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(71) Applicant: **NOVELIS INC.** [CA/US]; One Phipps Plaza,
3550 Peachtree Rd NE, Suite 1100, Atlanta, Georgia 30326
(US).

(72) Inventors: **MARIAUX, Aurele Blaise**; c/o Novelis Inc.,
1950 Vaughn Road, Kennesaw, Georgia 30144 (US).
DESPOIS, Aude Celine; 1950 Vaughn Road, Kennesaw,

Georgia 30144 (US). **FELBERBAUM, Milan**; c/o Novelis
Inc., 1950 Vaughn Road, Kennesaw, Georgia 30144 (US).
FLOREY, Guillaume Hubert; c/o Novelis Inc., 1950
Vaughn Road, Kennesaw, Georgia 30144 (US). **KEMPA,**
Stefan Felix; c/o Novelis Inc., 1950 Vaughn Road, Kenne-
saw, Georgia 30144 (US).

(74) Agent: **GUEBERT, Anthony L.** et al.; Kilpatrick
Townsend & Stockton LLP, 1100 Peachtree Street, Suite
2800, Atlanta, Georgia 30309 (US).

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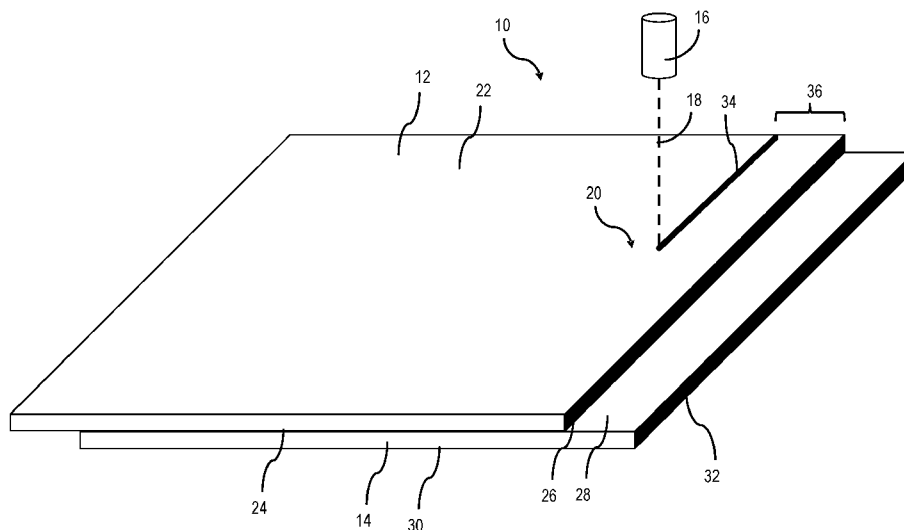


FIG. 1

(57) Abstract: A method of producing a component made of an aluminum alloy includes remote laser welding at least two metal products. A first metal product of the at least two metal products includes an aluminum alloy with a composition of: from 0.5 wt. % to 1.6 wt. % Mg; from 0.2 wt. % to 0.5 wt. % Si; up to 1.0 wt. % Fe; up to 0.5 wt. % Cu; up to 0.5 wt. % Mn; up to 0.3 wt. % Cr; up to 0.3 wt. % Ti; up to 0.5 wt. % Zn; up to 0.25 wt. % impurities; and Al. The laser welding may be performed without filler wire. The component obtained by the method can be used in a variety of applications, including automotive, transportation, and electronics applications.

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- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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HIGH MAGNESIUM ALUMINUM ALLOY WITH IMPROVED LASER WELDABILITY

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of and priority to U.S. Provisional Patent Application No. 63/520,964, filed on August 22, 2023, the content of which is hereby incorporated by reference in its entirety.

FIELD OF THE INVENTION

[0002] This application relates to the processing of metal substrates, such as but not limited to aluminum or aluminum alloy metal sheets, and more particularly to systems and methods for controlling welding or joining of the metal during processing.

