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METHODS AND SYSTEMS FOR PURIFYING METALS OR METAL ALLOYS

Abstract

Methods and systems for purifying metals or metal alloys are provided. The method comprises disposing a molten material comprising predominantly aluminum and at least one first metal having an atomic mass less than 13 in a first region of an electrolysis cell. The electrolysis cell comprises an anode, a cathode, and a molten salt electrolyte in contact with the anode and the cathode. The method comprises contacting the anode with the molten material, and applying an electrical voltage across the anode and the cathode such that at least a portion of the first metal in the molten material migrates to a third region in the electrolysis cell to produce a first material enriched in the first metal. The method comprises removing at least a first portion of the first material in the third region from the electrolysis cell.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application claims priority to U.S. Provisional Patent Application No. 63/490,057, which was filed on Mar. 14, 2023, the contents of which is hereby incorporated by reference into this specification.

FIELD OF USE
[0002] The present disclosure relates to methods and systems for purifying metals or metal alloys.
BACKGROUND
[0003] Some metals and metal alloys may require purification before use. For example, an aluminum feedstock can be purified for use according to the method disclosed in U.S. Pat. No. 10,407,786. However, purifying metals and metal alloys presents challenges.
SUMMARY
[0004] One non-limiting aspect according to the present disclosure is directed to a method comprising disposing a molten material comprising predominantly aluminum and at least one first metal having an atomic mass of less than 13 in a first region of an electrolysis cell. The electrolysis cell comprises an anode, a cathode, and a molten salt electrolyte in contact with the anode and the cathode. The molten salt electrolyte is disposed in a second region of the electrolysis cell. The method comprises contacting the anode with the molten material, and applying an electrical voltage across the anode and the cathode such that at least a portion of the first metal in the molten material migrates to a third region in the electrolysis cell to produce a first material enriched in the first metal. The second region is intermediate the first region and the third region. The method comprises removing at least a first portion of the first material in the third region from the electrolysis cell.
[0005] An additional non-limiting aspect according to the present disclosure is directed to a method comprising disposing a molten material comprising predominantly aluminum and lithium in a first region of an electrolysis cell. The electrolysis cell comprises an anode, a cathode, and a molten salt electrolyte in contact with the anode and the cathode. The molten salt electrolyte is disposed in a second region of the electrolysis cell. The method comprises contacting the anode with the molten material, and applying an electrical voltage across the anode and the cathode such that at least a portion of the lithium in the molten material migrates to a third region in the electrolysis cell to produce a first material enriched in lithium. The second region is intermediate the first region and the third region. The method comprises removing at least a first portion of the first material in the third region from the electrolysis cell.
[0006] Yet a further non-limiting aspect according to the present disclosure is directed to a method comprising feeding an aluminum feedstock into an aluminum electrolysis cell. The method comprises directing an electric current into an anode through an electrolyte and into a cathode. At least a portion of a surface of the anode is wetted with a portion of the aluminum feedstock. Concomitant with directing the electric current, at least a portion of at least one of lithium, beryllium, sodium, and magnesium in the aluminum feedstock is migrated to a location within the cell. The method comprises removing the migrated lithium, beryllium, sodium, and magnesium from the cell, thereby producing a purified product.
[0007] It is understood that the inventions disclosed and described in this specification are not limited to the aspects summarized in this Summary. The reader will appreciate the foregoing

details, as well as others, upon considering the following detailed description of various non-limiting and non-exhaustive aspects according to this specification.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The features and advantages of the examples, and the manner of attaining them, will become more apparent, and the examples will be better understood, by reference to the following description taken in conjunction with the accompanying drawing, wherein:

[0009] FIG. **1** is a flow chart illustrating a non-limiting embodiment of a method for purifying metals and metal alloys according to the present disclosure; and

[0010] FIG. **2** is a schematic side elevational view of a non-limiting embodiment of an electrolysis cell for purifying metals and metal alloys according to the present disclosure.

[0011] The exemplifications set out herein illustrate certain embodiments, in one or more forms, and such exemplifications are not to be construed as limiting the scope of the appended claims in any manner.

