No. IIP 1549282, awarded by National Science Foundation. The Government has certain rights in the invention.

10

FIELD

[0002] This application relates to a family of 5000-series aluminum alloys with high strength, good ductility, high creep resistance, high thermal stability and durability. The disclosed alloys are especially advantageous for, but not limited to,
15 improving performance of beverage can lids and tabs. Additionally, the disclosed alloys are, for example, advantageous for improving performance of roofing and siding materials, chemical and food equipment, storage tanks, home appliances, sheet-metal work, marine parts, transportation
20 parts, heavy duty cooking utensils, hydraulic tubes, fuel tanks, pressure vessels, heavy-duty truck and trailer bodies and assemblies, drilling rigs, missile components, and railroad cars.

BACKGROUND

25 [0003] The production of aluminum cans, largely to store beverages, is the single largest usage of aluminum in the world. The annual production is a staggering 320 billion cans per year, equating to 4.16 billion kilograms of aluminum. In addition, aluminum canning is likely the world's best example of
30 recycling, as 75% of the aluminum used in cans is recycled. The

production of aluminum cans is enormous, so an efficiency improvement comes with a giant multiplicative effect; a single gram of weight saved in the can may save over 200 thousand metric tons of aluminum globally per year. Together with this weight benefit, the energy consumption as well as the CO₂ emissions during transport are reduced - both key metrics in sustainability of the environment. Additionally, the lightness of aluminum cans helps save resources during filling, storage, transportation and scrap at the end of the product's life. Thus lightweighting the can has been a front-burner issue for decades.

[0004] The beverage packaging industry is constantly seeking ways to maintain the can's performance while continuing to trim the materials as much as possible. A common can design consists of two pieces: the can body is made of 3000-series aluminum, specifically AA3004, while the can lid and opener are made from 5000-series aluminum, specifically AA5182. The success behind the consistent and precise production of aluminum cans is based on the strong yet formable 3000- and 5000-series aluminum sheets. The can body is about 75% of the can's mass, while the smaller lid claims the rest, 25%. Two most obvious ways to design a lighter can are: (i) designing a smaller lid and (ii) reducing thickness of the can's wall and lid. To thin the can body and lid, stronger 3000-series and 5000-series alloys are needed, while maintaining important characteristics, such as density, formability and corrosion resistance. Aerospace-grade 2000- and 7000-series are very strong, but their low formability is not suitable for canning. Thus the common approach to develop new canning materials is to modify the currently utilized alloys, that is, modifying alloy composition and thermo-mechanical processes to the current 3000-series and 5000-series

alloys to strengthen them without sacrificing other important properties. Moreover, 75% of the aluminum in cans is recycled and is currently being used to recast aluminum sheets, which are returned to can manufacturers to produce new batches of cans.

5 Recycling plays a significant role in the economics of canning, thus modifying the current 3000-series and 5000-series alloys will help maintain the usage of low-cost recycled cans.

[0005] A well-known means to enhance the strength and
10 maintain the ductility of commercial aluminum alloys is the addition of small concentrations of Scandium (Sc). The strengthening originates from the creation during aging of L1₂-structured Al₃Sc nano-precipitates (~5-10 nm in diam.) which are coherent with the aluminum matrix. The small volume fraction,
15 nano-size and matrix coherency of these precipitates help the alloys maintain other properties, such as ductility and formability. Scandium, however, is extremely costly (ten-fold more expensive than silver), severely prohibiting its usage in cost-sensitive applications such as food and drink packaging.

20

[0006] Accordingly, stronger 5000-series aluminum alloys are needed, while maintaining important characteristics, such as density, formability and corrosion resistance. With a stronger material, the can's lid and tab can be made thinner, resulting
25 in a lighter beverage can. In addition, higher performance 5000-series aluminum alloys are needed constantly in many other applications for lightweighting purposes.

SUMMARY

[0007] The embodiments described herein relate to heat-
30 treatable aluminum-magnesium-based (5000-series) alloys, containing an Al₃Zr nanoscale precipitate, wherein the nanoscale

precipitate has an average diameter of about 20 nm or less and has an L1₂ structure in an α-Al face centered cubic matrix, wherein the average number density of the nanoscale precipitate is about 20²¹ m⁻³ or more. They exhibit high strength, good ductility, high creep resistance, high thermal stability and durability, while being essentially free of scandium (i.e., no scandium is added intentionally).

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Figures 1A and 1B: Microhardness evolution during (A) isochronal and (B) isothermal aging at 400°C of Al-4.5Mg-0.35Mn-0.2Si wt.% (AA5182), Al-4.5Mg-0.35Mn-0.3Zr wt.% (AA5182+Zr) and Al-4.5Mg-0.35Mn-0.2Si-0.3Zr-0.1Sn wt.% (AA5182+Zr+Sn) (invented alloy). Error bars are omitted for a few data points for the sake of figure clarity.

[0009] Figures 2A and 2B: (A) Bright field, two-beam transmission electron microscopy of Al-4.5Mg-0.35Mn-0.2Si-0.3Zr-0.1Sn wt.% (invented alloy), and (B) higher magnification view, displaying the existence of Al₃Zr nano-precipitates (circles).

[00010] Figure 3: Microhardness evolution during isochronal aging of Al-4.5Mg-0.35Mn-0.2Si wt.% (AA5182), Al-4.5Mg-0.35Mn-0.2Si-0.3Zr-0.003Sr wt.% (AA5182+Zr+Sr) (invented alloy) and Al-4.5Mg-0.35Mn-0.2Si-0.3Zr-0.5Zn wt.% (AA5182+Zr+Zn) (invented alloy). Error bars are omitted for a few data points for the sake of figure clarity.