BACKGROUND

[0003] Laser welding, and particularly remote laser welding, is commonly used in industries such as the automotive industry to join metal products such as metal products formed from aluminum and aluminum alloys. For example, 6xxx series aluminum alloys with high silicon levels are highly formable aluminum alloys that are used to form products in industries such as the automotive industry. However, current 6xxx series aluminum alloys are sensitive to cracking during joining by laser welding, and critical cracks are formed in the welds. To reduce such cracking, a filler wire is commonly used when laser welding 6xxx series aluminum alloys, with such filler wire typically being a 4xxx series aluminum alloy or a 5xxx series aluminum alloy. Current 5xxx series aluminum alloys have improved resistance to cracking during laser welding compared to 6xxx series aluminum alloys. However, current 5xxx series aluminum alloys have no age hardening potential and thus lack the high strength of current 6xxx series aluminum alloys.

SUMMARY

[0004] Embodiments covered by this patent are defined by the claims below, not this summary. This summary is a high-level overview of various embodiments and introduces some of the concepts that are further described in the Detailed Description section below. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used in isolation to determine the scope of the claimed subject matter. The subject matter should be understood by reference to appropriate portions of the entire specification of this patent, any or all drawings, and each claim.

[0005] According to certain embodiments, a method of producing a component made of an aluminum alloy includes remote laser welding at least two metal products. A first metal product of the at least two metal products includes an aluminum alloy with a composition including from 0.5 wt. % to 1.6 wt. % Mg; from 0.2 wt. % to 0.5 wt. % Si; up to 1.0 wt. % Fe; up to 0.5 wt. % Cu; up to 0.5 wt. % Mn; up to 0.3 wt. % Cr; up to 0.3 wt. % Ti; up to 0.5 wt. % Zn; up to 0.25 wt. % impurities; and Al.

[0006] In some embodiments, the laser welding may be performed without filler wire.

[0007] In various embodiments, the component obtained by the method can be used in a variety of applications, including automotive, transportation, and electronics applications, among others.

[0008] Various implementations described herein can include additional systems, methods, features, and advantages, which cannot necessarily be expressly disclosed herein but will be apparent to one of ordinary skill in the art upon examination of the following detailed description and accompanying drawings. It is intended that all such systems, methods, features, and advantages be included within the present disclosure and protected by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The specification makes reference to the following appended figures, in which use of like reference numerals in different figures is intended to illustrate like or analogous components.

[0010] FIG. 1 illustrates a laser welding system with metal products in a vertically overlapping arrangement according to embodiments.

[0011] FIG. 2 is a graph illustrating ratios of samples with a centerline crack and relative to an edge of a metal product according to embodiments.

[0012] FIG. 3 is a graph illustrating transverse cracks per millimeter and relative to an edge of a metal product according to embodiments.

DETAILED DESCRIPTION

[0013] Described herein are systems and methods for joining metal components from metal products via laser welding, such as but not limited to remote laser welding. In certain embodiments, at least one of the metal products includes an aluminum alloy with a composition including from 0.5 wt. % to 1.6 wt. % Mg; from 0.2 wt. % to 0.5 wt. % Si; up to 1.0 wt. % Fe; up to 0.5 wt. % Cu; up to 0.5 wt. % Mn; up to 0.3 wt. % Cr; up to 0.3 wt. % Ti; up to 0.5 wt. % Zn; up to 0.25 wt. % impurities; and Al. In various embodiments, the metal product may be

a monolithic product, such as but not limited to a sheet, a shate, or a plate, and/or the metal product may be a clad product with the aluminum alloy as a core layer and/or a clad layer. Compared to aluminum alloys commonly used in the automotive industry that are sensitive to cracking during joining by laser welding, the metal product with the aluminum alloy described herein may have improved weldability and improved resistance to crack formation. The metal product described herein may also allow for the formation of a weld with a smaller critical edge distance, or minimum distance between an edge of the metal product and a weld without the occurrence of centerline cracks, compared to traditional metal products. Advantageously, the systems and methods described herein may allow laser welding without filler wire. Various other benefits and advantages may be realized with the systems and methods described herein, and the aforementioned benefits and advantages should not be considered limiting.

[0014] The laser welding systems and methods described herein may join at least two metal products via laser welding, such as but not limited to remote laser welding.

[0015] In various embodiments, at least one metal product of the at least two metal products includes an improved aluminum alloy comprising magnesium (Mg) and silicon (Si), and in various embodiments, both of the at least two metal products may include the improved aluminum alloy.