DESCRIPTION OF NON-LIMITING EMBODIMENTS

[0012] Various embodiments are described and illustrated herein to provide an overall understanding of the structure, function, and use of the disclosed articles and methods. The various embodiments described and illustrated herein are non-limiting and non-exhaustive. Thus, an invention is not limited by the description of the various non-limiting and non-exhaustive embodiments disclosed herein. Rather, the invention is defined solely by the claims. The features and characteristics illustrated and/or described in connection with various embodiments may be combined with the features and characteristics of other embodiments. Such modifications and variations are intended to be included within the scope of this specification. As such, the claims may be amended to recite any features or characteristics expressly or inherently described in, or otherwise expressly or inherently supported by, this specification. Further, the applicant reserves the right to amend the claims to affirmatively disclaim features or characteristics that may be present in the prior art. The various embodiments disclosed and described in this specification can comprise, consist of, or consist essentially of the features and characteristics as variously described herein.

[0013] Various non-limiting embodiments of alloys discussed in connection with the present disclosure optionally include intentional additions of incidental elements that may, for example, aid in production of the alloy and/or improve one or more properties or characteristics of the alloy. In various non-limiting embodiments, the total concentration of incidental elements in alloys according to the present disclosure preferably does not exceed 1 weight percent based on the total weight of the alloy, and the concentration of any single incidental element preferably does not exceed 0.2 weight percent based on the total weight of the alloy.

[0014] Various non-limiting embodiments of alloys discussed in connection with the present disclosure may include impurities. As used herein, “impurities” are elements or other materials that may be present in relatively minor concentrations in alloys according to the present disclosure but that are not intentionally added to enhance production or affect properties or characteristics of the alloy. For example, impurities in the alloys according to the present disclosure may be present in minor concentrations due to, for example, unavoidable or unintentional presence of the impurities in feed materials, incorporation from the local atmosphere during melting, refining, or other processing, or contamination by contact with processing equipment. In various non-limiting embodiments, the total concentration of impurities in alloys discussed in the present disclosure preferably does not exceed 0.15 weight percent based on the total weight of the alloy, and the concentration of any single impurity preferably does not exceed 0.05 weight percent based on the

total weight of the alloy.
[0015] Aluminum alloys comprising a metal having an atomic number less than 13 can have desirable properties. For example, aluminum-lithium alloys may have a lower density than conventional aluminum alloys and, therefore, are desirable for reducing the weight of aerospace components while also maintaining a high strength. Parts made from aluminum-lithium alloys may be substantially more costly than parts made from alloys that do not contain lithium. Lithium is a costly alloying additive due to the intrinsic cost of lithium, and aerospace and automotive parts produced from aluminum-lithium alloys may require extensive machining, which generates a high volume of machining chips.
[0016] Machining chips and/or scrap materials comprising aluminum alloys comprising a metal having an atomic number less than 13 may require specialized processing and may also need to be separately processed from, for example, other aluminum alloys. The machining chips and/or scrap materials including aluminum alloys comprising a metal having an atomic number less than 13 may only be reused for other specialized aluminum alloys and may not be compatible with certain applications. The present disclosure provides methods and systems for purifying metals or metal alloys. The methods and systems can improve the recyclability of machining chips and/or scrap materials including an alloy comprising predominately aluminum and a metal having an atomic number less than 13, thereby reducing material losses from machining operations and recovering a processing stream with a high material value.
[0017] FIG. **1** provides a block diagram of a non-limiting embodiment of a method according to the present disclosure for separating elements from a molten material. A molten material comprising predominantly aluminum and a first metal can be prepared by heating a feedstock comprising an aluminum alloy to form the molten material (FIG. **1**, step **102**). For example, the feedstock can be a solid that is heated until substantially molten and able to flow. In various embodiments, the heating may be performed under an inert atmosphere in a furnace.
[0018] The feedstock can comprise various forms of aluminum alloys, such as, for example, machining chips, solid ingots, scrap material, and other forms. In embodiments comprising a feedstock comprising machining chips, the machining chips may be cleaned prior to heating the feedstock. In various non-limiting embodiments, the feedstock can comprise material processed according to the method described in International Application No. PCT/US2022/012740, filed Jan. 18, 2022, which is hereby incorporated herein by reference in its entirety.
[0019] The aluminum alloy of the feedstock can comprise the first metal, aluminum, incidental elements, and impurities. The first metal has an atomic number less than 13. For example, the first metal can be at least one of lithium, beryllium, sodium, and magnesium. In various examples, the first metal can be at least one of lithium and magnesium. In certain non-limiting embodiments, aluminum alloy can includes at least two first metals selected from lithium, beryllium, sodium, and magnesium.
[0020] In various non-limiting embodiments, the feedstock can comprise an aluminum-lithium alloy. As used herein, an “aluminum-lithium alloy” is an alloy comprising 0.1% to 5% lithium by weight, aluminum, incidental elements, and impurities. In various non-limiting embodiments, the aluminum-lithium alloy can comprise at least 0.5% lithium by weight, such as, for example, at least 1%, at least 1.5%, at least 2%, or at least 2.5% lithium, all by weight based on the total weight of the aluminum-lithium alloy. In various forms, an aluminum-lithium alloy may comprise 0.1% to 0.5%, 0.2% to 3%, 0.2% to 2%, 0.5% to 2%, 0.5 to 2.5%, or 1% to 5% lithium by weight, and a balance of aluminum, incidental elements, and impurities. As is known in the art, certain aluminum-lithium alloys may include additional intentional alloying additions such as, for example, copper, manganese, magnesium, zinc, titanium, zirconium, silicon, iron, chrome, and silver. Commercially available aluminum-lithium alloys that may be included in the feedstock can comprise one or more aluminum-lithium alloys of the 2099, 2199, 2050, 2055, 2060, 2090, 8090, 2195, 2397, and 2070 series, all as defined in the Teal Sheets published by the Aluminum