[00011] Figure 4: Mechanical properties of Al-4.5Mg-0.35Mn-0.2Si wt.% (AA5182) and Al-4.5Mg-0.35Mn-0.2Si-0.3Zr-0.1Sn wt.%

(AA5182+nano-precipitates) (invented alloy), after peak-aging and cold-rolling.

[00012] Figure 5: Microhardness of cold rolled Al-4.5Mg-0.35Mn-0.2Si wt.% (AA5182) and Al-4.5Mg-0.35Mn-0.2Si-0.3Zr-0.1Sn wt.% (AA5182+nano-precipitates) (invented alloy) versus annealing temperature (1 h at each temperature).

DETAILED DESCRIPTION

[00013] 5000-series aluminum alloys are strain-hardenable but not heat-treatable. They contain magnesium as the main alloying element, optionally with manganese, and typically have good strength, formability, and corrosion resistance. AA5182 aluminum alloy, containing 4-5Mg and 0.2-0.5Mn (wt.%), is currently being utilized for beverage can lids. It also is being used in automotive applications. The effect of Al₃Zr nano-precipitates on the mechanical performance of this alloy was investigated. Figure 1A displays the microhardness evolution during isochronal aging of Al-4.5Mg-0.35Mn-0.2Si wt.% (AA5182, example alloy), Al-4.5Mg-0.35Mn-0.3Zr wt.% and Al-4.5Mg-0.35Mn-0.2Si-0.3Zr-0.1Sn wt.% (invented alloy). AA5182 is not heat-treatable, thus its microhardness evolution is unchanged at all temperatures. With an addition of 0.3% Zr, the microhardness evolution also appears unchanged at all temperatures. There is a slight increase in microhardness from 400 to 550 °C, compared to the based AA5182 alloy, but this is within experimental error. With the addition of 0.3Zr+0.1Sn wt.%, a peak-microhardness of 86 ± 3 HV (a 23% increase) was observed at 450 °C, compared to 70 ± 4 HV in the based AA5182 alloy. This is a strong indication of Al₃Zr nano-precipitates, which are known to form around this temperature and enhance strength. This is corroborated by the microhardness

evolution during isothermal at 400 °C, as shown in Figure 1B, of these three alloys. Microhardness of the base AA5182 alloy is unchanged, while it starts to increase after aging for 24 h with addition of Zr. In the Al-4.5Mg-0.35Mn-0.2Si-0.3Zr-0.1Sn wt.%
5 invented alloy, it increases rapidly during aging and peaks at 24 h, reaching $\sim 90 \pm 5$ HV (a 29% increase), compared to 70 ± 5 HV in the based AA5182 alloy. It should be noted that an addition of only Zr, without an inoculant (Sn), is not sufficient to generate a high number density of Al₃Zr nano-
10 precipitates, hence the strength increase due to Zr addition, without Sn, is not significant. The precipitate structure of the peak-aged Al-4.5Mg-0.35Mn-0.2Si-0.3Zr-0.1Sn wt.% invented alloy is displayed in Figures 2A and 2B. Three different populations of precipitates, Al₆Mn, hexagonal α -Al(Mn,Fe)Si, and Al₃Zr nano-
15 precipitates, are observed. Fe is present in the alloy as an impurity element. The first two populations appear in a low number density, whereas a high number density of Al₃Zr nano-precipitates is observed.

20 [00014] Figure 3 displays the microhardness evolution during isochronal aging of Al-4.5Mg-0.35Mn-0.2Si wt.% (AA5182), Al-4.5Mg-0.35Mn-0.2Si-0.3Zr-0.003Sr wt.% (invented alloy) and Al-4.5Mg-0.35Mn-0.2Si-0.3Zr-0.5Zn wt.% (invented alloy). With an addition of 0.3Zr+0.003Sr wt.%, there is a significant increase
25 in microhardness from 250 to 500 °C, reaching 82 ± 4 HV (a 19% increase), compared to the based AA5182 alloy. With an addition of 0.3Zr+0.5Zn wt.%, there is also a significant increase in microhardness from 400 to 550 °C, reaching 82 ± 3 HV (a 19% increase), compared to the based AA5182 alloy. This is a strong
30 indication of the formation of Al₃Zr nano-precipitates, assisted by either Sr or Zn, which enhances strength.

[00015] Mechanical properties of Al-4.5Mg-0.35Mn-0.2Si wt.% (AA5182) and Al-4.5Mg-0.35Mn-0.2Si-0.3Zr-0.1Sn wt.% (invented alloy), after peak-aging and cold rolling are displayed in Figure 4. Both strength and elongation of the AA5182, with
5 addition of nano-precipitates, are increased compared to the based AA5182 alloy. An increase of 12% in yield strength, 8% in tensile strength, and 26% in elongation are observed.

[00016] Additionally, Figure 5 suggests that the
10 recrystallization temperature is at ~250 °C for cold-rolled Al-4.5Mg-0.35Mn-0.2Si wt.% (AA5182) and at ~300 °C for cold-rolled Al-4.5Mg-0.35Mn-0.2Si-0.3Zr-0.1Sn wt.% (invented alloy), containing nano-precipitates (an increase of 50 °C). This suggests that Al₃Zr nano-precipitates suppresses the
15 recrystallization, by pinning the movement of grain boundaries via Zener pinning.

[00017] Table 1 lists mechanical properties of thin sheets (0.25 mm in thickness) of Al-4.5Mg-0.25Mn-0.2Fe-0.09Si wt.%
20 (AA5182) in hard-temper (example alloy 1) and soft temper (example alloy 2), Al-4.5Mg-0.25Mn-0.2Fe-0.09Si-0.3Zr-0.1Sn wt.% (AA5182-nano) in hard-temper (invented alloy 1) and soft temper (invented alloy 2). AA5182 hard-temper is a common aluminum alloy for beverage can lids, whereas AA5182 soft-temper is
25 commonly used in automotive applications. The AA5182-nano alloy, in both hard- and soft-temper (invented alloys 1 and 2) achieve higher yield strength and tensile strength, while maintaining essentially the same elongation at break, compared to the AA5182 alloy with the respective tempers (example alloy 1 and 2). The
30 thin sheets of the alloys in Table 1 were fabricated by the following steps: casting, hot-rolling, annealing, cold-rolling,

and stabilizing heat treatment for hard-temper; and casting, hot-rolling, cold-rolling, and annealing for soft-temper.