[0016] The improved aluminum alloy comprises Mg and Si and may optionally comprise iron (Fe), copper (Cu), manganese (Mn), chromium (Cr), zinc (Zn), titanium (Ti), other elements (e.g., impurities) and combinations thereof. In certain embodiments, the improved aluminum alloy may be an aluminum alloy as described in International Patent Application No. WO 2020/185920 to Mariaux et al. ("Mariaux"), the content of which is hereby incorporated by reference in its entirety.

[0017] In some aspects, the improved aluminum alloy may comprise up to about 1.60 wt. % Mg, e.g., up to about 1.59 wt. % Mg, up to about 1.58 wt. % Mg, up to about 1.57 wt. % Mg, up to about 1.56 wt. % Mg, up to about 1.55 wt. % Mg, up to about 1.54 wt. % Mg, up to about 1.53 wt. % Mg, up to about 1.52 wt. % Mg, up to about 1.51 wt. % Mg, up to about 1.50 wt. % Mg, up to about 1.49 wt. % Mg, up to about 1.48 wt. % Mg, up to about 1.47 wt. % Mg, up to about 1.46 wt. % Mg, up to about 1.45 wt. % Mg, up to about 1.44 wt. % Mg, up to about 1.43 wt. % Mg, up to about 1.42 wt. % Mg, up to about 1.41 wt. % Mg, up to about 1.40 wt. % Mg, up to about 1.39 wt. % Mg, up to about 1.38 wt. % Mg, up to about 1.37 wt. % Mg, up to about 1.36 wt. % Mg, up to about 1.35 wt. % Mg, up to about 1.34 wt. % Mg, up to about 1.33 wt. % Mg, up to about 1.32 wt. % Mg, up to about 1.31 wt. % Mg, up to about 1.30 wt.

% Mg, up to about 1.29 wt. % Mg, up to about 1.28 wt. % Mg, up to about 1.27 wt. % Mg, up to about 1.26 wt. % Mg, up to about 1.25 wt. % Mg, up to about 1.24 wt. % Mg, up to about 1.23 wt. % Mg, up to about 1.22 wt. % Mg, up to about 1.21 wt. % Mg, up to about 1.20 wt. % Mg, up to about 1.19 wt. % Mg, up to about 1.18 wt. % Mg, up to about 1.17 wt. % Mg, up to about 1.16 wt. % Mg, up to about 1.15 wt. % Mg, up to about 1.14 wt. % Mg, up to about 1.13 wt. % Mg, up to about 1.12 wt. % Mg, up to about 1.11 wt. % Mg, up to about 1.10 wt. % Mg, up to about 1.09 wt. % Mg, up to about 1.08 wt. % Mg, up to about 1.07 wt. % Mg, up to about 1.06 wt. % Mg, up to about 1.05 wt. % Mg, up to about 1.04 wt. % Mg, up to about 1.03 wt. % Mg, up to about 1.02 wt. % Mg, up to about 1.01 wt. % Mg, up to about 1.00 wt. % Mg, up to about 0.95 wt. % Mg, up to about 0.90 wt. % Mg, up to about 0.85 wt. % Mg, up to about 0.80 wt. % Mg, up to about 0.75 wt. % Mg, up to about 0.70 wt. % Mg, up to about 0.65 wt. % Mg, up to about 0.60 wt. % Mg, up to about 0.55 wt. % Mg, and/or up to about 0.50 wt. % Mg. In terms of ranges, the improved aluminum alloy can comprise from about 0.50 wt. % to about 1.60 wt. % Mg, e.g., from about 0.60 wt. % to about 1.55 wt. % Mg, from about 0.70 wt. % to about 1.52 wt. % Mg, from about 0.80 wt. % to about 1.50 wt. % Mg, from about 0.90 wt. % to about 1.50 wt. % Mg, from about 1.00 wt. % to about 1.50 wt. % Mg, from about 1.10 wt. % to about 1.50 wt. % Mg, from about 1.20 wt. % to about 1.50 wt. % Mg, or from about 1.30 wt. % to about 1.50 wt. % Mg.