Association (last revised August 2018). In various non-limiting embodiments, the feedstock can comprise at least 80% aluminum by weight based on the total weight of the feedstock, such as, for example, at least 85% aluminum by weight, at least 90% aluminum by weight, or at least 95% aluminum by weight, all based on the total weight of the feedstock.

[0021] The sum of lithium, beryllium, sodium, and magnesium in the molten material can be 0.1% to 10%, by weight based on a total weight of the molten material. In various embodiments, the molten material can comprise 0.1% to 0.5%, 0.2% to 3%, 0.2% to 2%, 0.5% to 2%, 0.5 to 2.5%, 0% to 5% lithium, or 1% to 5% lithium, by weight based on a total weight of the molten material. In various embodiments, the molten material can comprise 0% to 10%, 0.1% to 10%, 0.2% to 9%, 0.2% to 8%, 0.5% to 2%, 0.5 to 2.5%, or 1% to 5% magnesium, by weight based on a total weight of the molten material. In various embodiments, the molten material can comprise 0% to 0.05%, 0.005% to 0.05%, 0.005% to 0.01% or 0% to 0.01% sodium, by weight based on a total weight of the molten material. In various embodiments, the molten material can comprise 0% to 0.1%, 0.0001% to 0.1%, 0% to 0.07%, or 0.0001% to 0.07% beryllium, by weight based on a total weight of the molten material. In certain embodiments, the molten material can comprise less than 0.05% of a sum of sodium and beryllium, by weight based on the total weight of the molten material.

[0022] The method comprises disposing the molten material in a first region of an electrolysis cell (FIG. **1**, step **104**). Referring to FIG. **2**, the electrolysis cell **200** can comprise a first region **200***a*, a second region **200***b*, a third region **200***c*, an anode **204**, a cathode **206**, and a molten salt electrolyte in contact with the anode **204** and the cathode **206**. The electrolysis cell **200** can comprise refractory walls **200***e* defining a cavity **200***d* that comprises the first region **200***a*, the second region **200***b*, and the third region **200***c*. The third region **200***c* is above the second region **200***b* in the cavity **200***d*, and the second region **200***b* is intermediate the third region **200***c* and the first region **200***a* in the cavity **200***d*. In various non-limiting embodiments, the molten material can be fed into the first region **200***a* in the cavity **200***d* of the electrolysis cell **200** through a port **214**.