Table 1

	Yield strength (MPa)	Tensile strength (MPa)	Elongation at break (%)
AA5182 - hard temper (example alloy 1)	355 ± 6	412 ± 7	6-8
AA5182-nano - hard temper (invented alloy 1)	390 ± 6	450 ± 8	6-8
AA5182 - soft temper (example alloy 2)	170 ± 5	315 ± 6	20-25
AA5182-nano - soft temper (invented alloy 2)	200 ± 4	330 ± 7	20-25

5 [00018] The disclosed aluminum alloys are essentially free of scandium, which is understood to mean that no scandium is added intentionally. Addition of scandium in aluminum alloys is advantageous for mechanical properties. For example, it is described in U.S. Patent No. 5,624,632, which is incorporated
 10 herein by reference. However, scandium is very expensive (ten times more expensive than silver), severely limiting its practical applications.

[00019] Zirconium, with a concentration of up to about 0.3
 15 wt.%, is sometimes added to aluminum alloys for grain refining. The refined grain structure helps improve castability, ductility, and workability of the final product. An example is described in U.S. Patent No. 5,976,278, which is incorporated herein by reference. In the present application, zirconium with
 20 a concentration of less than about 0.5 wt.%, and preferably less than about 0.4 wt.%, is added together with an inoculant element to form Al₃Zr nano-precipitates, wherein the nanoscale precipitate has an average diameter of about 20 nm or less and has an L1₂ structure in an α-Al face centered cubic matrix, and

wherein the average number density of the nanoscale precipitate is about 20^{21} m^{-3} or more, with a purpose to improve mechanical strength, ductility, creep resistance, thermal stability and durability of the based alloys. Generally, a zirconium
5 concentration of more than about 0.2 wt.% is needed so that Zr atoms have enough driving force to form Al_3Zr nano-precipitates.

[00020] Disclosed aluminum alloys comprise an inoculant, wherein the inoculant comprises one or more of tin, strontium,
10 zinc, gallium, germanium, arsenic, indium, antimony, lead, and bismuth. The presence of an inoculant accelerates precipitation kinetics of Al_3Zr nano-precipitates, thus these precipitates can be formed within a practical amount of time during heat-treatment. In the other words, the beneficial Al_3Zr nano-
15 precipitates can be formed within a few hours of heat treatment, with the presence of the inoculant, compared to between a few weeks and a few months of heat treatment without the presence of an inoculant. Among all inoculant elements, tin appears to be the best performer in terms of accelerating precipitation
20 kinetics of Al_3Zr nano-precipitates. A tin concentration of less than about 0.2% is needed for the mentioned purpose. Beyond this value, tin will form bubbles and/or a liquid phase in the aluminum solid matrix, which is detrimental for the mechanical properties. For example, this behavior is described in U.S.
25 Patent No. 9,453,272, which is incorporated herein by reference.

[00021] In one embodiment, an aluminum alloy comprises aluminum, magnesium, manganese, silicon, zirconium, and an
inoculant, and including a nanoscale precipitate comprising
30 Al_3Zr , wherein the nanoscale precipitate has an average diameter of about 20 nm or less and has an L1_2 structure in an α -Al face

centered cubic matrix, wherein the average number density of the nanoscale precipitate is about 20^{21} m^{-3} or more, and wherein the inoculant comprises one or more of tin, strontium, and zinc.

5 [00022] In one embodiment, if an aluminum alloy is in hard temper it possesses a yield strength of at least about 380 MPa, a tensile strength of at least about 440 MPa, and an elongation of at least about 5% at room temperature.

10 [00023] In one embodiment, if an aluminum alloy is in soft temper it possesses a yield strength of at least about 190 MPa, a tensile strength of at least about 320 MPa, and an elongation of at least about 18% at room temperature.

15 [00024] In one embodiment, an aluminum alloy possesses a recrystallization temperature of about 300°C.

[00025] In one embodiment, an aluminum alloy comprises about 3.0 to about 6.2% by weight magnesium; about 0.01 to about 1.8%
20 by weight manganese; about 0.01 to about 0.2% by weight silicon; about 0.2 to about 0.5% by weight zirconium; about 0.01 to about 0.2% by weight tin; and aluminum as the remainder.

[00026] In one embodiment, an aluminum alloy comprises about
25 3.0 to about 6.2% by weight magnesium; about 0.01 to about 1.8% by weight manganese; about 0.01 to about 0.2% by weight silicon; about 0.2 to about 0.5% by weight zirconium; about 0.001 to about 0.1% by weight strontium; and aluminum as the remainder.

30 [00027] In one embodiment, an aluminum alloy comprises about 3.0 to about 6.2% by weight magnesium; about 0.01 to 1.8% by weight manganese; about 0.01 to about 0.2% by weight silicon;

about 0.2 to about 0.5% by weight zirconium; about 0.1 to about 1% by weight zinc; and aluminum as the remainder.

[00028] In one embodiment, an aluminum alloy comprises a plurality of L1₂ precipitates having an average diameter of about 10 nm or less.

[00029] In one embodiment, an aluminum alloy comprises a plurality of L1₂ precipitates having an average diameter of about 3 nm to about 7 nm.