[0018] In some aspects, the improved aluminum alloy may comprise up to about 0.50 wt. % Si, e.g., up to about 0.49 wt. % Si, up to about 0.48 wt. % Si, up to about 0.47 wt. % Si, up to about 0.46 wt. % Si, up to about 0.45 wt. % Si, up to about 0.44 wt. % Si, up to about 0.43 wt. % Si, up to about 0.42 wt. % Si, up to about 0.41 wt. % Si, up to about 0.40 wt. % Si, up to about 0.39 wt. % Si, up to about 0.38 wt. % Si, up to about 0.37 wt. % Si, up to about 0.36 wt. % Si, up to about 0.35 wt. % Si, up to about 0.34 wt. % Si, up to about 0.33 wt. % Si, up to about 0.32 wt. % Si, up to about 0.31 wt. % Si, up to about 0.30 wt. % Si, up to about 0.29 wt. % Si, up to about 0.28 wt. % Si, up to about 0.27 wt. % Si, up to about 0.26 wt. % Si, up to about 0.25 wt. % Si, up to about 0.24 wt. % Si, up to about 0.23 wt. % Si, up to about 0.22 wt. % Si, up to about 0.21 wt. % Si, up to about 0.20 wt. % Si, up to about 0.19 wt. % Si, up to about 0.18 wt. % Si, up to about 0.17 wt. % Si, up to about 0.16 wt. % Si, or up to about 0.15 wt. % Si.

[0019] In certain aspects, the improved aluminum alloy may comprise at least about 0.15 wt. % Si, at least about 0.16 wt. % Si, at least about 0.17 wt. % Si, at least about 0.18 wt. % Si, at least about 0.19 wt. % Si, at least about 0.20 wt. % Si, at least about 0.21 wt. % Si, at least

about 0.22 wt. % Si, at least about 0.23 wt. % Si, at least about 0.24 wt. % Si, at least about 0.25 wt. % Si, at least about 0.26 wt. % Si, at least about 0.27 wt. % Si, at least about 0.28 wt. % Si, at least about 0.29 wt. % Si, at least about 0.30 wt. % Si, at least about 0.31 wt. % Si, at least about 0.32 wt. % Si, at least about 0.33 wt. % Si, at least about 0.34 wt. % Si, at least about 0.35 wt. % Si, at least about 0.36 wt. % Si, at least about 0.37 wt. % Si, at least about 0.38 wt. % Si, at least about 0.39 wt. % Si, at least about 0.40 wt. % Si, at least about 0.41 wt. % Si, at least about 0.42 wt. % Si, at least about 0.43 wt. % Si, at least about 0.44 wt. % Si, at least about 0.45 wt. % Si, at least about 0.46 wt. % Si, at least about 0.47 wt. % Si, at least about 0.48 wt. % Si, at least about 0.49 wt. % Si, or at least about 0.50 wt. % Si.

[0020] From a range perspective, the improved aluminum alloy may comprise from about 0.15 wt. % to about 0.5 wt. % Si, e.g., from about 0.20 wt. % to about 0.45 wt. % Si, from about 0.22 wt. % to about 0.43 wt. % Si, from about 0.25 wt. % to about 0.41 wt. % Si, from about 0.26 wt. % to about 0.40 wt. % Si, from about 0.28 wt. % to about 0.40 wt. % Si, from about 0.30 wt. % to about 0.40 wt. % Si, from about 0.31 wt. % to about 0.39 wt. % Si, from about 0.32 wt. % to about 0.38 wt. % Si, from about 0.33 wt. % to about 0.38 wt. % Si, from about 0.34 wt. % to about 0.38 wt. % Si, or from about 0.34 wt. % to about 0.37 wt. % Si.

[0021] In certain embodiments, the improved aluminum alloy may comprise from about 0.50 wt. % to about 1.5 wt. % Mg and from about 0.15 wt. % to about 0.50 wt. % Si. In some aspects, the ratio of Mg wt. % to Si wt. % in the improved aluminum alloy may be from about 10:1 to about 1:1 (e.g., about 10:1 to about 1.5:1; about 10:1 to about 2:1; about 9:1 to about 1.5:1; about 9:1 to about 2:1; about 8:1 to about 1.5:1; about 8:1 to about 2:1; about 7:1 to about 2:1; about 5:1 to about 2:1; about 4:1 to about 2:1; or about 3:1 to about 2:1).

