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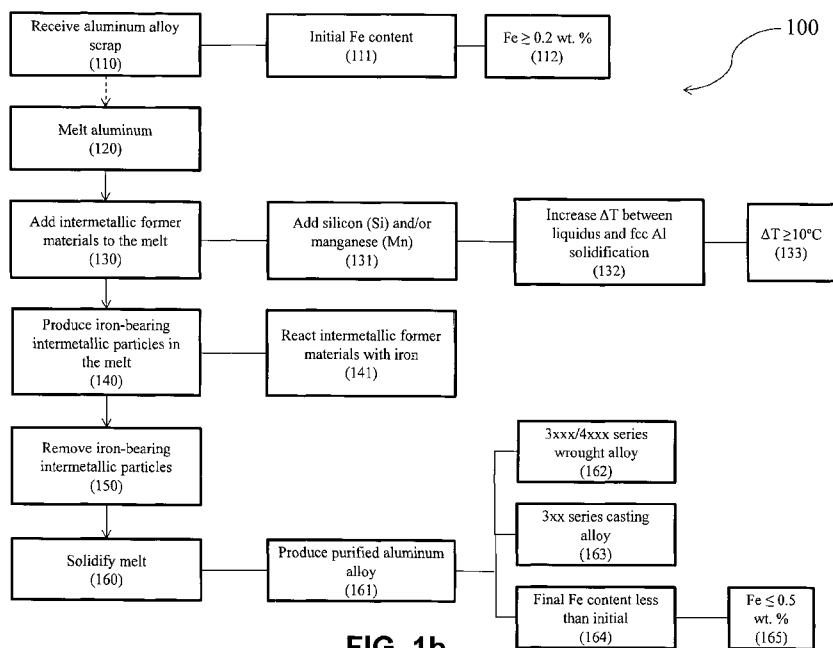


FIG. 1b

(57) Abstract: The present disclosure relates to methods of producing purified aluminum alloys from aluminum alloy scrap by producing a melt of the aluminum alloy scrap, adding one or more intermetallic former materials, producing iron-bearing intermetallic particles, removing the iron-bearing intermetallic particles, and solidifying the low-iron melt.

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METHODS OF RECYCLING ALUMINUM ALLOYS AND PURIFICATION THEREOF

BACKGROUND

[001] Aluminum alloys are useful in a variety of applications. Some aluminum alloys are also recyclable, and recycling those aluminum alloys preserves energy resources. In the United States and Canada, more than 5 million tons of aluminum are recycled each year.

SUMMARY OF THE INVENTION

[002] Broadly, the present disclosure relates to methods of producing purified aluminum alloys from aluminum alloy scrap. In one embodiment, the produced aluminum alloy is a 3xx aluminum casting alloy. In another embodiment, the produced aluminum alloy is one of a 3xxx or a 4xxx wrought aluminum alloy. Generally, the methods described herein for producing purified aluminum alloys include melting aluminum alloy scrap, adding one or more intermetallic former materials to the melt, and reacting the intermetallic former materials, such as Si and/or Mn, with elemental iron of the aluminum alloy scrap, thereby producing iron-bearing intermetallic particles. The produced iron-bearing intermetallic particles may subsequently be removed (e.g., by filtration). Addition of intermetallic former materials Si and/or Mn may also result in the production of an alloy having an increased amount of Si and/or Mn, resulting in the production of a 3xx aluminum casting alloy, or one of a 3xxx or a 4xxx wrought aluminum alloy. The addition of intermetallic former materials to the melt may result in an increase in the temperature window for removal of the intermetallic particles, which may, accordingly, increase the volume fraction of iron-bearing intermetallic particles available for removal. Thus, the addition of the intermetallic former materials to the melt may facilitate production of suitable end-use alloys, may facilitate the removal of iron from aluminum scrap in an industrially applicable temperature window, and may facilitate the reduction of the iron content in the aluminum alloy.

[003] In one embodiment, and referring now to FIG. 1a, aluminum scrap is melted (120) by conventional methods and intermetallic former materials may be added to the melt (130). The addition of intermetallic former materials may result in the production of iron-bearing intermetallic particles (140), such as by a reaction of the intermetallic former materials with iron within the melt (141). After or during their formation, the iron-bearing intermetallic particles may be removed by any suitable method, such as, but not limited to filtration or

sedimentation (150). Finally, the melt is solidified (160) and a purified aluminum alloy is produced (161).

[004] More particularly, and referring now to FIG. 1b, aluminum alloy scrap having an initial iron (Fe) content (111) may be received for recycling (110). For instance, the initial iron content may be at least 0.2 wt. % iron (Fe) (112). In one embodiment, the initial iron content is at least 0.3 wt. % iron (Fe). In another embodiment, the initial iron content is at least 0.4 wt. % iron (Fe). In yet another embodiment, the initial iron content is at least 0.5 wt. % iron (Fe). In another embodiment, the initial iron content is at least 0.6 wt. % iron (Fe). In yet another embodiment, the initial iron content is at least 0.7 wt. % iron (Fe). In another embodiment, the initial iron content is at least 0.8 wt. % iron (Fe). In yet another embodiment, the initial iron content is at least 0.9 wt. % iron (Fe). In another embodiment, the initial iron content is at least 1.0 wt. % iron (Fe). In yet another embodiment, the initial iron content is at least 1.5 wt. % iron (Fe). In another embodiment, the initial iron content is at least 2.0 wt. % iron (Fe). In another embodiment, the initial iron content is at least 2.5 wt. % iron (Fe). In yet another embodiment, the initial iron content is at least 3.0 wt. % iron (Fe).

[005] The aluminum alloy scrap is melted (120) by conventional methods, and intermetallic former materials such as, silicon (Si) and/or manganese (Mn), may be added to the melt (131). The addition of the intermetallic former materials is sufficient to produce iron-bearing intermetallic particles in the melt (140), such as by a reaction between the Si and/or Mn with the iron in the melt (141). The production may occur as a result of cooling the melt from a first temperature to a second temperature. In some embodiments, the first temperature is the liquidus temperature of the melt. In other embodiments, the first temperature is greater than the liquidus temperature of the melt. In some embodiments, the second temperature is greater than the solidification temperature of fcc aluminum. In some embodiments, the second temperature is below the solidification temperature of fcc aluminum, and above the solidus temperature of the melt. The addition of the intermetallic former materials (130) may be sufficient to realize an increase in the difference between the liquidus temperature of the melt and the solidification temperature of fcc aluminum (e.g., a purification temperature window, ΔT) (132). In this regard, the iron-bearing intermetallic particles may form in the temperature window. Generally, due to the addition of the intermetallic former materials (130), the temperature window between the first and second temperatures is at least 10°C (133). Within the temperature window (and sometimes at or below the second temperature), intermetallic particles may be removed (150) by methods including, but not limited to,

filtration and sedimentation of the melt. Following removal (150), the now low-iron melt is solidified thereafter (160) (e.g., cooled to below the solidus temperature of the low-iron melt). Due to the addition of intermetallic former materials (130), production of iron-bearing intermetallic particles (140), and removal of at least some of the iron-bearing intermetallic particles (150), solidifying the low-iron melt (160) produces a purified aluminum alloy (161). In one embodiment, one of a 3xxx or a 4xxx wrought aluminum alloy may be produced (162). In another embodiment, a 3xx casting aluminum alloy may be produced (163). The purified aluminum alloy may have an iron content less than the initial iron content (164), due to the removal (150) of the iron-bearing particles. For instance, the iron content of the purified aluminum alloy may be not greater than 0.5 wt. % iron (Fe) (165).

[006] As described above, intermetallic former materials are added to the melt (131), and iron-bearing intermetallic particles are produced in the melt (140). In one embodiment, intermetallic particles having the composition of $Al_{15}(Fe:Mn)_3Si_2$ may form in the melt, and the temperature window may lie between the liquidus of the melt and the solidification temperature of fcc aluminum. In this regard, the $Al_{15}(Fe:Mn)_3Si_2$ particles may solidify below the liquidus (i.e., the $Al_{15}(Fe:Mn)_3Si_2$ is the first solid to form below the liquidus). In one embodiment, due to the addition of intermetallic former materials Si and/or Mn, iron-bearing intermetallic particles $Al_{15}(Fe:Mn)_3Si_2$ are removed (150), and the temperature window between the liquidus of the melt and the solidification temperature of fcc aluminum is at least 10°C (133).

[007] The aluminum alloy scrap may be received (110) in a variety of forms. For instance the aluminum alloy scrap may be received as automotive scrap, aerospace scrap, beverage can scrap, electronic scrap, municipal scrap, and the like where aluminum alloys may find industrial applicability. In this regard, the aluminum alloy scrap may be aggregated from any of the types of scrap (e.g., mixed-stream scrap). In one embodiment, the aluminum alloy scrap is a mixed-stream aluminum alloy scrap. Similarly, scrap aluminum alloy may be produced as a part of regular production of casting of ingot, billet, or the shape casting of components. In this regard the aluminum alloy scrap may be comprised of at least a first scrap and a second scrap, wherein the first scrap and second scrap are heterogeneous (e.g., having relatively different compositions). In some embodiments, the aluminum alloy scrap comprises at least a first scrap and a second scrap having relatively different compositions.

[008] The melting (120) may be accomplished by any suitable method, such as conventional methods known in the art. Following the melting (120), the addition of intermetallic former

materials may occur at any suitable time. For instance, the addition may occur (a) prior to melting, (b) during melting of the scrap, or (c) after the scrap is above its liquidus temperature (e.g., after melting). Furthermore, the intermetallic former materials may be added as any suitable form. For instance, the intermetallic former material(s) may be added in a relatively pure form. For example, silicon may be added as relatively pure silicon, and manganese may be added as relatively pure manganese. Additionally, intermetallic former material-containing alloys may be used as a source of the intermetallic former material. For instance, silicon-containing aluminum alloys or manganese-containing aluminum alloys may be added to increase the silicon and/or manganese content of the melt. In one embodiment, intermetallic former material manganese may be added as manganese master alloy (e.g., Mn >10 wt. %, the balance being essentially aluminum).

[009] In addition to the relatively pure forms of intermetallic former materials, the intermetallic former materials may be added as scrap themselves. For instance, the aluminum alloy scrap may include at least a first and second scrap. In this regard, a first scrap may be an aluminum alloy scrap having insufficient intermetallic former materials to realize removal of iron-bearing intermetallic particles. A second scrap may be an aluminum alloy scrap having sufficient intermetallic former materials, when combined with at least a first scrap, to realize removal of iron-bearing intermetallic particles. Furthermore, the processes described herein may not be limited to the addition of at least a first and second scrap. For instance, a first and second scrap may comprise the aluminum alloy scrap, and additional intermetallic former materials may be added in other forms to realize the removal and/or an increased removal of iron-bearing intermetallic particles, relative to the at least first and second scrap.

[0010] As noted above, the addition of intermetallic formers (e.g., silicon (Si) and/or manganese (Mn) (131)) may be sufficient to realize an increase in the difference between the liquidus temperature of the melt and the solidification temperature of fcc aluminum (sometimes referred to herein as a "purification temperature window") (132). The iron-bearing intermetallic particles may be removed in the at least 10°C purification temperature window (133). In one embodiment, the purification temperature window is at least 15°C. In another embodiment, the purification temperature window is at least 20°C. In yet another embodiment, the purification temperature window is at least 30°C. In another embodiment, the purification temperature window is at least 40°C. In yet another embodiment, the purification temperature window is at least 50°C. In another embodiment, the purification temperature window is at least 60°C. In yet another embodiment, the purification

temperature window is at least 70°C. In another embodiment, the purification temperature window is at least 80°C. In yet another embodiment, the purification temperature window is at least 100°C.

[0011] After, or during their production, the iron-bearing intermetallic particles may be removed (150) by suitable methods, such as, but not limited to filtration or sedimentation, and combinations thereof. For example, filtration of the iron-bearing intermetallic particles may be performed using a variety of filters, such as filters made from refractory filter materials. Suitable refractory filter materials may include, but are not limited to, alumina, silica, silicon carbide, silicon nitride, calcium oxide, graphite, carbon, among others. In some embodiments, the iron-bearing intermetallic particles are removed by filtration, wherein the filtration comprises at least one refractory filter material. In this regard, multiple refractory filter materials may be used in one filter to facilitate removal of iron-bearing intermetallic particles from the melt. Some suitable refractory filters are disclosed in U.S. Patent No. 5,126,047.