[00030] In one embodiment, an aluminum alloy comprises about 4.5% by weight magnesium, about 0.35% by weight manganese, about 0.2% by weight silicon, about 0.3% by weight zirconium, about 0.1% by weight tin, and aluminum as the remainder.

[00031] In one embodiment, an aluminum alloy comprises about 4.5% by weight magnesium, about 0.35% by weight manganese, about 0.2% by weight silicon, about 0.3% by weight zirconium, about 0.003% by weight strontium, and aluminum as the remainder.

[00032] In one embodiment, an aluminum alloy comprises about 4.5% by weight magnesium, about 0.35% by weight manganese, about 0.2% by weight silicon, about 0.3% by weight zirconium, about 0.5% by weight zinc, and aluminum as the remainder.

[00033] In one embodiment, an aluminum alloy comprises no more than about 0.5% iron as an impurity element.

[00034] In one embodiment, an aluminum alloy comprises aluminum, magnesium, manganese, silicon, zirconium, and an inoculant, and including a nanoscale precipitate comprising

Al₃Zr, wherein the nanoscale precipitate has an average diameter of about 20 nm or less and has an L1₂ structure in an α-Al face centered cubic matrix, wherein the average number density of the nanoscale precipitate is about 20²¹ m⁻³ or more, and wherein the
5 inoculant comprises one or more of gallium, germanium, arsenic, indium, antimony, lead, and bismuth.

[00035] One method for manufacturing a component from a disclosed aluminum alloy comprises: a) melting the alloy at a
10 temperature of about 700 to about 900°C; b) then casting the melted alloy into casting molds at ambient temperature; c) then using a cooling medium to cool the cast ingot; and d) then heat aging the cast ingot at a temperature of about 350°C to about 450°C for a time of about 2 to about 48 hours. In one
15 embodiment, the method further comprises cold rolling the cast ingot to form a sheet product. In one embodiment, the method further comprises a final stabilizing heat treatment of the sheet product at a temperature of about 140°C to about 170°C for a time of about 1 to about 5 hours. In some embodiments, the
20 cooling medium can be air, water, ice, or dry ice. The heat aging step stated above (350-450°C for 2-48 hours) is determined to be peak-aging for components comprising the disclosed aluminum alloys. When a component manufactured from a disclosed aluminum alloy is peak-aged, the microstructure of the component
25 is thermally stable and is unchanged by exposure to elevated temperatures for extended times.

[00036] Another method for manufacturing a component from a disclosed aluminum alloy comprises: a) melting the alloy at a
30 temperature of about 700 to 900°C; b) then casting the alloy into casting molds at ambient temperature; c) then using a cooling medium to cool the cast ingot; and d) then hot rolling

the cast ingot into a sheet. In one embodiment, the method further comprises then heat aging the sheet at a temperature of about 350°C to about 450°C for a time of about 2 to about 48 hours. In one embodiment, the method further comprises then
5 cold rolling the sheet, after the heat aging step, to form a thin sheet or foil product. In one embodiment, the method further comprises a final stabilizing heat treatment of the thin sheet or foil product at a temperature of about 140°C to about 170°C for a time of about 1 to about 5 hours.

10

[00037] Another method for manufacturing a component from a disclosed aluminum alloy comprises: a) melting the alloy at a temperature of about 700 to 900°C; b) then casting the alloy into casting molds at ambient temperature; c) then using a
15 cooling medium to cool the cast ingot; d) then hot rolling the cast ingot into a sheet; e) then cold rolling the sheet to form a thin sheet or foil product; and f) then heat aging the thin sheet or foil product at a temperature of about 300°C to about 410°C for a time of about 2 to about 24 hours.

20

[00038] Some applications for the disclosed alloys include, for example, beverage can lids, beverage can tabs, roofing materials, siding materials, chemical manufacturing equipment, food manufacturing equipment, storage tanks, home appliances,
25 sheet-metal work, marine parts, transportation parts, heavy duty cooking utensils, hydraulic tubes, fuel tanks, pressure vessels, truck bodies, truck assemblies, trailer bodies, trailer assemblies, drilling rigs, missile components, and railroad cars. Some fabricated forms of the disclosed aluminum alloys
30 include, for example, wires, sheets, plates and foils.

[00039] From the foregoing, it will be understood that numerous modifications and variations can be effectuated without departing from the true spirit and scope of the novel concepts of the present invention. It is to be understood that no
5 limitation with respect to the specific embodiments illustrated and described is intended or should be inferred.

Claims:

1. An aluminum alloy comprising:

aluminum, magnesium, manganese, silicon, zirconium, and an inoculant, and including a nanoscale precipitate comprising Al_3Zr ;

wherein the nanoscale precipitate has an average diameter of about 20 nm or less and has an L1_2 structure in an α -Al face centered cubic matrix;

wherein the average number density of the nanoscale precipitate is about 20^{21} m^{-3} or more;

wherein the inoculant comprises one or more of tin, strontium, and zinc;

wherein, if the aluminum alloy is in hard temper, it possesses a yield strength of at least about 380 MPa, a tensile strength of at least about 440 MPa, and an elongation of at least about 5% at room temperature; and

wherein, if the aluminum alloy is in soft temper, it possesses a yield strength of at least about 190 MPa, a tensile strength of at least about 320 MPa, and an elongation of at least about 18% at room temperature.

2. The aluminum alloy of claim 1, comprising:

about 3.0 to about 6.2% by weight magnesium;
about 0.01 to about 1.8% by weight manganese;
about 0.01 to about 0.2% by weight silicon;
about 0.2 to about 0.5% by weight zirconium;
about 0.01 to about 0.2% by weight tin; and
aluminum as the remainder.