[0022] As mentioned, in addition to Mg and Si, the improved aluminum alloy optionally may include other elements.

[0023] In some embodiments, the improved aluminum alloy can optionally comprise up to about 1.0 wt. % Fe, e.g., up to about 0.95 wt. % Fe, up to about 0.90 wt. % Fe, up to about 0.85 wt. % Fe, up to about 0.80 wt. % Fe, up to about 0.75 wt. % Fe, up to about 0.70 wt. % Fe, up to about 0.65 wt. % Fe, up to about 0.60 wt. % Fe, up to about 0.55 wt. % Fe, up to about 0.50 wt. % Fe, up to about 0.45 wt. % Fe, up to about 0.40 wt. % Fe, up to about 0.35 wt. % Fe, up to about 0.30 wt. % Fe, up to about 0.25 wt. % Fe, up to about 0.20 wt. % Fe, up to about 0.15 wt. % Fe, up to about 0.10 wt. % Fe, up to about 0.08 wt. % Fe, up to about 0.05 wt. % Fe, up to about 0.03 wt. % Fe, or up to about 0.01 wt. % Fe. In terms of ranges, the improved aluminum alloy can optionally comprise from about 0.01 wt. % to about 1.0 wt. % Fe, e.g., from about

0.03 wt. % to about 0.90 wt. % Fe, from about 0.05 wt. % to about 0.80 wt. % Fe, from about 0.08 wt. % to about 0.80 wt. % Fe, from about 0.08 wt. % to about 0.75 wt. % Fe, from about 0.01 wt. % to about 0.70 wt. % Fe, from about 0.20 wt. % to about 0.60 wt. % Fe, from about 0.20 wt. % to about 0.55 wt. % Fe, from about 0.25 wt. % to about 0.55 wt. % Fe, from about 0.25 wt. % to about 0.50 wt. % Fe, or from about 0.30 wt. % to about 0.50 wt. % Fe. In some cases, Fe is not present in the improved alloy (e.g., 0 wt. %).

[0024] In some embodiments, the improved aluminum alloy may optionally comprise Cu. In some aspects, the aluminum alloy can comprise up to about 0.5 wt. % Cu, e.g., up to about 0.45 wt. % Cu, up to about 0.40 wt. % Cu, up to about 0.35 wt. % Cu, up to about 0.30 wt. % Cu, up to about 0.25 wt. % Cu, up to about 0.20 wt. % Cu, up to about 0.15 wt. % Cu, up to about 0.10 wt. % Cu, up to about 0.05 wt. % Cu, up to about 0.04 wt. % Cu, up to about 0.03 wt. % Cu, up to about 0.02 wt. % Cu, or up to about 0.01 wt. % Cu. In terms of ranges, the improved aluminum alloy can optionally comprise from about 0.01 wt. % to about 0.5 wt. % Cu, e.g., from about 0.03 wt. % to about 0.40 wt. % Cu, from about 0.03 wt. % to about 0.30 wt. % Cu, from about 0.03 wt. % to about 0.10 wt. % Cu, from about 0.04 wt. % to about 0.08 wt. % Cu, or from about 0.04 wt. % to about 0.06 wt. % Cu. In some cases, Cu is not present in the improved alloy (e.g., 0 wt. %).

[0025] In various embodiments, the improved aluminum alloy may optionally comprise up to about 0.5 wt. % Mn, e.g., up to about 0.45 wt. % Mn, up to about 0.40 wt. % Mn, up to about 0.35 wt. % Mn, up to about 0.30 wt. % Mn, up to about 0.25 wt. % Mn, up to about 0.20 wt. % Mn, up to about 0.15 wt. % Mn, up to about 0.10 wt. % Mn, up to about 0.05 wt. % Mn, up to about 0.04 wt. % Mn, up to about 0.03 wt. % Mn, up to about 0.02 wt. % Mn, or up to about 0.01 wt. % Mn. In terms of ranges, the improved aluminum alloy can optionally comprise from about 0.01 wt. % to about 0.5 wt. % Mn, e.g., from about 0.03 wt. % to about 0.40 wt. % Mn, from about 0.03 wt. % to about 0.30 wt. % Mn, from about 0.03 wt. % to about 0.25 wt. % Mn, from about 0.04 wt. % to about 0.20 wt. % Mn, or from about 0.10 wt. % to about 0.20 wt. % Mn. In some cases, Mn is not present in the improved alloy (e.g., 0 wt. %).