[0012] The processes described herein may generally result in a solidified (160), purified aluminum alloy (161) having a purified iron content, wherein the purified iron content is less than the initial iron content of the aluminum alloy scrap (164). In one approach, the processes may result in a purified aluminum alloy having at least 10% less iron than the aluminum alloy scrap. By way of non-limiting example, aluminum alloy scrap having an initial iron content of 0.8 wt. % may be purified to have 10% less iron. Thus, in this non-limiting example, the purified iron content would be $0.8 \text{ wt. \%} \times (100\% - 10\%) = 0.72 \text{ wt. \%}$ iron (Fe). In one embodiment, the purified iron content is 15% less than the initial iron content. In another embodiment, the purified iron content is 20% less than the initial iron content. In yet another embodiment, the purified iron content is 25% less than the initial iron content. In another embodiment, the purified iron content is 35% less than the initial iron content. In yet another embodiment, the purified iron content is 45% less than the initial iron content. In another embodiment, the purified iron content is 60% less than the initial iron content. In yet another embodiment, the purified iron content is 75% less than the initial iron content. In another embodiment, the purified iron content is 85% less than the initial iron content.

[0013] In another approach, purified aluminum alloys may include not greater than 1.80 wt. % iron (Fe) (165). In one embodiment, a purified aluminum alloy includes not greater than 1.5 wt. % iron (Fe). In another embodiment, a purified aluminum alloy includes not greater

than 1.2 wt. % iron (Fe). In yet another embodiment, a purified aluminum alloy includes not greater than 1.0 wt. % iron (Fe). In another embodiment, a purified aluminum alloy includes not greater than 0.8 wt. % iron (Fe). In yet another embodiment, a purified aluminum alloy includes not greater than 0.5 wt. % iron (Fe). In another embodiment, a purified aluminum alloy includes not greater than 0.40 wt. % iron (Fe). In yet another embodiment, a purified aluminum alloy includes not greater than 0.35 wt. % iron (Fe). In another embodiment, a purified aluminum alloy includes not greater than 0.30 wt. % iron (Fe). In yet another embodiment, a purified aluminum alloy includes not greater than 0.25 wt. % iron (Fe). In another embodiment, a purified aluminum alloy includes not greater than 0.20 wt. % iron (Fe). In yet another embodiment, a purified aluminum alloy includes not greater than 0.15 wt. % iron (Fe). In another embodiment, a purified aluminum alloy includes not greater than 0.12 wt. % iron (Fe). In yet another embodiment, a purified aluminum alloy includes not greater than 0.10 wt. % iron (Fe).

[0014] Regarding solidification (160), a purified aluminum alloy (161) may be cast from the low-iron melt as a shape cast component, or may be cast as ingot/billet. Cast ingot or billet may also be re-melted at a later time for use in shape casting. Additionally, a cast ingot or billet may be re-melted, and combined with other materials to produce a target aluminum alloy composition. For instance, relatively pure aluminum may be added, and/or other alloying additions may be added to produce the desired aluminum alloy. A cast ingot or billet may be worked, for instance, by hot working and/or cold working via any of rolling, forging, extrusion, as well as stress relief by compression and/or stretching. Shape casting of the purified aluminum alloy may include any suitable shape casting method, including permanent mold casting, high pressure die casting, sand mold casting, investment casting, squeeze casting and semi-solid casting, among others.

[0015] The purified aluminum alloy may be a Si-based aluminum alloy. For instance, Si-based aluminum alloys may include 3xx casting aluminum alloys or 4xxx wrought aluminum alloys. As part of the purification processes described herein, silicon (Si) may be added to the melt, and consequently, at least some of the silicon (Si) may remain in the purified aluminum alloy. Purified aluminum alloys may generally include at least 3.0 wt. % silicon (Si). In one embodiment, a purified aluminum alloy includes at least 4.0 wt. % silicon (Si). In another embodiment, a purified aluminum alloy includes at least 5.0 wt. % silicon (Si). In yet another embodiment, a purified aluminum alloy includes at least 6.0 wt. % silicon (Si). In another embodiment, a purified aluminum alloy includes at least 6.5 wt. % silicon (Si). In yet

another embodiment, a purified aluminum alloy includes at least 7.0 wt. % silicon (Si). In another embodiment, a purified aluminum alloy includes at least 7.5 wt. % silicon (Si). In yet another embodiment, a purified aluminum alloy includes at least 8.5 wt. % silicon (Si). In another embodiment, a purified aluminum alloy includes at least 9.0 wt. % silicon (Si). In one embodiment, a purified aluminum alloy includes not greater than 23.0 wt. % silicon (Si). In another embodiment, a purified aluminum alloy includes not greater than 20.0 wt. % silicon (Si). In yet another embodiment, a purified aluminum alloy includes not greater than 15.0 wt. % silicon (Si).

[0016] As used herein, a “3xx aluminum alloy” means an aluminum casting alloy comprising silicon (Si) as the predominate alloying ingredient, as defined by the Aluminum Association document “Designations and Chemical Composition Limits for Aluminum Alloys in the Form of Castings and Ingot” (2009) (a.k.a., “the Pink Sheets”).

[0017] As used herein, a “4xxx aluminum alloy” means a wrought aluminum alloy comprising silicon (Si) as the predominate alloying ingredient, as defined by the Aluminum Association document “International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys” (2015) (a.k.a., the “Teal Sheets”).

[0018] In one embodiment, the methods for producing purified aluminum alloys described herein are used to produce aluminum alloys consistent with the aluminum alloys disclosed in commonly owned U.S. Patent Publication No. 2013/0105045. In another embodiment, the methods for producing purified aluminum alloys described herein are used to produce aluminum alloys consistent with the aluminum alloys disclosed in commonly owned U.S. Patent Publication No. 2017/0016092. In yet another embodiment, the methods for producing purified aluminum alloys described herein are used to produce aluminum alloys consistent with the aluminum alloys disclosed in commonly owned WIPO International Publication No. 2017/027734.

[0019] The purified aluminum alloy may be a Mn-based aluminum alloy. For instance, Mn-based aluminum alloys may include 4xxx wrought aluminum alloys. As part of the purification processes described herein, manganese (Mn) may be added to the melt, and consequently, at least some of the manganese (Mn) may remain in the purified aluminum alloy. Purified aluminum alloys may generally include at least 0.05 wt. % manganese (Mn). In one embodiment, a purified aluminum alloy includes at least 0.10 wt. % manganese (Mn). In another embodiment, a purified aluminum alloy includes at least 0.20 wt. % manganese (Mn). In yet another embodiment, a purified aluminum alloy includes at least 0.30 wt. %

manganese (Mn). In another embodiment, a purified aluminum alloy includes at least 0.40 wt. % manganese (Mn). In one embodiment, a purified aluminum alloy includes not greater than 1.8 wt. % manganese (Mn). In another embodiment, a purified aluminum alloy includes not greater than 1.5 wt. % manganese (Mn). In yet another embodiment, a purified aluminum alloy includes not greater than 1.2 wt. % manganese (Mn). In another embodiment, a purified aluminum alloy includes not greater than 0.9 wt. % manganese (Mn). In yet another embodiment, a purified aluminum alloy includes not greater than 0.8 wt. % manganese (Mn). In another embodiment, a purified aluminum alloy includes not greater than 0.7 wt. % manganese (Mn). In yet another embodiment, a purified aluminum alloy includes not greater than 0.4 wt. % manganese (Mn).

[0020] As used herein, a “3xxx aluminum alloy” means a wrought aluminum alloy comprising manganese (Mn) as the predominate alloying ingredient, as defined by the Aluminum Association document “International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys” (2015) (a.k.a., the “Teal Sheets”).

[0021] Also, as used herein, the term “3xxx aluminum alloy” or “4xxx aluminum alloy” only refers to the composition and not any associated processing, i.e., as used herein either a 3xxx aluminum alloy or 4xxx aluminum alloy does not need to be a wrought product to be considered a 3xxx or 4xxx aluminum alloy composition.

[0022] To facilitate production of suitable aluminum alloy products, other alloying additions may be added to the melt, such as being added (a) to the melt prior to removing the iron-bearing intermetallic particles and/or (b) to the melt after removing the iron-bearing intermetallic particles. Alternatively, other alloying additions may be added (c) during or (d) after re-melting of the purified aluminum alloy, such as, prior to shape casting, or casting as ingot/billet. Alloying additions may be added to tailor the physical properties (e.g., tensile properties; toughness; corrosion resistance; others) of a purified aluminum alloy.

[0023] As used herein, “other alloying additions” or “alloying additions” means elements other than aluminum, silicon, iron, and manganese, that may be purposefully added to the melt (e.g., to produce a pre-selected target composition and, ultimately, a pre-selected solidified alloy product). The other alloying additions may be added to facilitate the realization of desired physical properties of a pre-selected target composition. Other alloying addition elements include chromium (Cr), nickel (Ni), zinc (Zn), titanium (Ti), tin (Sn), and

strontium (Sr), among others. In one embodiment, the alloying additions comprise at least one of copper (Cu) or magnesium (Mg).

[0024] Components may be produced from the purified aluminum alloys. For instance, components may be shape cast using the purified aluminum alloys. Components made from the purified aluminum alloys may be used in any suitable application, such as in any of an automotive, aerospace, industrial or commercial transportation application, among others. In one embodiment, the purified aluminum alloy component is an automotive part (e.g., a body-in-white (BIW) part; a suspension part). In one embodiment, the purified aluminum alloy component is included in an automobile. In one embodiment, the purified aluminum alloy component is an aerospace component. In one embodiment, the purified aluminum alloy component is included in an aerospace vehicle. In one embodiment, the purified aluminum alloy component is an industrial component. In one embodiment, the purified aluminum alloy component is a commercial transportation component. In one embodiment, the purified aluminum alloy component is included in a commercial transportation vehicle.

[0025] The use of tailored additions of intermetallic former materials, optionally with other alloying additions, facilitates the production of predetermined, low-iron, aluminum alloys from aluminum alloy scrap. In one embodiment, and referring now to FIG. 1c, a target purified aluminum alloy composition is pre-selected (210) for production using the methods described herein. In this regard, the pre-selected target composition may be a 3xx cast aluminum alloy, or one of a 3xxx or 4xxx wrought aluminum alloy. Based on the pre-selection step and composition of the aluminum alloy scrap, a particular amount of intermetallic former materials may be added to the aluminum alloy scrap (220). The aluminum alloy scrap composition may be determined (221) prior to adding the particular amount of intermetallic former materials and/or other alloying additions. In this manner, the particular amount of intermetallic former materials may be sufficient to realize removal of iron-bearing intermetallic particles (225). The particular amount of intermetallic former materials that may be added may be chosen using any suitable method. In this regard, the addition of intermetallic former materials may be chosen on a basis of experimental results, or may be chosen on a basis of recycling simulations (e.g., modeling), among others. For instance, a database of simulations may be utilized to calculate an appropriate amount of intermetallic former materials sufficient to realize removal of iron-bearing intermetallic particles. After removal of the iron-bearing intermetallic particles (225) using the methods described herein and/or use of any other alloying additions (222), a purified aluminum alloy

having the pre-selected target composition may be produced. As one may appreciate, a target composition may be considered a composition range.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] FIG. 1a is an embodiment of producing a purified aluminum alloy.

[0027] FIG. 1b is an embodiment of producing a purified aluminum alloy using intermetallic former materials silicon (Si) and/or manganese (Mn).

[0028] FIG. 1c is an embodiment of producing a purified aluminum alloy having a pre-selected target composition.

[0029] FIG. 2a is a micrograph of as-cast MIC6[®] alloy, taken at 300x magnification.

[0030] FIG. 2b is a micrograph of as-cast MIC6[®] alloy, taken at 3000x magnification.

[0031] FIG. 3a is a solidification pathway diagram of MIC6[®] alloy of Example 1, generated by Pandat[®], for a solid fraction of from 0 to 1.

[0032] FIG. 3b is a solidification pathway diagram of MIC6[®] alloy of Example 1, generated by Pandat[®], for a solid fraction of from 0 to 0.2.

[0033] FIG. 4a is a solidification pathway diagram for MIC6[®], Alloy 1, and Alloy 2 of Example 1, generated by Pandat[®], for a solid fraction of from 0 to 1.

[0034] FIG. 4b is a solidification pathway diagram for MIC6[®], Alloy 1, and Alloy 2 of Example 1, generated by Pandat[®], for a solid fraction of from 0 to 0.2.

[0035] FIG. 5 is a plot of a solidification pathway diagram and the liquid aluminum Mn and Fe composition in the liquid aluminum, generated by Pandat[®], for a solid fraction of from 0 to 1.

[0036] FIG. 6a is a contour plot illustrating the effect of adding intermetallic former materials Si and Mn on the lowest possible iron content in a recycling simulation.

[0037] FIG. 6b is a contour plot illustrating the effect of adding intermetallic former materials Si and Mn on the purification temperature window in a recycling simulation.

[0038] FIG. 6c is a contour plot illustrating the effect of adding alloying additions Cu and Mg on the lowest possible iron content in a recycling simulation.