[0023] The cathode **206** extends from a first side **210** of the electrolysis cell **200** into the cavity **200***d* through the third region **200***c* and into the second region **220***b*. The cathode **206** may not contact the first region **200***a* in the cavity **200***d*. The anode **204** extends from a second side **212** of the electrolysis cell **200** through the first region **200***a* and into the second region **200***b*. The anode may not contact the third region **200***c* in the cavity **200***d*. The anode **204** can be an elongated vertical anode, and the cathode **206** can be an elongated vertical cathode. The anode **204** and the cathode **206** can be electrically connected to an external power source such that an electrical circuit is formed including the anode **204**, the cathode **206**, the molten salt electrolyte, and the external power source.

[0024] The anode **204** and cathode **206** can be arranged within the cavity **200***d* of the electrolysis cell **200** to form an anode-cathode overlap (ACO). As used herein, “anode-cathode overlap” (ACO) means a distance, d.sub.ACO, from a distal end **204***a* of the anode **204** to a distal end **206***a* of the cathode **206**. In some embodiments, the distance, d.sub.ACO, can be in a range of 0 inches to 50 inches, such as, for example, 1 inch to 50 inches, 5 inches to 50 inches, 10 inches to 50 inches, 20 inches to 50 inches, 25 inches to 50 inches, 0 inches to 12 inches, 2 inches to 10 inches, 3 inches to 8 inches, or 3 inches to 6 inches. In various non-limiting embodiments, the distance, d.sub.ACO, is a vertical distance.

[0025] The anode **204** and cathode **206** can be arranged within the cavity **200***d* of the electrolysis cell **200** to form an anode to cathode spacing (ACS). As used herein, “anode to cathode spacing” (ACS) means a distance, d.sub.ACS, separating a side **204***b* of the anode **204** from a side **206***b* of the cathode **206**. In some embodiments, the distance, d.sub.ACS, can be in a range of 0.125 inch to 3 inches, such as, for example, 0.125 inch to 1 inch, 0.125 inch to 0.250 inch, 0.250 inch to 0.5 inch, 0.125 inch to 0.75 inch, 0.125 inch to 1 inch, or 0.125 inch to 0.5 inch. In various non-limiting embodiments, the distance, d.sub.ACS, is a horizontal distance.

[0026] In various non-limiting embodiments, there may be at least two cathodes **206** and at least two anodes **204**. The cathodes **206** and anodes **204** can be configured in pairs having respective distances, d.sub.ACO and d.sub.ACS.

[0027] The anode **204** and the cathode **206**, individually, can comprise at least one of a lithium wettable material, a beryllium wettable material, a sodium wettable material, and a magnesium wettable material. For example, the anode **204** and cathode **206**, individually, can comprise a lithium wettable material. In various non-limiting embodiments, the anode **204** can comprise at least one of TiB.sub.2, ZrB.sub.2, HfB.sub.2, SrB.sub.2, a carbonaceous material, W, Mo, and steel, and the cathode **206** can comprises at least one of TiB.sub.2, ZrB.sub.2, HfB.sub.2, SrB.sub.2, and a carbonaceous material. The wettable material of the anode **204** and the cathode **206** may be applied as a coating to the respective electrode. The wettable material can facilitate the migration of the first metal throughout the cavity **200***d*, such as, for example, from the first region **200***a* to the third region **200***c*.

[0028] The molten salt electrolyte can be disposed in a second region **200***b* of the electrolysis cell **200**. The molten material in the first region **200***a* has a first density, the molten salt electrolyte in the second region **200***b* has a second density, and a first material in the third region **200***c* has a third density. The first density is greater than the second density, and the second density is greater than the third density. Therefore, the molten material, the molten salt electrolyte, and the first material may form separate layers in the electrolysis cell **200** such that the molten salt electrolyte floats on top of the molten material in the cavity **200***d*, and the first material floats on top of the molten salt electrolyte in the cavity **200***d*.

[0029] The molten salt electrolyte can comprise a composition suitable to achieve the second density, support migration of the first metal from the first region **200***a* to the third region **200***c*, and enable a suitable electrical current to flow between the anode **204** and the cathode **206**. For example, the molten salt electrolyte can comprise at least one of a molten lithium salt, a molten beryllium salt, a molten sodium salt, and a molten magnesium salt. For example, the molten salt electrolyte can comprise a molten lithium salt. In various non-limiting embodiments, the molten salt electrolyte can comprise at least one of a molten fluoride salt and a molten chloride salt, such as, for example, at least one of sodium fluoride, potassium fluoride, and barium fluoride.