3. The aluminum alloy of claim 1, comprising:

about 3.0 to about 6.2% by weight magnesium;
about 0.01 to about 1.8% by weight manganese;

- about 0.01 to about 0.2% by weight silicon;
about 0.2 to about 0.5% by weight zirconium;
about 0.001 to about 0.1% by weight strontium; and
aluminum as the remainder.
4. The aluminum alloy of claim 1, comprising:
about 3.0 to about 6.2% by weight magnesium;
about 0.01 to about 1.8% by weight manganese;
about 0.01 to about 0.2% by weight silicon;
about 0.2 to about 0.5% by weight zirconium;
about 0.1 to about 1% by weight zinc; and
aluminum as the remainder.
5. The aluminum alloy of claim 1, wherein the plurality of L1₂ precipitates has an average diameter of about 10 nm or less.
6. The aluminum alloy of claim 1, wherein the plurality of L1₂ precipitates has an average diameter of about 3 nm to about 7 nm.
7. The aluminum alloy of claim 1, comprising:
about 4.5% by weight magnesium;
about 0.35% by weight manganese;
about 0.2% by weight silicon;
about 0.3% by weight zirconium;
about 0.1% by weight tin; and
aluminum as the remainder.
8. The aluminum alloy of claim 1, comprising:
about 4.5% by weight magnesium;
about 0.25% by weight manganese;

about 0.09% by weight silicon;
about 0.2% by weight iron;
about 0.3% by weight zirconium;
about 0.1% by weight tin; and
aluminum as the remainder.

9. The aluminum alloy of claim 1, comprising:
about 4.5% by weight magnesium;
about 0.35% by weight manganese;
about 0.2% by weight silicon;
about 0.3% by weight zirconium;
about 0.003% by weight strontium; and
aluminum as the remainder.
10. The aluminum alloy of claim 1, comprising:
about 4.5% by weight magnesium;
about 0.35% by weight manganese;
about 0.2% by weight silicon;
about 0.3% by weight zirconium;
about 0.5% by weight zinc; and
aluminum as the remainder.
11. The aluminum alloy of claim 1, wherein the alloy possesses
a recrystallization temperature of about 300°C.
12. The aluminum alloy of claim 1, wherein the alloy is
essentially free of scandium.
13. The aluminum alloy of claim 1, wherein the alloy comprises
no more than about 0.5% iron as an impurity.

14. A method for manufacturing a component from the aluminum alloy of claim 1, the method comprising:

- a) melting the alloy at a temperature of about 700°C to about 900°C;
- b) then casting the melted alloy into casting molds at ambient temperature;
- c) then using a cooling medium to cool the cast ingot; and
- d) then heat aging the cast ingot at a temperature of about 350°C to about 450°C for a time of about 2 hours to about 48 hours.

15. The method of claim 14, further comprising cold rolling the cast ingot to form a sheet product.

16. The method of claim 15, further comprising stabilization heat treating the sheet product at a temperature of about 140°C to about 170°C for a time of about 1 to about 5 hours.

17. A method for manufacturing a component from the aluminum alloy of claim 1, the method comprising:

- a) melting the alloy at a temperature of about 700 to about 900°C;
- b) then casting the alloy into casting molds at ambient temperature;
- c) then using a cooling medium to cool the cast ingot; and
- d) then hot rolling the cast ingot into a sheet.

18. The method of claim 17, further comprising then heat aging the sheet at a temperature of about 350°C to about 450°C for a time of about 2 to about 48 hours.

19. The method of claim 18, further comprising then cold rolling the sheet, after the heat aging step, to form a thin sheet or foil product.

20. The method of claim 19, further comprising stabilization heat treating the thin sheet or foil product at a temperature of about 140°C to about 170°C for a time of about 1 to about 5 hours.

21. The method of claim 17, further comprising:

e) then cold rolling the sheet to form a thin sheet or foil product; and

f) then heat aging the thin sheet or foil product at a temperature about 300°C to about 410°C for a time of about 2 to about 24 hours.

22. A beverage can lid comprising the aluminum alloy of claim 1.

23. A beverage can tab comprising the aluminum alloy of claim 1.

24. An aluminum alloy component comprising the aluminum alloy of claim 1, wherein the aluminum alloy component is selected from a group consisting of roofing materials, siding materials, chemical manufacturing equipment, food manufacturing equipment, storage tanks, home appliances, sheet-metal work, marine parts, transportation parts, heavy duty cooking utensils, hydraulic tubes, fuel tanks, pressure vessels, truck bodies, truck assemblies, trailer bodies, trailer assemblies, drilling rigs, missile components, and railroad cars.

25. A fabricated form of the aluminum alloy of claim 1, the fabricated form selected from a group consisting of wires, sheets, plates and foils.

26. An aluminum alloy comprising:

aluminum, magnesium, manganese, silicon, zirconium, and an inoculant, and including a nanoscale precipitate comprising Al_3Zr ;

wherein the nanoscale precipitate has an average diameter of about 20 nm or less and has an L1_2 structure in an α -Al face centered cubic matrix;

wherein the average number density of the nanoscale precipitate is about 20^{21} m^{-3} or more;

wherein the inoculant comprises one or more of gallium, germanium, arsenic, indium, antimony, lead, and bismuth;

wherein, if the aluminum alloy is hard tempered, it possesses a yield strength of at least about 380 MPa, a tensile strength of at least about 440 MPa, and an elongation of at least about 5% at room temperature; and

wherein, if the aluminum alloy is soft tempered, it possesses a yield strength of at least about 190 MPa, a tensile strength of at least about 320 MPa, and an elongation of at least about 18% at room temperature.