[0039] FIG. 6d is a contour plot illustrating the effect of adding alloying additions Cu and Mg on the purification temperature window in a recycling simulation.

[0040] FIG. 7 is a data table for the recycling simulation of Example 3 showing the solid phase fraction, the liquid aluminum composition, and the precipitation phases.

[0041] FIG. 8 is a data table for the recycling simulation of Example 4 showing the solid phase fraction, the liquid aluminum composition, and the precipitation phases.

[0042] FIG. 9 is a data table for the recycling simulation of Example 5 showing the solid phase fraction, the liquid aluminum composition, and the precipitation phases.

[0043] FIG. 10 is a data table for the recycling simulation of Example 6 showing the solid phase fraction, the liquid aluminum composition, and the precipitation phases.

[0044] FIG. 11 is a data table for the recycling simulation of Example 7 showing the solid phase fraction, the liquid aluminum composition, and the precipitation phases.

DETAILED DESCRIPTION

Example 1

[0045] A recyclable aluminum alloy of MIC6[®] was cast as ingot. Table 1a gives a typical composition of aluminum alloy MIC6[®].

Table 1a: Composition of Aluminum Alloy MIC6[®]

Element	Composition (wt. %)
Si	1.05
Fe	0.53
Cu	1.3
Mn	0.75
Mg	1.65
Zn	2.5
Cr	0.16
Al	Balance

Micrographs were taken of the as-cast aluminum alloy. Micrographs taken at 300x and 3000x magnification are shown in FIG. 2a and 2b, respectively. As shown, the as-cast microstructure of the aluminum alloy contains an intermetallic phase. The intermetallic phase exhibited a Chinese script-like structure, and was identified as $Al_{15}(Fe:Mn)_3Si_2$ using SEM-EDX analysis. The composition of the intermetallic phase was further confirmed by constructing a Pandat[®] phase diagram using the composition given in Table 1, and analyzing the solidification pathway. The phase diagram constructed by Pandat[®], as shown in FIG. 3a-3b, illustrates the solidification pathway. As shown in FIG. 3b, a small purification temperature window of 2.5°C exists where solid intermetallic $Al_{15}(Fe:Mn)_3Si_2$ forms absent of solid aluminum. In principle, intermetallic $Al_{15}(Fe:Mn)_3Si_2$ particles can be separated from

the liquid phase (e.g., by filtration) in the 2.5°C temperature window. However, in practice, the temperature window (2.5°C) is too small to achieve a significant separation.

[0046] The addition of intermetallic formers silicon and manganese to the MIC6[®] alloy modifies the solidification pathway. As shown in Table 1b and FIGS. 4a-4b, adding manganese (“Alloy 1”) and a combination of silicon and manganese (“Alloy 2”) increases the purification temperature window (ΔT) and the solid fraction of intermetallic $Al_{15}(Fe:Mn)_3Si_2$.

Table 1b: Effect of Intermetallic Formers on Alloy MIC6[®]

Alloy	Composition, wt%								ΔT (°C)	$Al_{15}(Fe:Mn)_3Si_2$ Solid Phase Fraction (v/v %)
	Si	Mn	Cu	Fe	Mg	Zn	Cr	Al		
MIC6	1.05	0.75	1.3	0.53	1.65	2.5	0.16	bal.	2.5	0.02
Alloy 1	1.05	2.00	1.3	0.53	1.65	2.5	0.16	bal.	43.5	3.77
Alloy 2	8.00	2.00	1.3	0.53	1.65	2.5	0.16	bal.	97.3	6.1

[0047] The solid fraction, iron and manganese compositions in the bulk aluminum, and phase change temperatures for Alloy 2 are shown in FIG. 5. As illustrated, intermetallic $Al_{15}(Fe:Mn)_3Si_2$ begins to form at approximately 690°C. At 592°C, solid aluminum (fcc) forms in equilibrium with the intermetallic and liquid phases. Thus, there is a temperature window of approximately 97°C, from 592°C to 690°C, where intermetallic $Al_{15}(Fe:Mn)_3Si_2$ particles can be separated from the liquid aluminum phase absent of solid aluminum. This purification temperature window of approximately 97°C is sufficient to separate the intermetallic particles from the bulk liquid aluminum. In one approach, the purification temperature window is at least 10°C in order to separate the intermetallic particles from the bulk liquid aluminum.

[0048] As shown in FIG. 5, iron can be reduced in the bulk aluminum by adding intermetallic formers, and removing the intermetallic $Al_{15}(Fe:Mn)_3Si_2$ particles. As illustrated, the iron concentration in the aluminum is reduced from 0.53 wt. % to approximately 0.05 wt. % at the solidification point of fcc aluminum (592°C). However, a separation that realizes 0.05 wt. % iron in the bulk aluminum without removing solid aluminum is likely not possible. Thus, in one approach intermetallic particles are removed (e.g., by filtration) above the aluminum solidification temperature (e.g., 10-20°C above), thereby avoiding the removal of solid aluminum.

Example 2

[0049] Purifying aluminum alloys by adding intermetallic formers and removing the iron-bearing intermetallic particles may be performed on a variety of aluminum alloys. In this regard, recyclability process models were constructed for other common aluminum alloy compositions. Pandat[®], a thermodynamic simulation software, and an accompanying aluminum thermodynamic database, PanAluminum[®], were utilized to construct process models. As described in greater detail below, intermetallic formers were chosen for each aluminum alloy composition. The mixture of the intermetallic formers and aluminum alloy provides the process simulation with an overall composition. The overall composition was utilized by Pandat[®] to determine the lowest iron concentration and the corresponding purification temperature window (ΔT) of the mixture.

[0050] Intermetallic formers were chosen for each recycling process. The mass of intermetallic formers was chosen by a Java computer script that matches the amount of intermetallic formers with a composition in a simulation database that realizes a good separation result. In this approach, the mass of intermetallic formers was chosen based on maximizing ΔT and minimizing the iron concentration. The database of simulations comprised 11,520 simulations carried out using each combination of the elements and compositions provided in Table 2, below.

Table 2: Elements and Compositions of Simulation Database

Element	Compositions (wt. %)
Fe	0.5; 0.75, 1.0; 1.25, 1.5
Mn	0.1, 0.5; 1.0; 1.5; 2.0; 2.5
Si	1.0, 4.0, 7.0, 10.0, 13.0, 16.0, 19.0, 22.0
Mg	0.1; 0.4; 0.7
Cu	0.1, 0.25, 1.25, 2.25
Zn	0.1, 0.5; 1.5; 2.5

[0051] The 11,520 simulations were then used to construct contour plots. Contour plots illustrating the effect of Mn and Si, as intermetallic formers, on the iron concentration and the purification temperature window are shown in FIGS. 6a-6b for an aluminum alloy having 2.25 wt. % Cu, 0.7wt. % Mg, 0.5 wt. % Zn. As illustrated, increasing the Si and Mn content decreases the iron concentration and increases the purification temperature window. For the

shown Si and Mn content ranges and given composition, the iron concentration varies from 0.10 to about 0.70 wt. % and the purification temperature window varies from 20°C to about 100°C. Contour plots illustrating the effect of Cu and Mg on the lowest possible iron concentration and purification temperature window are shown in FIGS. 6c-6d for an aluminum alloy having 2.0 wt. % Mn, 10.0 wt. % Si, and 0.5 wt. % Zn. As illustrated, increasing the Cu and Mg content decreases the iron concentration, and increases the purification temperature window. For the shown Cu and Mg content ranges and given composition, the iron concentration varies from 0.11 to about 0.14 wt. % and the purification temperature window varies from 94°C to about 104°C.

Example 3

[0052] Using the simulation methodology of Example 2, a simulation was performed on an alloy (“Alloy 3”) having the composition shown in Table 3b, below. Intermetallic formers of manganese and silicon were added as (1) a manganese master alloy (85 wt. % Al and 15 wt. % Mn) and (2) as pure silicon. The simulation yielded a lowest possible iron composition of about 0.10 wt. % at a temperature of 600.2°C, providing a purification temperature window of about 77°C. The simulation shows that a final alloy composition having 0.13 - 0.17 wt. % iron will be realized by the removal of the intermetallic phases when the filtration is performed approximately 10-20°C above the aluminum solidification temperature. The mass of Alloy 3 and intermetallic formers are provided below in Table 3a. The composition of Alloy 3, the melt composition (overall composition of Alloy 3 and intermetallic formers), and the final melt composition after purification are given in Table 3b. A complete set of data for the recycling simulation is shown in FIG. 7.

Table 3a: Mass of Materials of Example 3

Material	Mass (lbs)
Alloy 3	1000
15% Al - 85% Mn Master Alloy	11.2
Pure Silicon	91.8

Table 3b: Process Compositions of Example 3

Element	Alloy 3 Composition (wt. %)	Melt Composition Prior to Purification (wt. %)	Melt Composition After Purification (wt. %)
Si	0.75	9.00	8.94

Element	Alloy 3 Composition (wt. %)	Melt Composition Prior to Purification (wt. %)	Melt Composition After Purification (wt. %)
Fe	0.57	0.52	0.13 - 0.17
Cu	0.20	0.18	0.19
Mn	1.03	1.80	0.63 - 0.74
Mg	0.50	0.45	0.47 - 0.48
Cr	0.09	0.08	0.08
Ni	0.05	0.05	0.05
Zn	0.12	0.11	0.12
Ti	0.05	0.04	0.04
Zr	0.02	0.01	0.01

Example 4

[0053] Using the methodology of Example 2, a simulation was performed on a mixture of two alloys (“Alloy 4a” and “Alloy 4b”), having the compositions shown in Table 4b, below. Alloy 4a is a typical 6061 aluminum alloy. Intermetallic formers of manganese, and silicon, were added as (1) a manganese master alloy (85 wt. % Al and 15 wt. % Mn), and (2) as pure silicon. Pure copper was also added to raise the copper level in the alloys to approximately 1.0 wt. %. The simulation yielded a lowest possible iron composition of about 0.08 wt. % at a temperature of about 594.9°C, providing a purification temperature window of about 105°C. The simulation shows a final alloy composition having 0.11 - 0.14 wt. % iron will be realized by the removal of the intermetallic phases when the filtration is performed at approximately 10-20°C above the aluminum solidification temperature. The mass of Alloy 4a, Alloy 4b, Mn master alloy, pure Si, and pure copper are provided below in Table 4a. The compositions of Alloy 4a, Alloy 4b, the melt composition (overall composition of Alloy 4a, Alloy 4b, Mn master alloy, pure Si, and pure Copper), and the final melt composition after purification are given in Table 4b. A more complete set of data for the recycling simulation is given in FIG. 8.

Table 4a: Mass of Materials of Example 4

Material	Mass (lbs)
Alloy 4a	400
Alloy 4b	600

Material	Mass (lbs)
15% Al - 85% Mn Master Alloy	10.7
Pure Silicon	96
Pure Copper	8

Table 4b: Process Compositions of Example 4

Element	Alloy 4a Composition (wt. %)	Alloy 4b Composition (wt. %)	Melt Composition Prior to Purification (wt. %)	Melt Composition After Purification (wt. %)
Si	0.6	0.82	9.27	9.25-9.26
Fe	0.7	0.23	0.37	0.11-0.14
Cu	0.275	0.42	1.03	1.07
Mn	0.15	0.99	1.40	0.58-0.69
Mg	1.00	0.42	0.58	0.4-0.6
Cr	0.20	0.045	0.10	0.10
Ni	0.00	0.05	0.03	0.03
Zn	0.25	0.05	0.12	0.12
Ti	0.15	0.134	0.13	0.04

Example 5

[0054] Using the methodology of Example 2, a simulation was performed on a mixture of two alloys ("Alloy 5a" and "Alloy 5b"), having the compositions shown in Table 5b, below. Intermetallic formers of manganese and silicon were added as (1) a manganese master alloy (85 wt. % Al and 15 wt. % Mn), and (2) as pure silicon. The simulation yielded a lowest possible iron composition of about 0.08 wt. % at a temperature of about 592.7°C, providing a purification temperature window of about 84°C. The simulation shows a final alloy composition having 0.10 - 0.13 wt. % iron will be realized by the removal of the intermetallic phases when the filtration is performed at approximately 10-20°C above the aluminum solidification temperature. The mass of Alloy 5a, Alloy 5b, Mn master alloy, and pure Si are provided below in Table 5a. The compositions of Alloy 5a, Alloy 5b, the melt composition (overall composition of Alloy 5a, Alloy 5b, Mn master alloy, and pure Si), and the final melt

composition after purification are given in Table 5b. A more complete set of data for the recycling simulation is given in FIG. 9.