[0030] In various non-limiting embodiments, an inert gaseous atmosphere may be provided within the electrolysis cell **200** by flowing an inert gas into the electrolysis cell **200**. For example, the inert gaseous atmosphere can comprise at least one of nitrogen gas and argon gas. The inert gaseous atmosphere may be positioned above the third region **200***c* in a fourth region **200***f*.

[0031] Referring again to FIG. **1**, the method can comprise contacting the anode **204** with the molten material, and applying an electrical voltage across the anode **204** and the cathode **206** such that at least a portion of the first metal in the molten material migrates to the third region **200***c* in the electrolysis cell **200** to produce the first material (FIG. **1**, step **106**). For example, an electric current can be directed into the anode **204** through the molten salt electrolyte and into the cathode **206**. At least a portion of the anode **204** can be wetted with at least a portion of the molten material. For example, the first metal may wet the anode **204**. Thereafter, concomitant with directing the electric current, at least a portion of the first metal can migrate to a location in the third region **200***c* of the electrolysis cell **200**, which can enrich a concentration of the first metal in the first material.

[0032] Without being bound by any particular theory, it is believed that the anode **204** is configured to undergo an electrochemical reaction, such that the first metal is anodized to form ions that are transported to the electrolyte. The ions are then reduced onto the cathode **206** and form a purified first metal. In various non-limiting embodiments, impurities may remain on a surface of the anode **204** and/or the first region **200***a*. Without being bound by any particular theory, it is believed that the purified first metal can creep up the surface of the cathode **206** into the third region **200***c* due to the buoyancy of the purified first metal in the molten salt electrolyte.

[0033] Referring again to FIG. **1**, the method comprises removing at least a first portion of the first material in the third region **200***c* from the electrolysis cell **200** (FIG. **1**, step **108**). Removing the first material can comprise tapping the cell and/or siphoning off the first material. In various non-limiting embodiments, the first portion of the first material can be removed from the cavity **200***d* of the electrolysis cell **200** through a port **216**.

[0034] The first material can be a purified product. In various non-limiting embodiments, the first portion removed from the third region **200***c* of the electrolysis cell **200** can comprise at least 95% of the first metal, by weight based on a total weight of the first portion. For example, in certain embodiments the first portion removed from the third region **200***c* of the electrolysis cell **200** can comprises at least 95% lithium, by weight based on a total weight of the first portion.

[0035] Referring yet again to FIG. **1**, the method can comprise casting the first portion removed from electrolysis cell **200** into an ingot and/or introducing the first portion removed from the electrolysis cell **200** into a furnace as a feedstock for producing a metal or metal alloy (FIG. **1**, step **110**). The first portion can be used to produce a product, such as, for example, at least one of an aerospace part and an automotive part.

[0036] In various non-limiting embodiments, the method comprises removing at least a second material from the first region **200***a* of the electrolysis cell **200** (FIG. **1**, step **112**). The second material can be enriched in aluminum and/or deficient in the first metal. For example, the molten material can comprise a first aluminum concentration based on a total weight of the molten material, the second material can comprise a second aluminum concentration based on a total weight of the second material, and the second aluminum concentration can be greater than the first aluminum concentration. The second aluminum concentration can be at least 95% aluminum by weight, based on the total weight of the second material, such as, for example, at least 96%, at least 97%, at least 98%, at least 99%, at least 99.9%, or at least 99.99% by weight aluminum, all based on the total weight of the second material.

[0037] In various non-limiting embodiments, the second material can be removed from the cavity **200***d* of the electrolysis cell **200** through a port **218**. The port **218** may be disposed at an end of the electrolysis cell **200** opposite an end of the electrolysis cell at which port **214** is disposed such that a continuous flow of material is created from the port **214**, through the first region **200***a*, to the port **218**. The method can be a batch process, a continuous process, or a semi-continuous process.

[0038] The following numbered clauses are directed to various non-limiting embodiments and aspects according to the present disclosure.