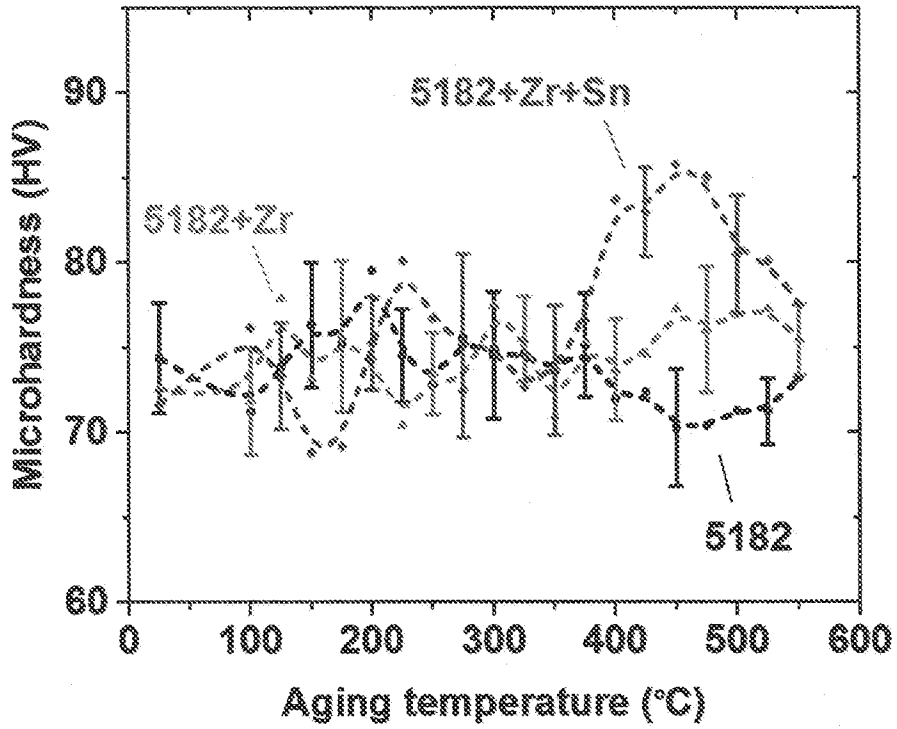


FIG. 1A

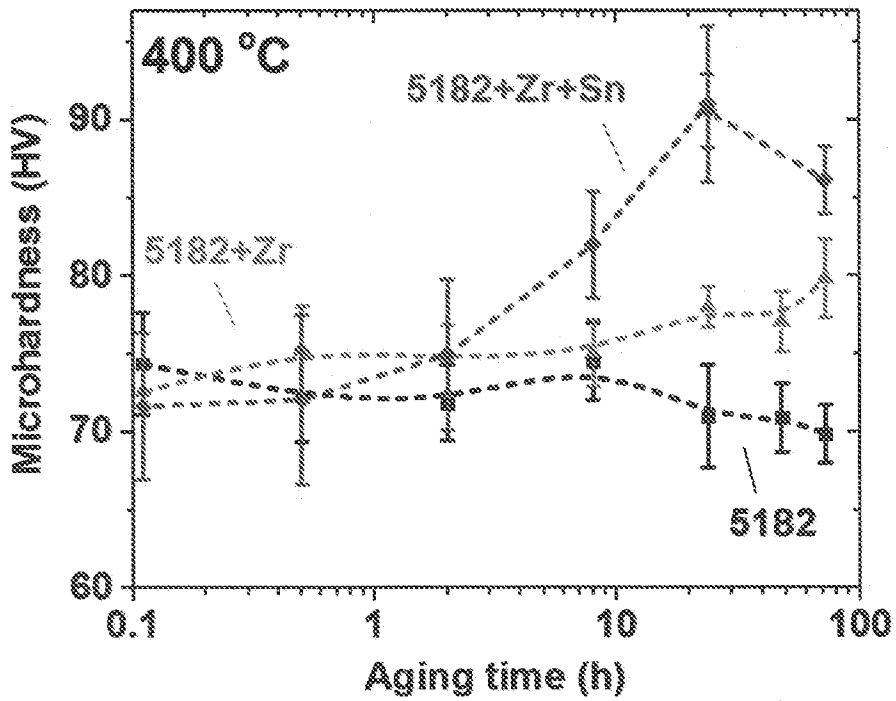


FIG. 1B

2/5

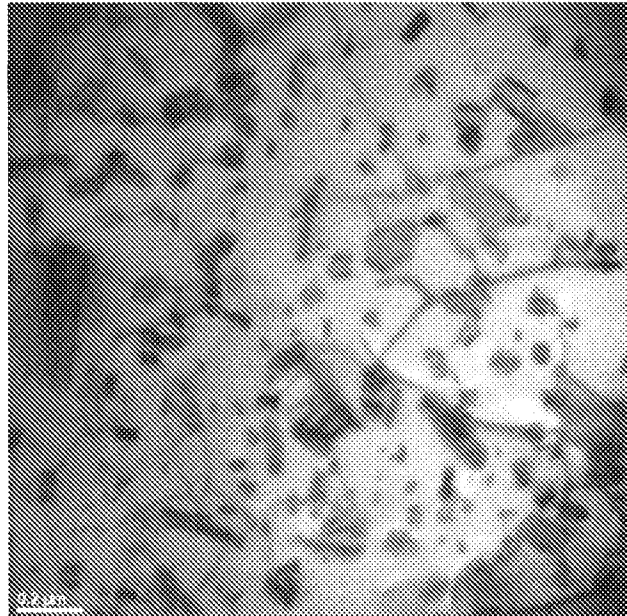


FIG. 2A

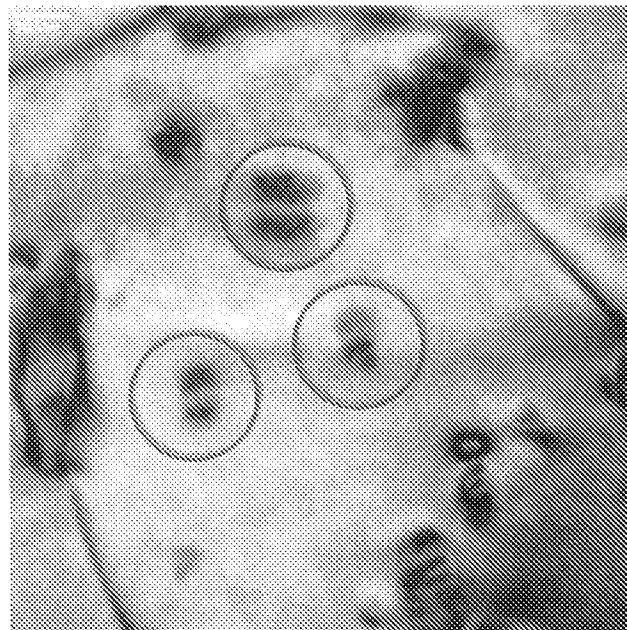


FIG. 2B

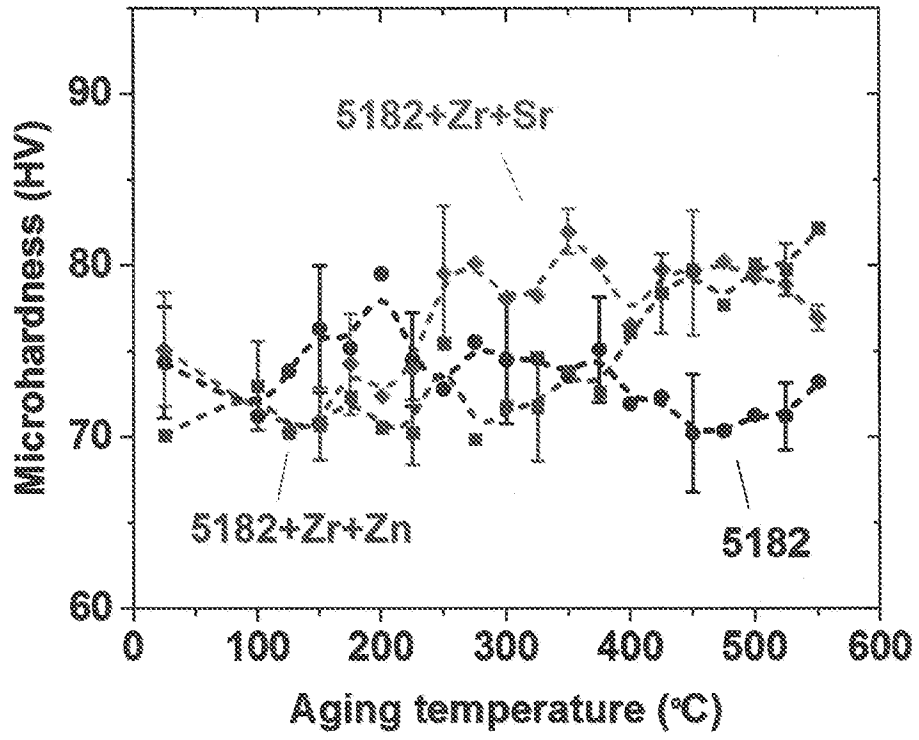


FIG. 3

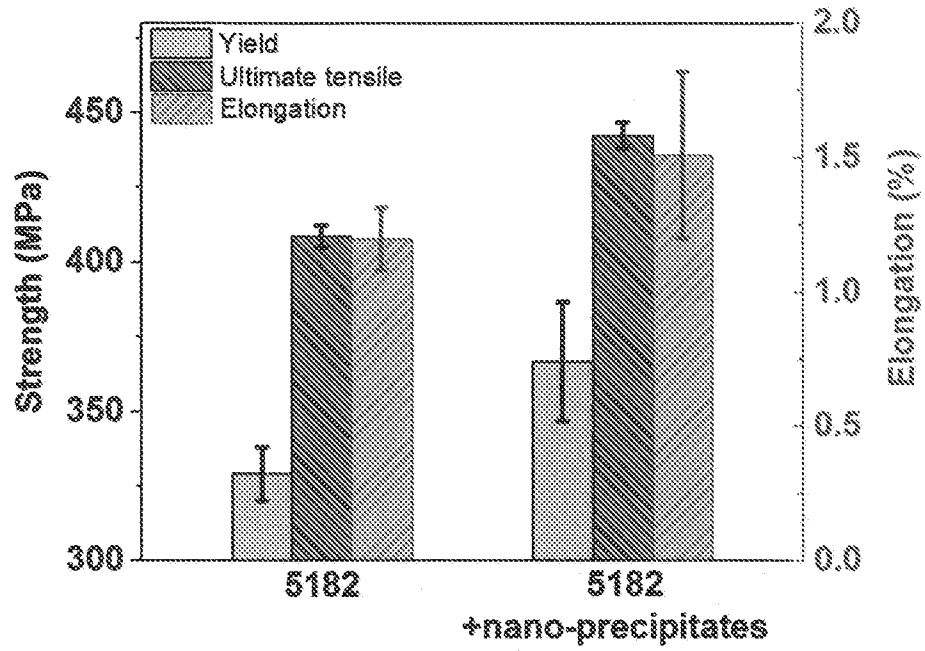


FIG. 4

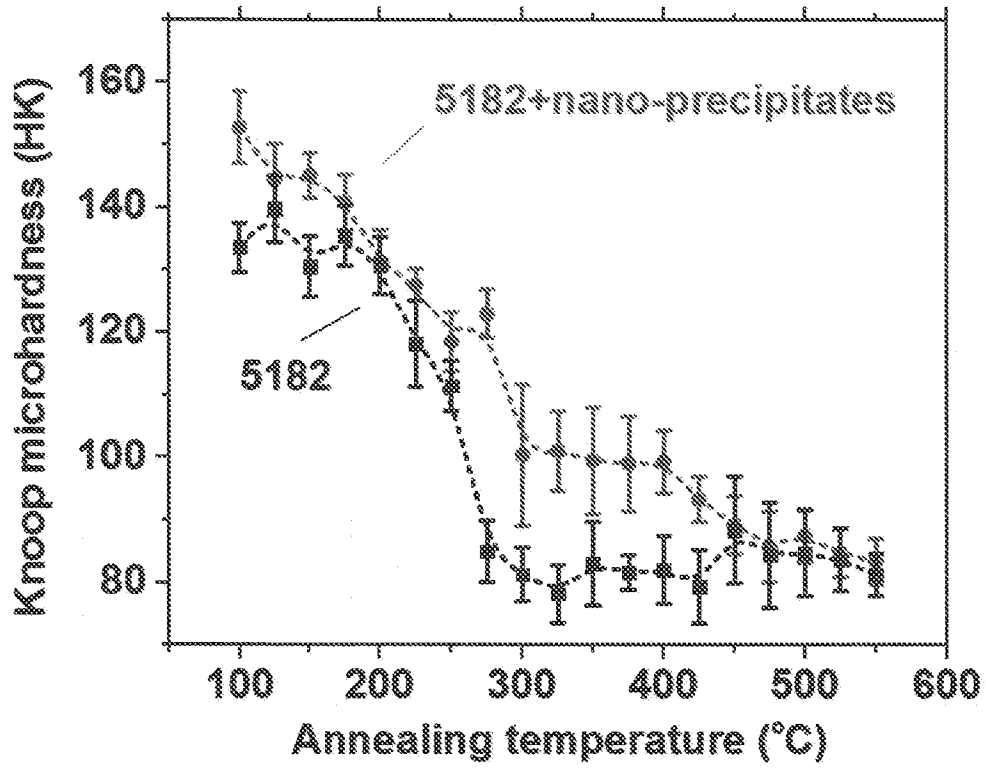


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/020899**A. CLASSIFICATION OF SUBJECT MATTER****C22C 21/08(2006.01)i, C22F 1/06(2006.01)i**

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 21/08; B22D 21/00; C22F 1/047; C22C 21/06; C22C 1/02; C22F 1/06

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & keywords: aluminum alloy, magnesium, manganese, silicon, zirconium, inoculant, zinc, tin, strontium, precipitate, casting, hot rolling, heat treatment

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2015-0284825 A1 (ALERIS ALUMINUM KOBLENZ GMBH) 08 October 2015 See paragraphs [0022], [0073], [0086] and claims 1, 5, 27.	1-26
A	US 2016-0271688 A1 (WUBST et al.) 22 September 2016 See paragraph [0021] and claims 1, 3.	1-26