Table 5a: Mass of Materials of Example 5

Material	Mass (lbs)
Alloy 5a	400
Alloy 5b	600
15% Al - 85% Mn Master Alloy	15
Pure Silicon	110

Table 5b: Process Compositions of Example 5

Element	Alloy 5a Composition (wt. %)	Alloy 5b Composition (wt. %)	Melt Composition Prior to Purification (wt. %)	Melt Composition After Purification (wt. %)
Si	0.75	0.82	10.48	10.48
Fe	0.57	0.53	0.49	0.10-0.12
Cu	0.2	0.11	0.13	0.14
Mn	1.03	1.03	2.05	0.64-0.74
Mg	0.5	0.0488	0.20	0.21
Cr	0.085	0.05	0.06	0.06
Ni	0.05	0.05	0.04	0.04
Zn	0.12	0.087	0.09	0.10
Ti	0.049	0.05	0.04	0.03
Zr	0.015	0.046	0.03	0.03

Example 6

[0055] Using the methodology of Example 2, a simulation was performed on a mixture of two alloys (“Alloy 6a” and “Alloy 6b”), having the compositions shown in Table 6b, below. Intermetallic former silicon was added as pure silicon. The simulation yielded a lowest possible iron composition of about 0.10 wt. % at a temperature of about 597.9°C, providing a purification temperature window of about 67°C. The simulation shows a final alloy composition having 0.12 - 0.16 wt. % iron will be realized by the removal of the intermetallic phases when the filtration is performed at approximately 10-20°C above the aluminum solidification temperature. The mass of Alloy 6a, Alloy 6b, and pure Si are provided below

in Table 6a. The compositions of Alloy 6a, Alloy 6b, the melt composition (overall composition of Alloy 6a, Alloy 6b, and pure Si), and the final melt composition after purification are given in Table 6b. A more complete set of data for the recycling simulation is given in FIG. 10.

Table 6a: Mass of Materials of Example 6

Material	Mass (lbs)
Alloy 6a	400
Alloy 6b	600
Pure Silicon	77.5

Table 6b: Process Compositions of Example 6

Element	Alloy 6a Composition (wt. %)	Alloy 6b Composition (wt. %)	Melt Composition Prior to Purification (wt. %)	Melt Composition After Purification (wt. %)
Si	1.5	2.35	9.06	9.05-9.06
Fe	0.22	0.25	0.22	0.12-0.16
Cu	0.53	0.45	0.45	0.46
Mn	0.92	1.05	0.93	0.63-0.74
Mg	0.35	0	0.13	0.13
Cr	0.06	0	0.02	0.02
Ni	0.05	0.03	0.04	0.04
Zn	0.75	0.8	0.72	0.73
Ti	0.07	0.1	0.08	0.04
Zr	0.007	0.01	0.01	0.01

Example 7

[0056] Using the methodology of Example 2, a simulation was performed on an alloy (“Alloy 7”) having the compositions shown in Table 7b, below. Intermetallic former silicon was added as pure silicon. Pure copper was also added to raise the copper level in the alloys to approximately 1.9 wt. %. The simulation yielded a lowest possible iron composition of about 0.09 wt. % at a temperature of about 595.1°C, providing a purification temperature window of about 100°C. The simulation shows a final alloy composition having 0.12 - 0.15 wt. % iron will be realized by the removal of the intermetallic phases when the filtration is

performed at approximately 10-20°C above the aluminum solidification temperature. The mass of Alloy 7, Mn master alloy, and pure Si are provided below in Table 7a. The compositions of Alloy 7, the melt composition (overall composition of Alloy 7, pure silicon, and pure copper), and the final melt composition after purification are given in Table 7b. A more complete set of data for the recycling simulation is given in FIG. 11.

Table 7a: Mass of Materials of Example 7

Material	Mass (lbs)
Alloy 7	1000
Pure Silicon	92
Pure Copper	16

Table 7b: Process Compositions of Example 7

Element	Alloy 7 Composition (wt. %)	Melt Composition Prior to Purification (wt. %)	Melt Composition After Purification (wt. %)
Si	0.82	9.04	9.04-9.05
Fe	0.23	0.21	0.12-0.15
Cu	0.42	1.82	1.84-1.85
Mn	0.99	0.89	0.89
Mg	0.042	0.04	0.04
Cr	0.045	0.04	0.04
Ni	0.05	0.05	0.05
Zn	0.05	0.05	0.05
Ti	0.134	0.12	0.12
Zr	0.055	0.05	0.05

CLAIMS

What is claimed is:

1. A method comprising:

(a) melting aluminum alloy scrap, thereby producing a melt, wherein the aluminum alloy scrap comprises an initial iron content, wherein the initial iron content is at least 0.20 wt. % iron (Fe);

(b) adding intermetallic former materials to the melt, wherein the intermetallic former materials comprise silicon (Si), manganese (Mn), or both Si and Mn;

(c) producing, due to the adding step (b), iron-bearing intermetallic particles in the melt;

(d) removing at least some of the iron-bearing intermetallic particles from the melt, thereby producing a low-iron melt;

(e) solidifying the low-iron melt, thereby producing a purified aluminum alloy from the low-iron melt, wherein the purified aluminum alloy includes a purified iron content, wherein the purified iron content is less than the initial iron content.

2. The method of claim 1, wherein the intermetallic former materials comprise silicon, and wherein the adding step (b) comprises adding a sufficient amount of the silicon to produce the low-iron melt, wherein the low-iron melt includes at least 3 wt. % Si.

3. The method of any of the preceding claims, wherein the purified aluminum alloy is one of a 3xx aluminum casting alloy or a 4xxx wrought aluminum alloy.

4. The method of any of the preceding claims, wherein the purified aluminum alloy comprises not greater than 0.35 wt. % iron (Fe).

5. The method of any of the preceding claims, wherein the purified aluminum alloy comprises not greater than 0.20 wt. % iron (Fe).

6. The method of any of the preceding claims, wherein the purified aluminum alloy comprises not greater than 0.15 wt. % iron (Fe).

7. The method of any of the preceding claims, wherein the intermetallic former materials comprise both silicon and manganese, and wherein the adding step (b) comprises adding a sufficient amount of the silicon and the manganese to produce the low-iron melt, wherein the low-iron melt includes not greater than 1.8 wt. % manganese (Mn).

8. The method of claim 1, wherein the purified aluminum alloy is a 3xxx wrought aluminum alloy.

9. The method of any of the preceding claims, wherein the producing step comprises:

(i) cooling the melt from a first temperature to a second temperature, thereby producing the iron-bearing intermetallic particles.

10. The method of claim 9, comprising:

at or below the second temperature, completing the removing step.

11. The method of claim 10, wherein the removing step comprises at least one of filtration of the melt and sedimentation of the melt.

12. The method of claim 11, wherein the removing comprises filtration using a refractory filter material.

13. The method of claim 10, wherein the second temperature is at least 10°C higher than a solidification temperature of fcc aluminum.

14. The method of claim 13, wherein the solidifying step (e) comprising:

cooling the melt from the second temperature to below a solidus temperature of the low-iron melt.

15. The method of claim 14, wherein the first temperature is the liquidus temperature, and wherein the liquidus temperature is at least 10°C higher than the second temperature.

16. The method of any of the preceding claims, comprising:

adding alloying additions to the melt.

17. The method of claim 16, comprising:

after the removing step (d), completing the adding alloy additions step.

18. The method of claim 17, wherein the alloying additions include at least one of copper (Cu), and magnesium (Mg).

19. The method of any of the preceding claims, wherein the purified iron content is at least 10% less than the initial iron content.

20. The method of any of the preceding claims, wherein the purified iron content is at least 25% less than the initial iron content.

21. The method of any of the preceding claims, wherein the purified iron content is at least 60% less than the initial iron content.