[0039] Clause 1. A method comprising: disposing a molten material comprising predominantly aluminum and at least one first metal having an atomic mass less than 13 in a first region of an electrolysis cell, the electrolysis cell comprising an anode, a cathode, and a molten salt electrolyte in contact with the anode and the cathode, wherein the molten salt electrolyte is disposed in a second region of the electrolysis cell; contacting the anode with the molten material, and applying an electrical voltage across the anode and the cathode such that at least a portion of the first metal in the molten material migrates to a third region in the electrolysis cell to produce a first material enriched in the first metal, wherein the second region is intermediate the first region and the third region; and removing at least a first portion of the first material in the third region from the electrolysis cell.

[0040] Clause 2. The method of clause 1, further comprising heating a feedstock comprising an aluminum alloy to form the molten material.

[0041] Clause 3. The method of clause 2, wherein the feedstock comprises machining chips comprising the aluminum alloy.

[0042] Clause 4. The method of clause 3, further comprising cleaning the machining chips prior to heating the feedstock comprising the machining chips.

[0043] Clause 5. The method of any of clauses 1-4, further comprising removing at least a second material from the first region of the electrolysis cell, wherein the molten material comprises a first aluminum concentration based on a total weight of the molten material, the second material comprises a second aluminum concentration based on a total weight of the second material, and the

second aluminum concentration is greater than the first aluminum concentration.
[0044] Clause 6. The method of any of clauses 1-5, further comprising casting the first portion removed from electrolysis cell into an ingot.
[0045] Clause 7. The method of any of clauses 1-6, further comprising introducing the first portion removed from the electrolysis cell into a furnace as a feedstock for producing a metal or metal alloy.
[0046] Clause 8. The method of any of clauses 1-7, wherein the anode and the cathode, individually, comprise at least one of a lithium wettable material, a beryllium wettable material, a sodium wettable material, and a magnesium wettable material.
[0047] Clause 9. The method any of clauses 1-8, wherein the anode and cathode, individually, comprise a lithium wettable material.
[0048] Clause 10. The method any of clauses 1-9, wherein a sum of lithium, beryllium, sodium, and magnesium in the molten material is 0.1% to 10%, by weight based on a total weight of the molten material.
[0049] Clause 11. The method any of clauses 1-10, wherein the molten material comprises 0.1% to 5% lithium, by weight based on a total weight of the molten material.
[0050] Clause 12. The method of clause 11, wherein the first portion removed from the third region of the electrolysis cell comprises at least 95% lithium, by weight based on a total weight of the first portion.
[0051] Clause 13. The method of any of clauses 11-12, wherein the molten salt electrolyte comprises a molten lithium salt.
[0052] Clause 14. The method of any of clauses 1-13, wherein the molten salt electrolyte comprises at least one of a molten lithium salt, a molten beryllium salt, a molten sodium salt and a molten magnesium salt.
[0053] Clause 15. The method of any of clauses 1-14, wherein the method is a batch process.
[0054] Clause 16. The method of any of clauses 1-15, wherein the method is a continuous process.
[0055] Clause 17. The method of any of clauses 1-16, wherein the molten material has a first density, the molten salt electrolyte has a second density, the first material has a third density, the first density is greater than the second density, and the second density is greater than the third density.
[0056] Clause 18. The method of any of clauses 1-17, wherein the cathode extends from a first side of the electrolysis cell through the third region and into the second region, the anode extends from a second side of the electrolysis cell through the first region into the second region, the cathode does not contact the first region, and the anode does not contact the third region.
[0057] Clause 19. The method of any of clauses 1-18, further comprising providing an inert gaseous atmosphere within the electrolysis cell.
[0058] Clause 20. A method comprising: disposing a molten material comprising predominantly aluminum and lithium in a first region of an electrolysis cell, the electrolysis cell comprising an anode, a cathode, and a molten salt electrolyte in contact with the anode and the cathode, wherein the molten salt electrolyte is disposed in a second region of the electrolysis cell; contacting the anode with the molten material, and applying an electrical voltage across the anode and the cathode such that at least a portion of the lithium in the molten material migrates to a third region in the electrolysis cell to produce a first material enriched in the lithium, wherein the second region is intermediate the first region and the third region; and removing at least a first portion of the first material in the third region from the electrolysis cell.
[0059] Clause 21. A method comprising: feeding an aluminum feedstock into an aluminum electrolysis cell; directing an electric current into an anode through an electrolyte and into a cathode; wetting at least a portion of a surface of the anode with a portion of the aluminum feedstock; concomitant with directing the electric current, migrating at least a portion of at least one of lithium, beryllium, sodium, and magnesium in the aluminum feedstock to a location within

the cell; and removing at least a portion of the migrated lithium, beryllium, sodium, and magnesium from the cell, thereby producing a purified product.