A	CN 103866167 A (UNIVERSITY OF SCIENCE AND TECHNOLOGY, BEIJING et al.) 18 June 2014 See paragraph [0022] and claims 1, 4, 5, 8, 9.	1-26
A	JP 2008-025006 A (KOBE STEEL LTD.) 07 February 2008 See paragraphs [0089]-[0091] and claim 1.	1-26
A	US 2001-0025675 A1 (HASZLER et al.) 04 October 2001 See paragraph [0038] and claims 1, 2.	1-26

 Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

15 June 2018 (15.06.2018)

Date of mailing of the international search report

15 June 2018 (15.06.2018)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

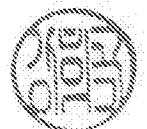
189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea

Facsimile No. +82-42-481-8578

Authorized officer

KANG, Hee Gok

Telephone No. +82-42-481-8264



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2018/020899

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2015-0284825 A1	08/10/2015	CN 101896631 A	24/11/2010
		CN 101896631 B	25/11/2015
		DE 112008003052 T5	16/12/2010
		US 2010-0319817 A1	23/12/2010
		US 9039848 B2	26/05/2015
		WO 2009-062866 A1	22/05/2009
		US 2016-0271688 A1	22/09/2016
DE 102016002689 A1	22/09/2016		
CN 103866167 A	18/06/2014	CN 103866167 B	25/01/2017
JP 2008-025006 A	07/02/2008	JP 05059353 B2	24/10/2012
US 2001-0025675 A1	04/10/2001	AR 006759 A1	29/09/1999
		AT 197317 T	15/11/2000
		AU 2293397 A	29/10/1997
		AU 735772 B2	12/07/2001
		BR 9708513 A	04/01/2000
		CA 2250977 A1	16/10/1997
		CA 2250977 C	26/03/2002
		CN 1217030 A	19/05/1999
		DE 69703441 T2	19/04/2001
		DE 69703441 T3	17/01/2008
		DK 0892858 T3	26/02/2001
		DK 0892858 T4	22/10/2007
		EP 0799900 A1	08/10/1997
		EP 0892858 A1	20/09/2000
		EP 0892858 B1	02/11/2000
		EP 0892858 B2	15/08/2007
		ES 2153189 T3	16/02/2001
		ES 2153189 T5	16/02/2008
		GR 3035225 T3	30/04/2001
		HK 1019235 A1	13/07/2001
		JP 03262278 B2	04/03/2002
		JP 11-507102 A	22/06/1999
		KR 10-0453642 B1	16/12/2004
		KR 10-2000-0005424 A	25/01/2000
		NO 326337 B1	10/11/2008
		NO 984634 A	02/10/1998
		NZ 331972 A	28/04/2000
		PT 892858 E	30/04/2001
		RU 2194787 C2	20/12/2002
		TR 9801984 T2	21/07/2000
		TW 349127 B	01/01/1999
		US 6238495 B1	29/05/2001
		US 6342113 B2	29/01/2002
WO 97-38146 A1	16/10/1997		
ZA 9702889 B	03/11/1997		