100

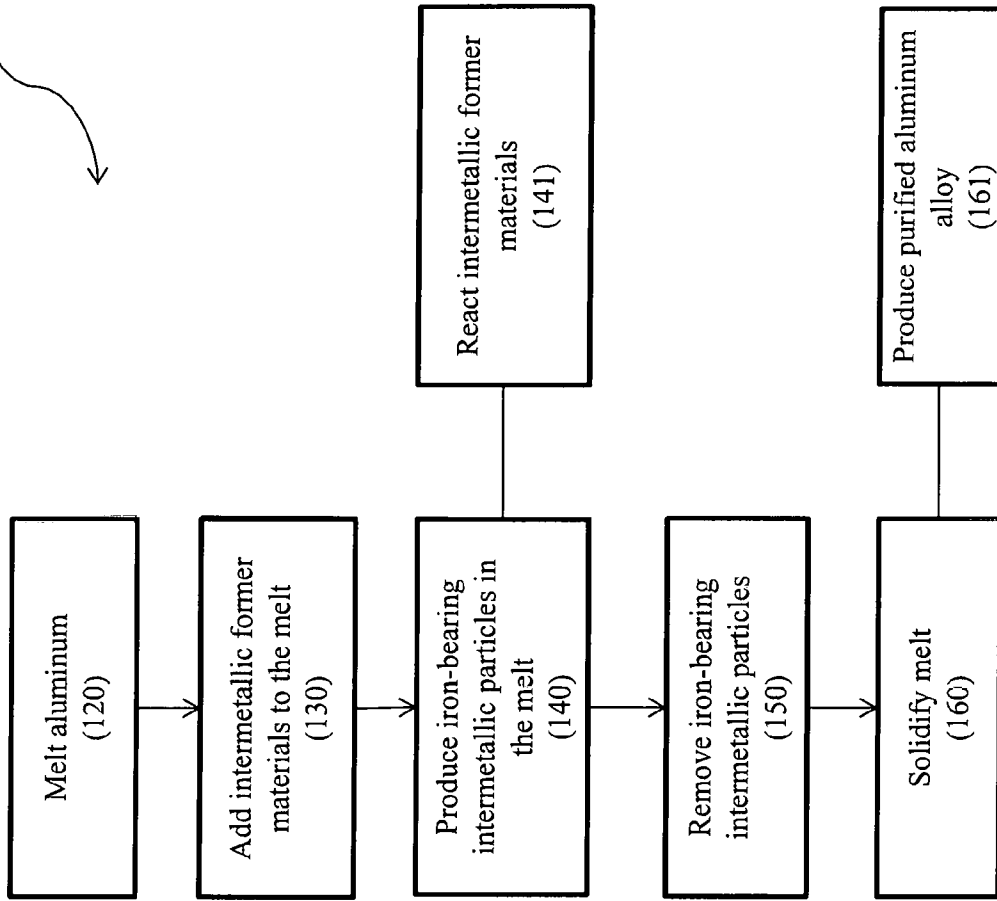


FIG. 1a

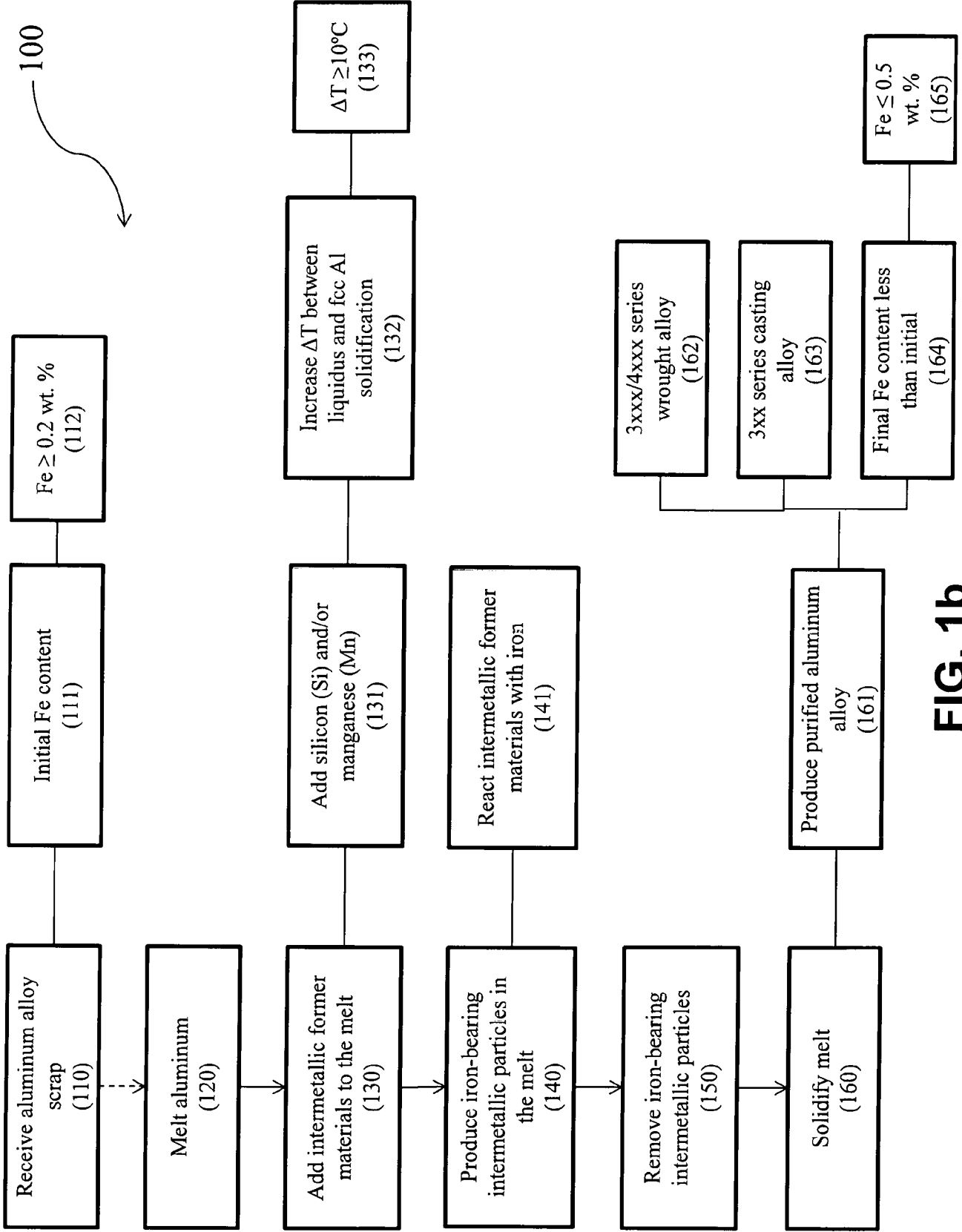


FIG. 1b

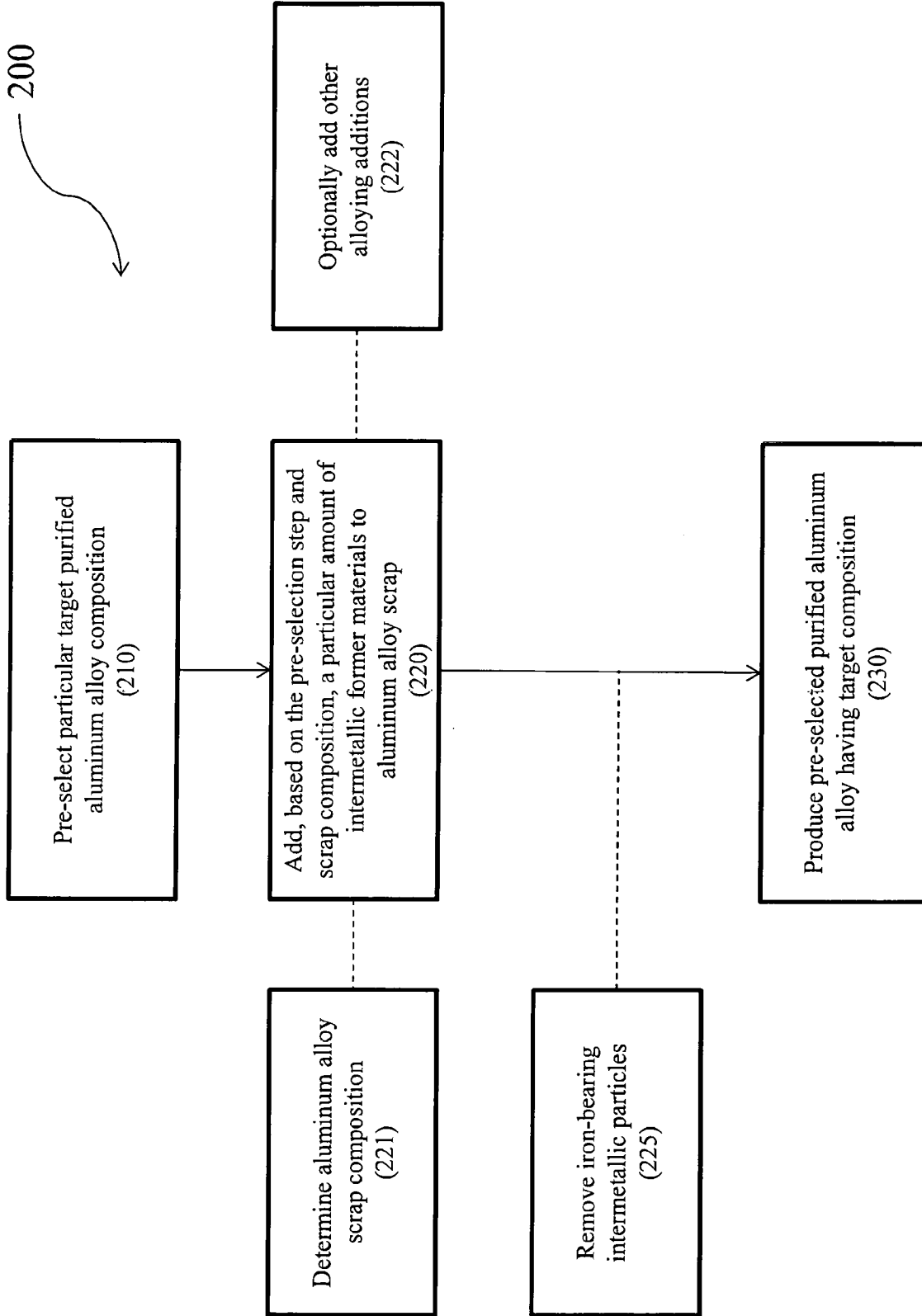


FIG. 1c

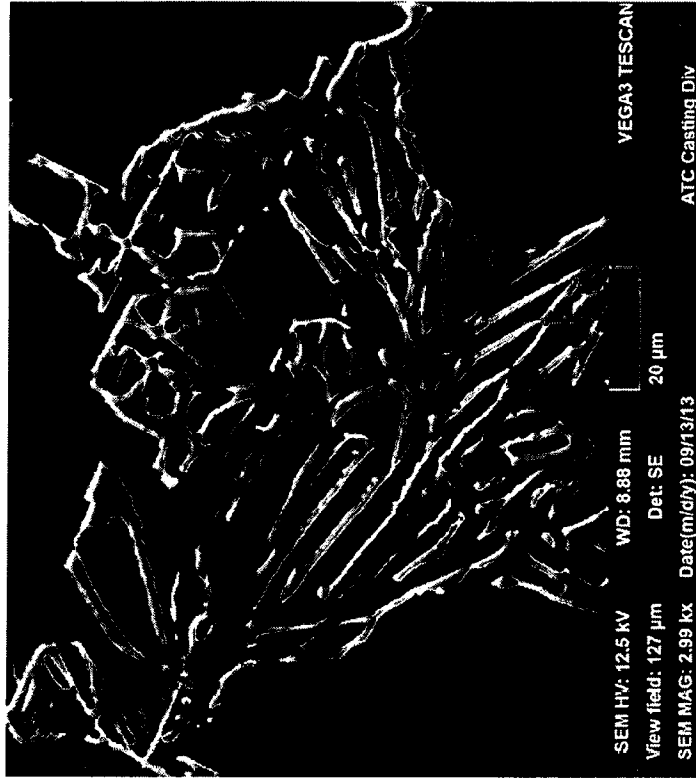


FIG. 2b

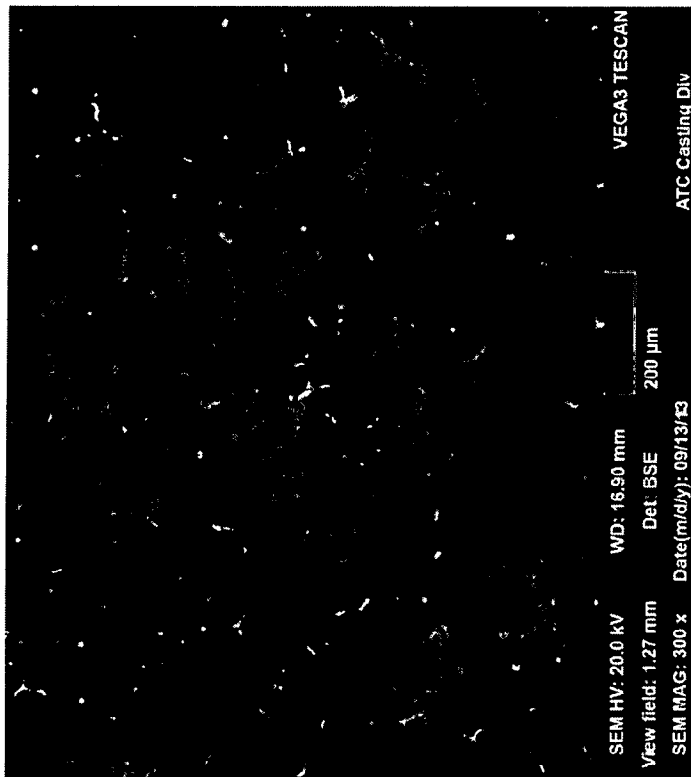


FIG. 2a

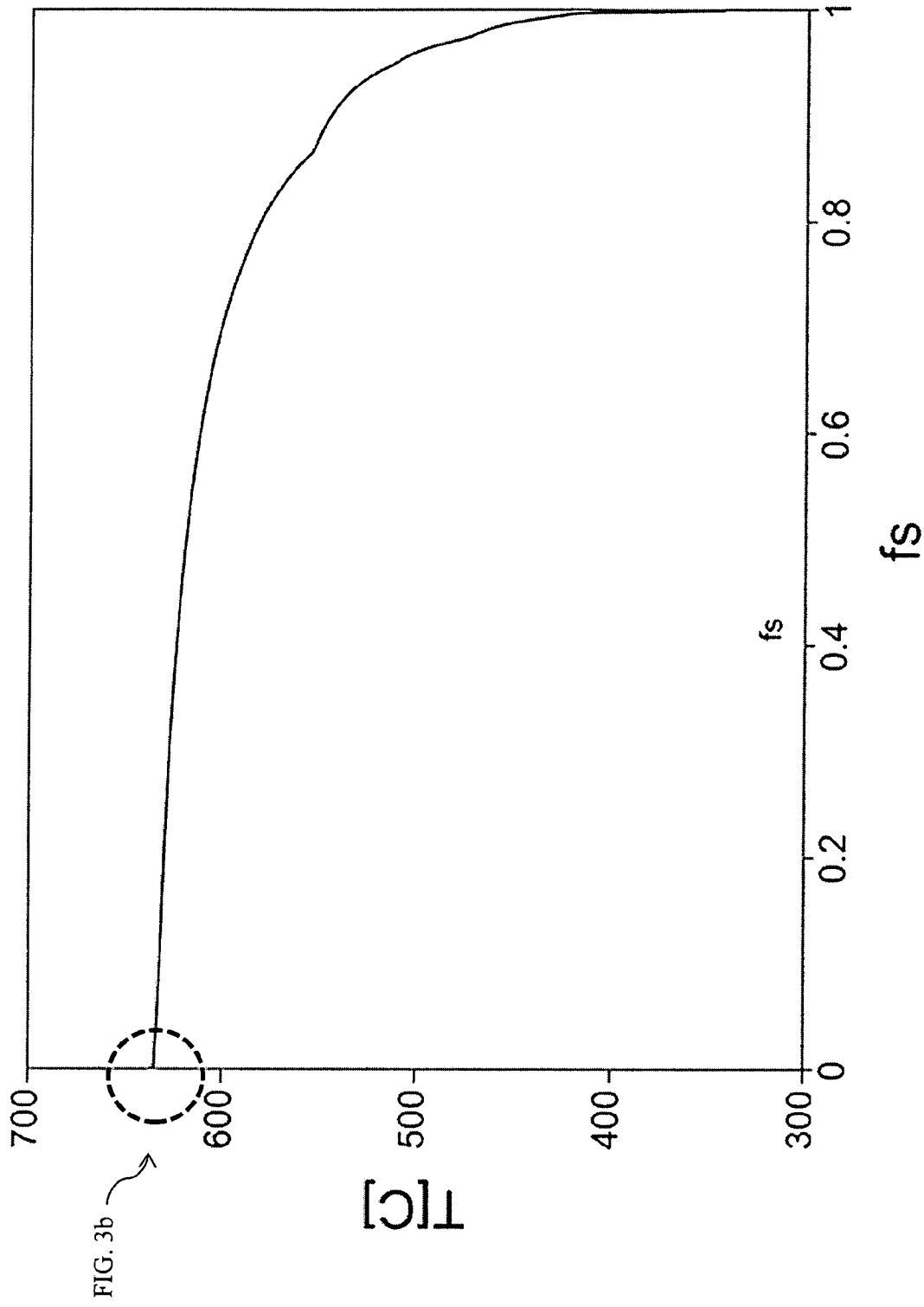


FIG. 3a

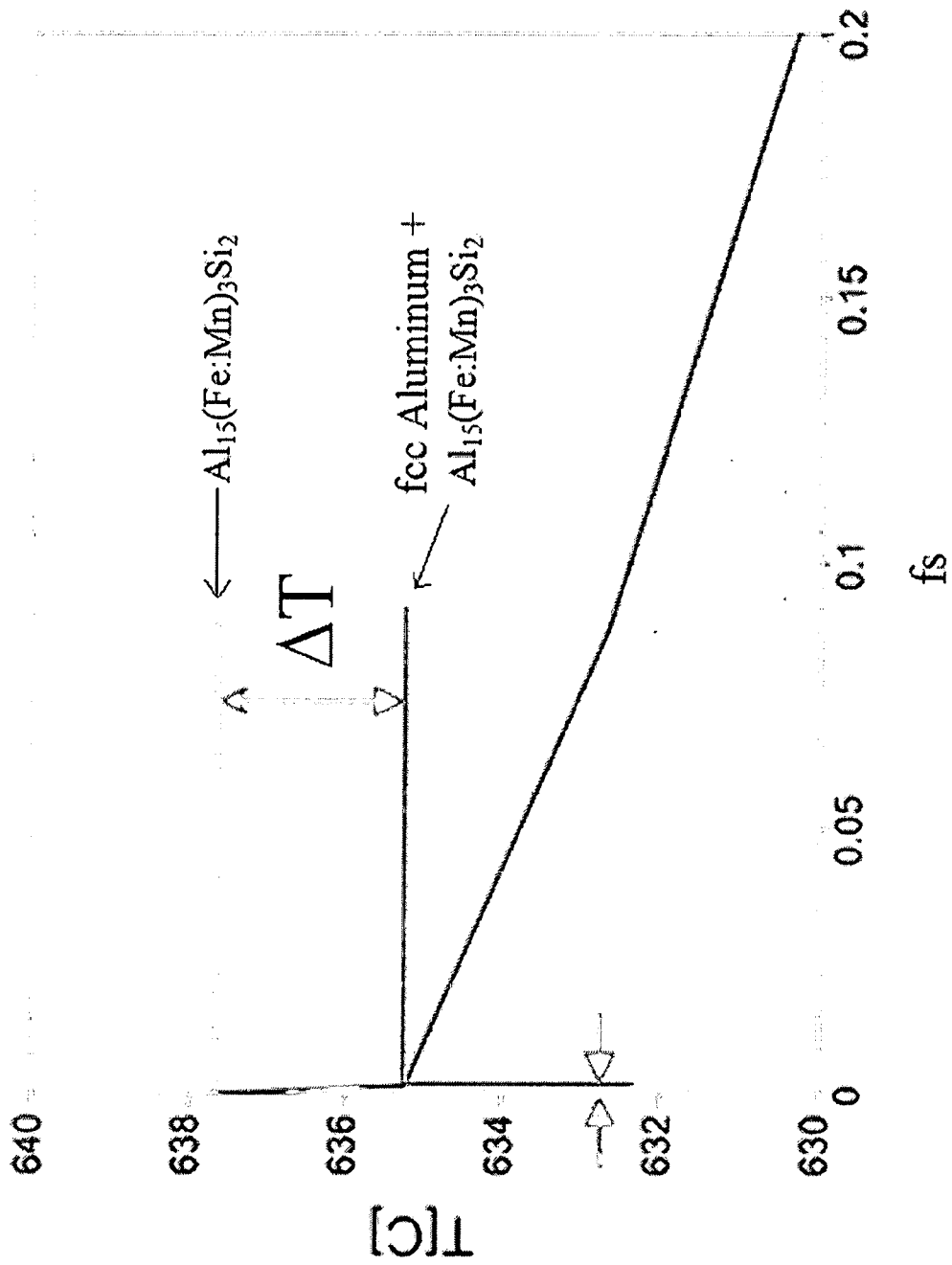


FIG. 3b

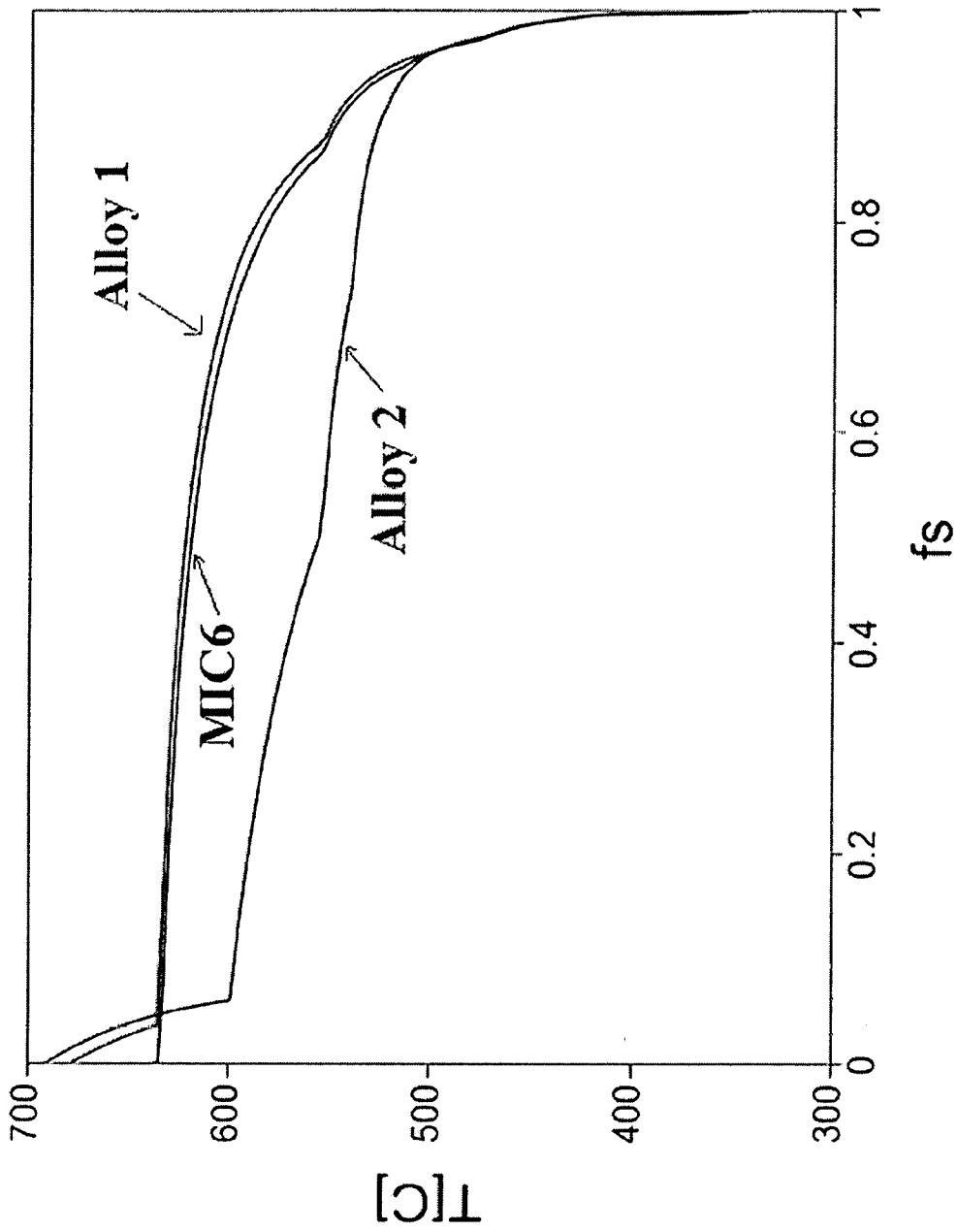


FIG. 4a

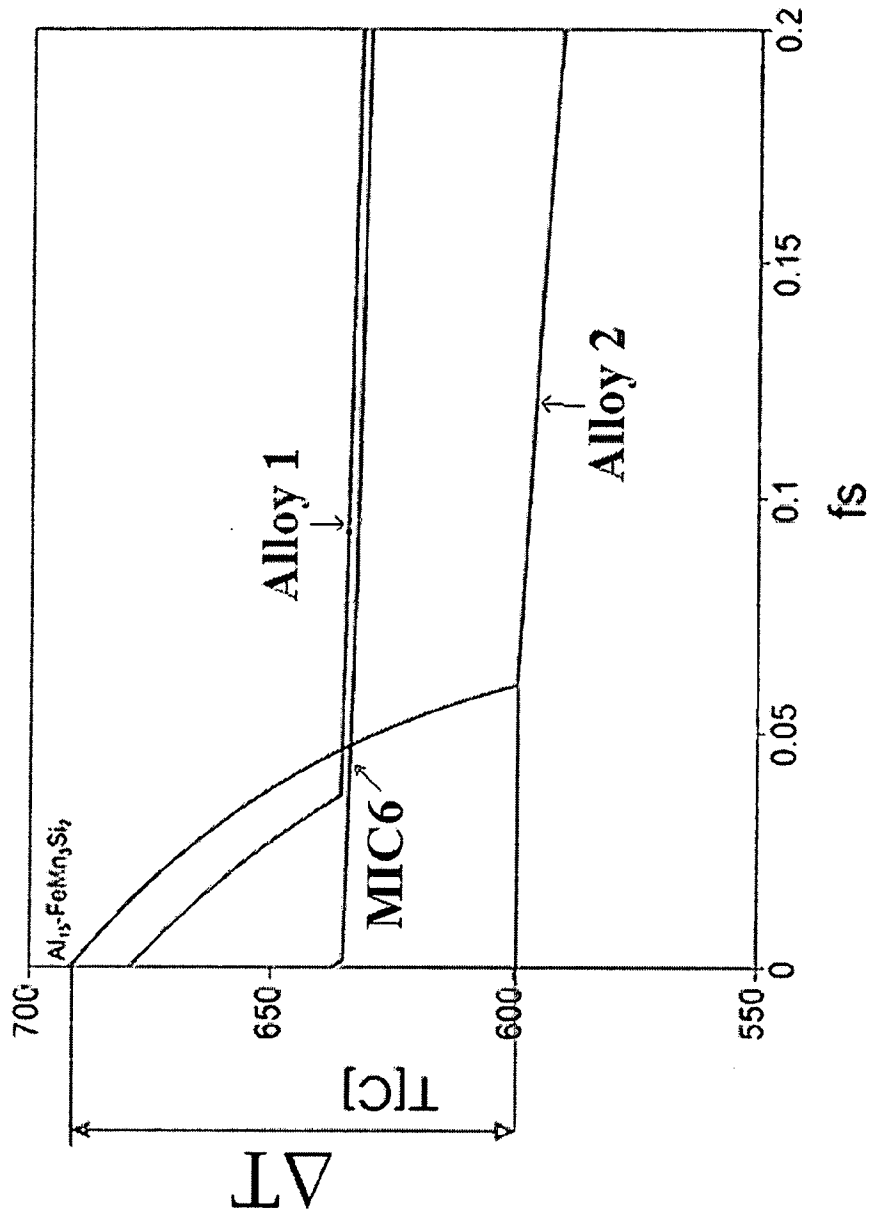


FIG. 4b

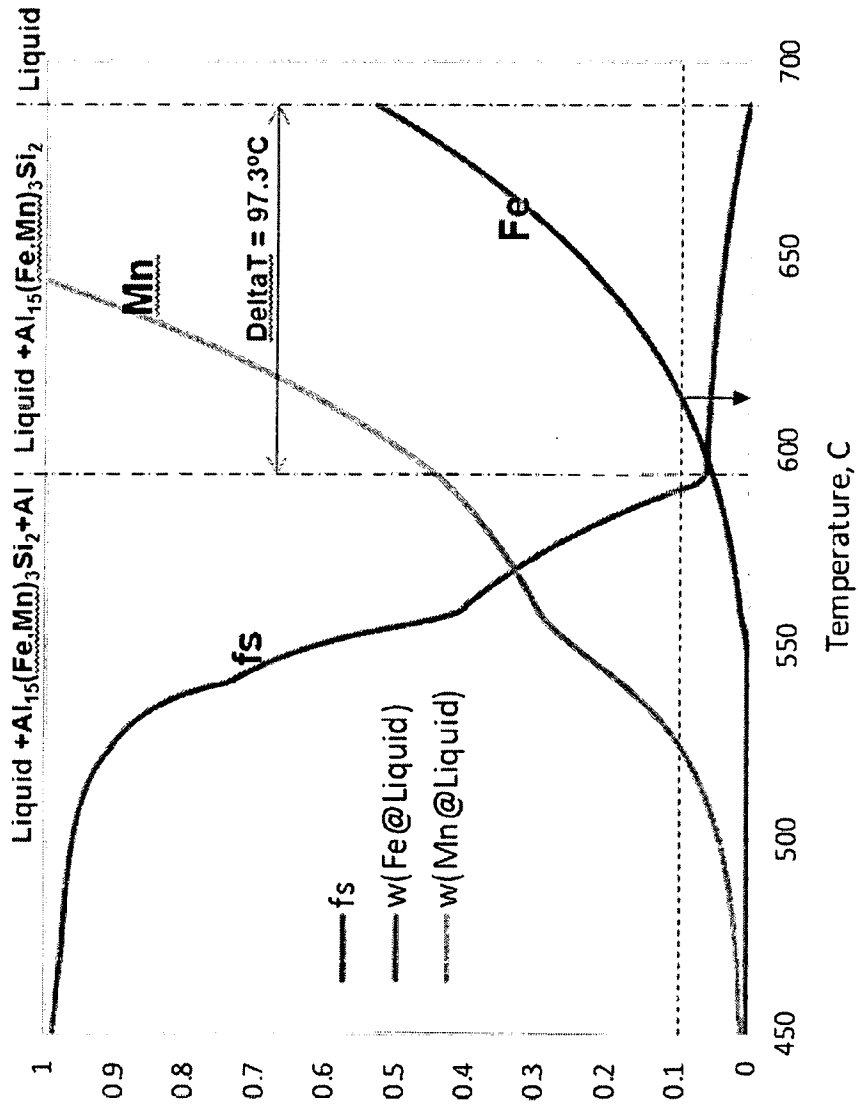


FIG. 5

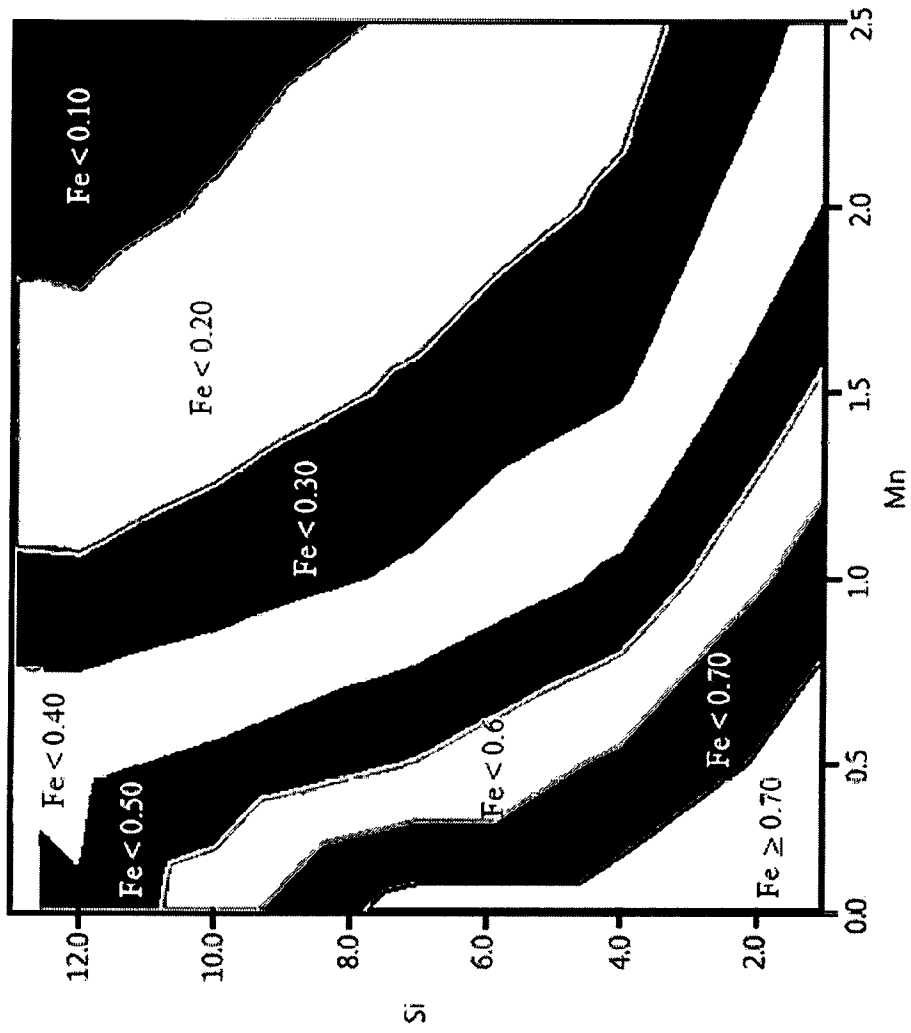


FIG. 6a

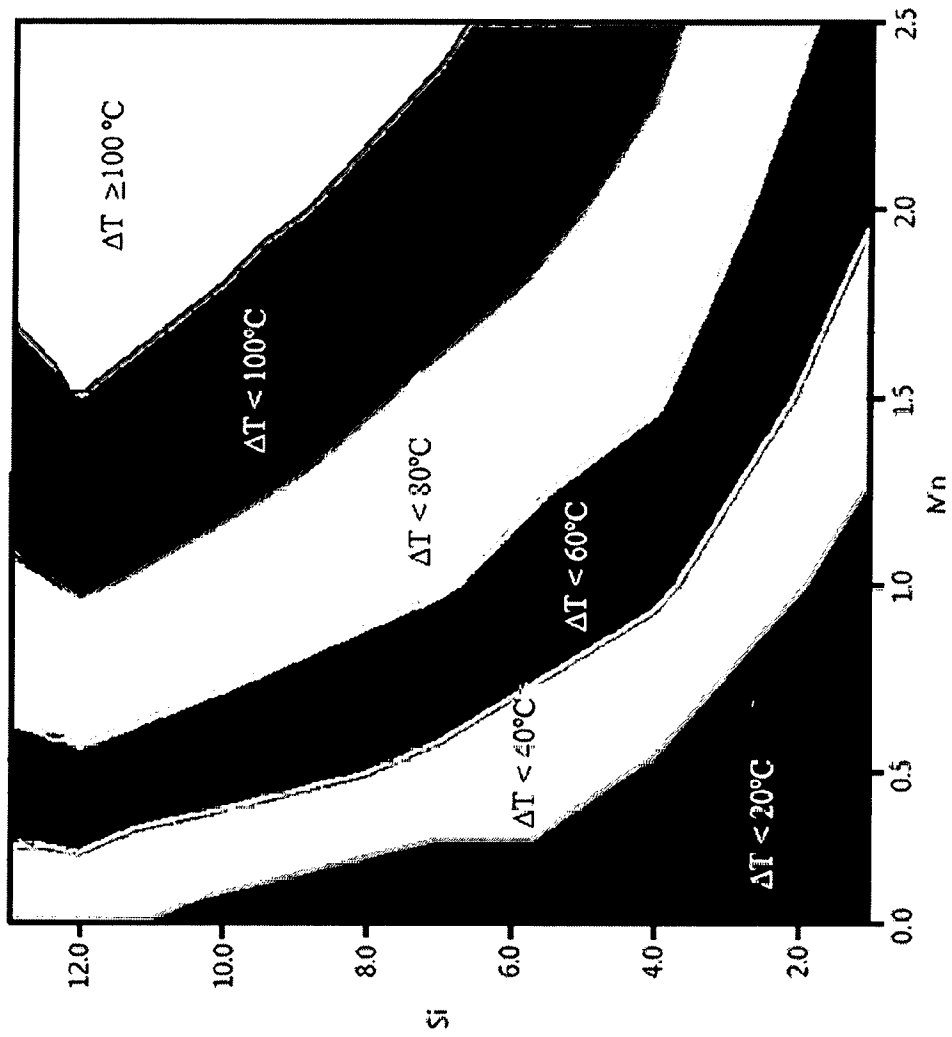


FIG. 6b

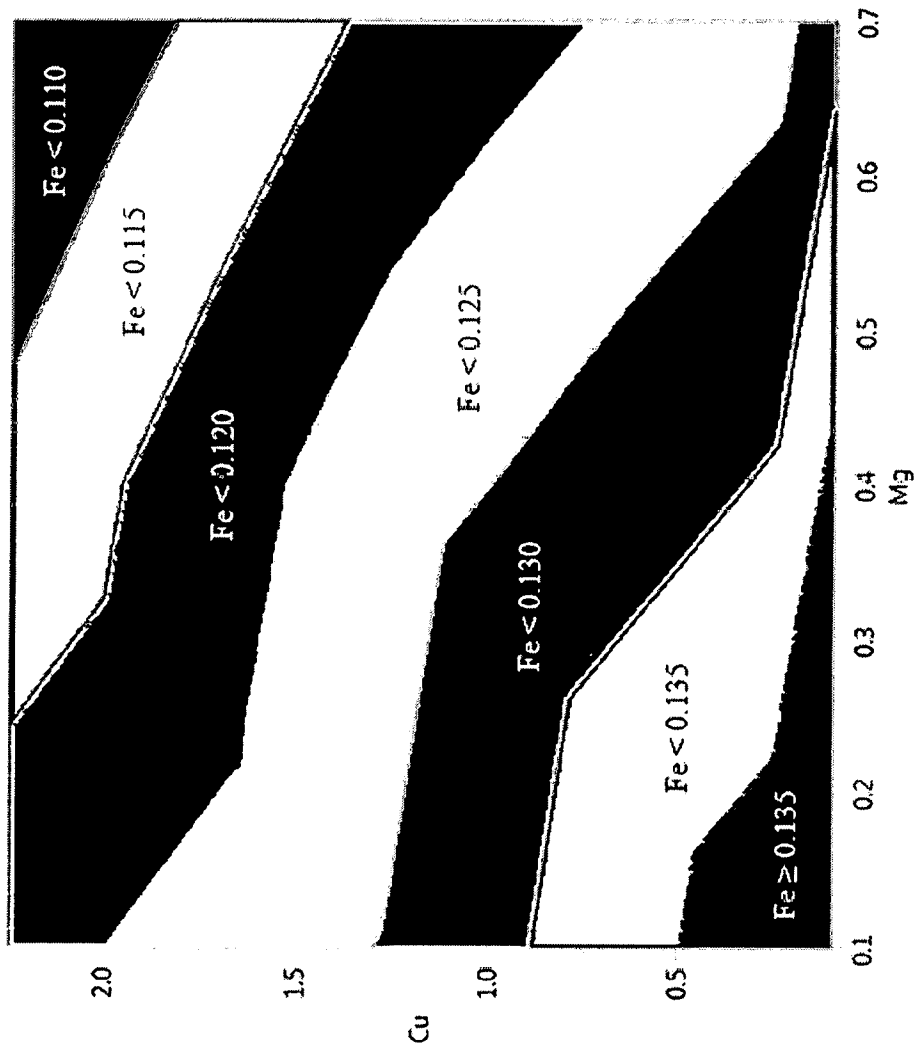


FIG. 6C

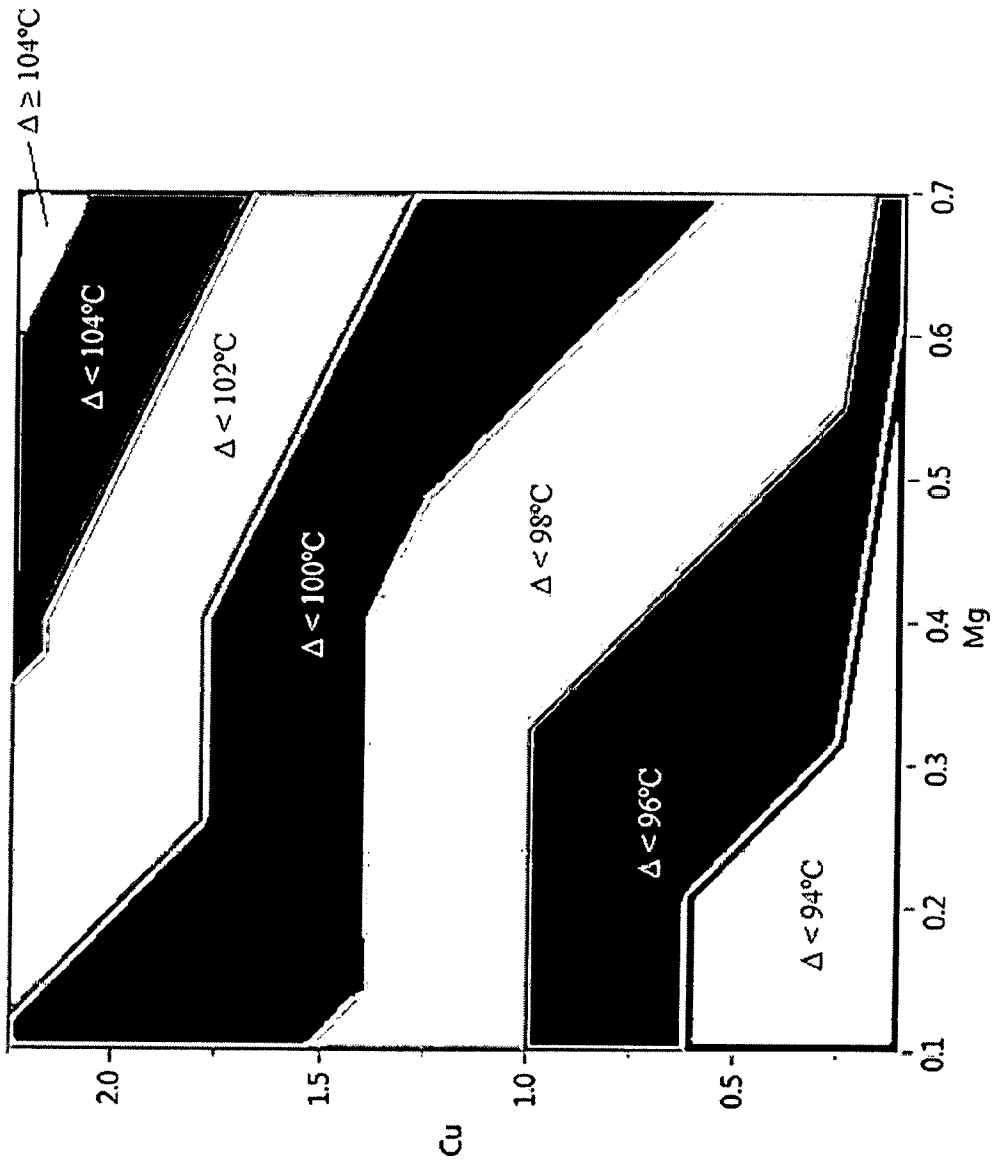


FIG. 6d

Example 3

T (°C)	Sold Phase Fraction	Phases	Liquid Elemental Composition (wt. %)										
			Cr	Cu	Fe	Mg	Mn	Ni	Si	Ti	Zn	Zr	
677	0	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂	0.08	0.18	0.52	0.45	1.8	0.05	9	0.04	0.11	0.01	
628.3	0.038	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂	0.08	0.19	0.2	0.47	0.84	0.05	8.95	0.04	0.12	0.01	
625.8	0.039	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂	0.08	0.19	0.19	0.47	0.81	0.05	8.95	0.04	0.12	0.01	
623.2	0.04	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂	0.08	0.19	0.18	0.47	0.77	0.05	8.95	0.04	0.12	0.01	
620.6	0.042	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.08	0.19	0.17	0.47	0.74	0.05	8.94	0.04	0.12	0.01	
618.1	0.043	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.08	0.19	0.16	0.47	0.71	0.05	8.94	0.04	0.12	0.01	
615.5	0.044	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.08	0.19	0.15	0.47	0.68	0.05	8.94	0.04	0.12	0.01	
613	0.045	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.08	0.19	0.14	0.47	0.65	0.05	8.94	0.04	0.12	0.01	
610.4	0.046	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.08	0.19	0.13	0.48	0.63	0.05	8.94	0.04	0.12	0.01	
607.8	0.047	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.08	0.19	0.12	0.48	0.6	0.05	8.94	0.03	0.12	0.01	
605.3	0.048	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.08	0.19	0.12	0.48	0.57	0.05	8.93	0.03	0.12	0.01	
602.7	0.049	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.08	0.19	0.11	0.48	0.55	0.05	8.93	0.03	0.12	0.01	
600.2	0.077	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , fcc Al	0.08	0.2	0.1	0.49	0.53	0.05	9.16	0.02	0.12	0.01	
597.6	0.109	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , fcc Al	0.08	0.2	0.1	0.5	0.52	0.06	9.44	0.01	0.12	0.01	

FIG. 7

Example 4

T (°C)	Solid Phase Fraction	Phases	Liquid Elemental Composition (wt. %)								
			Cr	Cu	Fe	Mg	Mn	Ni	Si	Ti	Zn
699.9	0.000	Liquid, Al ₃ Ti	0.1	1.03	0.37	0.58	1.4	0.03	9.27	0.12	0.12
658.9	0.002	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.1	1.03	0.36	0.58	1.38	0.03	9.28	0.07	0.12