[0060] Clause 22. A product produced with the first portion produced by the method according to any of clauses 1-20 or the purified product according to clause 21.

[0061] Clause 23. The product of clause 22, wherein the product comprises at least one of an aerospace part and an automotive part.

[0062] As used herein, “at least one of” a list of elements or other items means one of the elements/items or any combination of two or more of the listed elements/items. As an example “at least one of A, B, and C” means any of A only; B only; C only; A and B; A and C; B and C; or A, B, and C.

[0063] Any references herein to “various embodiments”, “some embodiments”, “one embodiment”, “an embodiment”, “a non-limiting embodiment”, or like phrases mean that a particular feature, structure, step, or characteristic described in connection with the example is included in at least one embodiment. Thus, appearances of the phrases “various embodiments”, “some embodiments”, “one embodiment”, “an embodiment”, “a non-limiting embodiment”, or like phrases in the specification do not necessarily refer to the same embodiment. Furthermore, the particular described features, structures, steps, or characteristics may be combined in any suitable manner in one or more embodiments. Thus, the particular features, structures, steps, or characteristics illustrated or described in connection with one embodiment may be combined, in whole or in part, with the features, structures, steps, or characteristics of one or more other embodiments, without limitation. Such modifications and variations are intended to be included within the scope of the present embodiments.

[0064] In this specification, unless otherwise indicated, all numerical parameters are to be understood as being prefaced and modified in all instances by the term “about,” in which the numerical parameters possess the inherent variability characteristic of the underlying measurement techniques used to determine the numerical value of the parameter. At the very least, and not as an attempt to limit the application of the doctrine of equivalents to the scope of the claims, each numerical parameter described herein should at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques.

[0065] Also, any numerical range recited herein includes all sub-ranges subsumed within the recited range. For example, a range of “1 to 10” includes all sub-ranges between (and including) the recited minimum value of 1 and the recited maximum value of 10, that is, having a minimum value equal to or greater than 1 and a maximum value equal to or less than 10. Also, all ranges recited herein are inclusive of the end points of the recited ranges. For example, a range of “1 to 10” includes the end points 1 and 10. Any maximum numerical limitation recited in this specification is intended to include all lower numerical limitations subsumed therein, and any minimum numerical limitation recited in this specification is intended to include all higher numerical limitations subsumed therein. Accordingly, Applicant reserves the right to amend this specification, including the claims, to expressly recite any sub-range subsumed within the ranges expressly recited. All such ranges are inherently described in this specification.

[0066] The grammatical articles “a”, “an”, and “the”, as used herein, are intended to include “at least one” or “one or more”, unless otherwise indicated, even if “at least one” or “one or more” is expressly used in certain instances. Thus, the foregoing grammatical articles are used herein to refer to one or more than one (i.e., to “at least one”) of the particular identified elements. Further, the use of a singular noun includes the plural and the use of a plural noun includes the singular, unless the context of the usage requires otherwise.

[0067] One skilled in the art will recognize that the herein described articles and methods, and the discussion accompanying them, are used as examples for the sake of conceptual clarity and that various configuration modifications are contemplated. Consequently, as used herein, the specific examples/embodiments set forth and the accompanying discussions are intended to be representative of their more general classes. In general, use of any specific exemplar is intended to be representative of its class, and the non-inclusion of specific components, devices, operations/actions, and objects should not be taken to be limiting. While the present disclosure provides descriptions of various specific aspects for the purpose of illustrating various aspects of the present disclosure and/or its potential applications, it is understood that variations and modifications will occur to those skilled in the art. Accordingly, the invention or inventions described herein should be understood to be at least as broad as they are claimed and not as more narrowly defined by particular illustrative aspects provided herein.

Claims

1. A method comprising: disposing a molten material comprising predominantly aluminum and at least one first metal having an atomic mass less than 13 in a first region of an electrolysis cell, the electrolysis cell comprising an anode, a cathode, and a molten salt electrolyte in contact with the anode and the cathode, wherein the molten salt electrolyte is disposed in a second region of the electrolysis cell; contacting the anode with the molten material, and applying an electrical voltage across the anode and the cathode such that at least a portion of the first metal in the molten material migrates to a third region in the electrolysis cell to produce a first material enriched in the first metal, wherein the second region is intermediate the first region and the third region; and removing at least a first portion of the first material in the third region from the electrolysis cell.
2. The method of claim 1, further comprising heating a feedstock comprising an aluminum alloy to form the molten material.
3. The method of claim 2, wherein the feedstock comprises machining chips comprising the aluminum alloy.
4. The method of claim 3, further comprising cleaning the machining chips prior to heating the feedstock comprising the machining chips.
5. The method of claim 1, further comprising removing at least a second material from the first region of the electrolysis cell, wherein the molten material comprises a first aluminum concentration based on a total weight of the molten material, the second material comprises a second aluminum concentration based on a total weight of the second material, and the second aluminum concentration is greater than the first aluminum concentration.
6. The method of claim 1, further comprising casting the first portion removed from electrolysis cell into an ingot.
7. The method of claim 1, further comprising introducing the first portion removed from the electrolysis cell into a furnace as a feedstock for producing a metal or metal alloy.
8. The method of claim 1, wherein the anode and the cathode, individually, comprise at least one of a lithium wettable material, a beryllium wettable material, a sodium wettable material, and a magnesium wettable material.
9. The method of claim 1, wherein the anode and cathode, individually, comprise a lithium wettable material.
10. The method of claim 1, wherein a sum of lithium, beryllium, sodium, and magnesium in the molten material is 0.1% to 10%, by weight based on a total weight of the molten material.
11. The method of claim 1, wherein the molten material comprises 0.1% to 5% lithium, by weight based on a total weight of the molten material.
12. The method of claim 11, wherein the first portion removed from the third region of the electrolysis cell comprises at least 95% lithium, by weight based on a total weight of the first portion.
13. The method of claim 11, wherein the molten salt electrolyte comprises a molten lithium salt.
14. The method of claim 1, wherein the molten salt electrolyte comprises at least one of a molten lithium salt, a molten beryllium salt, a molten sodium salt, and a molten magnesium salt.

15. The method of claim 1, wherein the method is a batch process.
16. The method of claim 1, wherein the method is a continuous process.
17. The method of claim 1, wherein the molten material has a first density, the molten salt electrolyte has a second density, the first material has a third density, the first density is greater than the second density, and the second density is greater than the third density.
18. The method of claim 1, wherein the cathode extends from a first side of the electrolysis cell through the third region and into the second region, the anode extends from a second side of the electrolysis cell through the first region into the second region, the cathode does not contact the first region, and the anode does not contact the third region.
19. The method of claim 1, further comprising providing an inert gaseous atmosphere within the electrolysis cell.
20. A method comprising: disposing a molten material comprising predominantly aluminum and lithium in a first region of an electrolysis cell, the electrolysis cell comprising an anode, a cathode, and a molten salt electrolyte in contact with the anode and the cathode, wherein the molten salt electrolyte is disposed in a second region of the electrolysis cell; contacting the anode with the molten material, and applying an electrical voltage across the anode and the cathode such that at least a portion of the lithium in the molten material migrates to a third region in the electrolysis cell to produce a first material enriched in the lithium, wherein the second region is intermediate the first region and the third region; and removing at least a first portion of the first material in the third region from the electrolysis cell.
21. A method comprising: feeding an aluminum-containing feedstock into an aluminum electrolysis cell; directing an electric current into an anode through an electrolyte and into a cathode; wetting at least a portion of a surface of the anode with a portion of the aluminum feedstock; concomitant with directing the electric current, migrating at least a portion of at least one of lithium, beryllium, sodium, and magnesium in the aluminum feedstock to a location within the cell; and removing the migrated lithium, beryllium, sodium, and magnesium from the cell, thereby producing a purified product.