625.7	0.025	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.1	1.06	0.18	0.6	0.82	0.03	9.26	0.04	0.12
623.1	0.026	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.1	1.06	0.17	0.6	0.78	0.03	9.26	0.04	0.12
620.5	0.027	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.1	1.06	0.16	0.6	0.75	0.03	9.26	0.04	0.12
618.0	0.029	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.1	1.07	0.15	0.6	0.72	0.03	9.26	0.04	0.12
615.4	0.030	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.1	1.07	0.14	0.6	0.69	0.03	9.26	0.04	0.12
612.9	0.031	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.1	1.07	0.13	0.6	0.66	0.03	9.26	0.04	0.12
610.3	0.032	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.1	1.07	0.13	0.6	0.63	0.03	9.26	0.03	0.12
607.7	0.033	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.1	1.07	0.12	0.6	0.61	0.03	9.26	0.03	0.12
605.2	0.034	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.1	1.07	0.11	0.6	0.58	0.03	9.25	0.03	0.12
602.6	0.035	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.1	1.07	0.1	0.6	0.56	0.03	9.25	0.03	0.13
600.1	0.036	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.1	1.07	0.1	0.61	0.53	0.03	9.25	0.03	0.13
597.5	0.037	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti, AlCrSi(Ti)	0.1	1.08	0.09	0.61	0.51	0.03	9.25	0.03	0.13
594.9	0.056	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti, AlCrSi(Ti), fcc Aluminum	0.09	1.09	0.08	0.62	0.49	0.03	9.41	0.02	0.13
592.4	0.086	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti, AlCrSi(Ti), fcc Aluminum	0.09	1.12	0.08	0.63	0.48	0.03	9.66	0.01	0.13

FIG. 8

Example 5

T (°C)	Sold Phase Fraction	Phases	Liquid Elemental Composition (wt. %)									
			Cr	Cu	Fe	Mg	Mn	Ni	Si	Ti	Zn	Zr
677.2	0.000	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂	0.06	0.13	0.49	0.2	2.05	0.04	10.48	0.04	0.09	0.03
613.2	0.049	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.064	0.138	0.128	0.212	0.767	0.042	10.477	0.035	0.095	0.032
610.6	0.050	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.064	0.138	0.121	0.212	0.735	0.042	10.477	0.033	0.096	0.032
608	0.051	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.064	0.138	0.114	0.213	0.703	0.043	10.476	0.032	0.096	0.032
605.5	0.052	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.064	0.138	0.107	0.213	0.673	0.043	10.476	0.031	0.096	0.032
602.9	0.053	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.064	0.139	0.101	0.213	0.644	0.043	10.475	0.03	0.096	0.032
600.4	0.054	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.064	0.139	0.095	0.213	0.616	0.043	10.474	0.029	0.096	0.032
597.8	0.055	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.064	0.139	0.089	0.214	0.589	0.043	10.474	0.027	0.096	0.032
595.2	0.056	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.064	0.139	0.084	0.214	0.563	0.043	10.473	0.026	0.096	0.032
592.7	0.059	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti, fcc Al	0.064	0.139	0.079	0.214	0.539	0.043	10.491	0.025	0.096	0.032
590.1	0.093	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , fcc Al	0.064	0.144	0.075	0.221	0.525	0.044	10.823	0.022	0.099	0.033

FIG. 9

Example 6

T (°C)	Solid Phase Fraction	Phases	Liquid Elemental Composition (wt. %)									
			Cr	Cu	Fe	Mg	Mn	Ni	Si	Ti	Zn	
664.5	0	Liquid, Al ₃ Ti	0.02	0.45	0.22	0.13	0.93	0.04	9.06	0.08	0.72	
621.0	0.007	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.02	0.454	0.17	0.131	0.775	0.04	9.06	0.042	0.726	
618.4	0.008	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.02	0.454	0.16	0.131	0.743	0.04	9.059	0.04	0.727	
615.8	0.009	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.02	0.455	0.151	0.131	0.713	0.04	9.057	0.039	0.728	
613.3	0.011	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.02	0.456	0.141	0.132	0.684	0.041	9.056	0.037	0.729	
610.7	0.012	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.02	0.456	0.133	0.132	0.655	0.041	9.055	0.036	0.73	
608.2	0.013	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.02	0.457	0.124	0.132	0.628	0.041	9.053	0.035	0.731	
605.6	0.014	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.02	0.457	0.116	0.132	0.602	0.041	9.052	0.033	0.732	
603.0	0.015	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.02	0.458	0.109	0.132	0.577	0.041	9.051	0.032	0.733	
600.5	0.016	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.02	0.458	0.101	0.132	0.553	0.041	9.05	0.031	0.733	
597.9	0.044	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , fcc Al	0.02	0.47	0.096	0.136	0.536	0.042	9.276	0.019	0.748	
595.4	0.076	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , fcc Al	0.02	0.484	0.091	0.139	0.521	0.043	9.548	0.011	0.764	

FIG. 10

Example 7

T (°C)	Solid Phase Fraction	Phases	Liquid Elemental Composition (wt. %)									
			Cr	Cu	Fe	Mg	Mn	Ni	Si	Ti	Zn	Zr
695.0	0	Liquid, Al ₃ Ti	0.04	1.82	0.21	0.04	0.89	0.05	9.04	0.12	0.05	0.05
620.7	0.007	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.04	1.83	0.17	0.04	0.76	0.05	9.05	0.04	0.05	0.05
618.2	0.008	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.04	1.84	0.16	0.04	0.73	0.05	9.05	0.04	0.05	0.05
615.6	0.009	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.04	1.84	0.15	0.04	0.70	0.05	9.05	0.04	0.05	0.05
613.0	0.011	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.04	1.84	0.14	0.04	0.67	0.05	9.05	0.04	0.05	0.05
610.5	0.012	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.04	1.84	0.13	0.04	0.64	0.05	9.05	0.03	0.05	0.05
607.9	0.013	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.04	1.85	0.12	0.04	0.61	0.05	9.04	0.03	0.05	0.05
605.4	0.014	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.04	1.85	0.12	0.04	0.59	0.05	9.04	0.03	0.05	0.05
602.8	0.015	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.04	1.85	0.11	0.04	0.56	0.05	9.04	0.03	0.05	0.05
600.2	0.016	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.04	1.85	0.1	0.04	0.54	0.05	9.04	0.03	0.05	0.05
597.7	0.016	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , Al ₃ Ti	0.04	1.86	0.1	0.04	0.52	0.05	9.04	0.03	0.05	0.05
595.1	0.043	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , fcc Al	0.04	1.90	0.09	0.04	0.50	0.05	9.25	0.02	0.05	0.05
592.6	0.073	Liquid, Al ₁₅ (Fe:Mn) ₃ Si ₂ , fcc Al	0.04	1.95	0.09	0.04	0.49	0.05	9.5	0.01	0.05	0.05

FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/000178**A. CLASSIFICATION OF SUBJECT MATTER****C22B 21/00(2006.01)i, C22B 21/06(2006.01)i**

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

B. FIELDS SEARCHEDMinimum documentation searched (classification system followed by classification symbols)
C22B 21/00; C22B 21/06; C22B 4/02; C22B 9/02; C22C 1/02Documentation 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 modelsElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords:
aluminum alloy scrap, melt, iron content, intermetallic former materials, manganese, silicon**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5741348 A (VAN DER DONK et al.) 21 April 1998 See column 3, lines 32-40; claim 1; and figure 1.	1-3, 8
A	US 2004-0261572 A1 (DE VRIES, PAUL ALEXANDER) 30 December 2004 See paragraphs [0001]-[0038]; and figure 2.	1-3, 8
A	US 2008-0000326 A1 (DE VRIES, PAUL ALEXANDER) 03 January 2008 See paragraphs [0001]-[0055]; and figure 1.	1-3, 8
A	JP 3329013 B2 (NIPPON LIGHT METAL CO., LTD.) 30 September 2002 See paragraphs [0004]-[0025]; and claims 1-7.	1-3, 8
A	JP 3237330 B2 (NIPPON LIGHT METAL CO., LTD.) 10 December 2001 See paragraphs [0003]-[0015]; and claims 1-3.	1-3, 8

 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

21 December 2018 (21.12.2018)

Date of mailing of the international search report

21 December 2018 (21.12.2018)

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/000178

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. Claims Nos.: 10-15, 17-18
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
Claims 10-15 and 17-18 are not clear because they refer to multiple dependent claims, which do not comply with PCT Rule 6.4(a).

3. Claims Nos.: 4-7, 9, 16, 19-21
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of any additional fees.

3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

- Remark on Protest**
- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
 - The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
 - No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2018/000178

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JP 3237330 B2	10/12/2001	JP 7054070 A	28/02/1995