[0026] In some embodiments, the improved aluminum alloy may comprise up to about 0.3 wt. % Cr, e.g., up to about 0.25 wt. % Cr, up to about 0.20 wt. % Cr, up to about 0.15 wt. % Cr, up to about 0.10 wt. % Cr, up to about 0.08 wt. % Cr, up to about 0.05 wt. % Cr, up to about 0.03 wt. % Cr, up to about 0.02 wt. % Cr, up to about 0.01 wt. % Cr, or up to about 0.008 wt. % Cr. In terms of ranges, the improved aluminum alloy can optionally comprise from about 0.005 wt. % to about 0.30 wt. % Cr, e.g., from about 0.008 wt. % to about 0.30 wt. % Cr, from

about 0.01 wt. % to about 0.30 wt. % Cr, from about 0.03 wt. % to about 0.25 wt. % Cr, from about 0.05 wt. % to about 0.25 wt. % Cr, from about 0.06 wt. % to about 0.20 wt. % Cr, or from about 0.08 wt. % to about 0.15 wt. % Cr. In some cases, Cr is not present in the improved alloy (e.g., 0 wt. %).

[0027] In some aspects, the improved aluminum alloy may comprise up to about 0.3 wt. % Ti, e.g., up to about 0.25 wt. % Ti, up to about 0.20 wt. % Ti, up to about 0.15 wt. % Ti, up to about 0.10 wt. % Ti, up to about 0.08 wt. % Ti, up to about 0.05 wt. % Ti, up to about 0.03 wt. % Ti, up to about 0.02 wt. % Ti, up to about 0.01 wt. % Ti, or up to about 0.008 wt. % Ti. In terms of ranges, the improved aluminum alloy can optionally comprise from about 0.005 wt. % to about 0.30 wt. % Ti, e.g., from about 0.008 wt. % to about 0.30 wt. % Ti, from about 0.01 wt. % to about 0.30 wt. % Ti, from about 0.03 wt. % to about 0.25 wt. % Ti, from about 0.05 wt. % to about 0.25 wt. % Ti, from about 0.06 wt. % to about 0.20 wt. % Ti, or from about 0.08 wt. % to about 0.15 wt. % Ti. In some cases, Ti is not present in the improved alloy (e.g., 0 wt. %).

[0028] The improved aluminum alloy may optionally comprise Zn. In some aspects, the improved aluminum alloy can comprise up to about 0.5 wt. % Zn, e.g., up to about 0.45 wt. % Zn, up to about 0.40 wt. % Zn, up to about 0.35 wt. % Zn, up to about 0.30 wt. % Zn, up to about 0.25 wt. % Zn, up to about 0.20 wt. % Zn, up to about 0.15 wt. % Zn, up to about 0.10 wt. % Zn, up to about 0.08 wt. % Zn, up to about 0.05 wt. % Zn, up to about 0.03 wt. % Zn, up to about 0.02 wt. % Zn, up to about 0.01 wt. % Zn, or up to about 0.008 wt. % Zn. In terms of ranges, the improved aluminum alloy can optionally comprise from about 0.005 wt. % to about 0.50 wt. % Zn, e.g., from about 0.008 wt. % to about 0.30 wt. % Zn, from about 0.01 wt. % to about 0.30 wt. % Zn, from about 0.03 wt. % to about 0.25 wt. % Zn, from about 0.05 wt. % to about 0.25 wt. % Zn, from about 0.06 wt. % to about 0.20 wt. % Zn, or from about 0.08 wt. % to about 0.15 wt. % Zn. In some cases, Zn is not present in the improved alloy (e.g., 0 wt. %).

[0029] Optionally, the improved aluminum alloy described herein may further include other minor elements, sometimes referred to as impurities, in amounts of about 0.05 wt. % or below, about 0.04 wt. % or below, about 0.03 wt. % or below, about 0.02 wt. % or below, or about 0.01 wt. % or below. These impurities may include, but are not limited to, V, Ni, Sc, Hf, Zr, Sn, Ga, Bi, Na, Pb, or combinations thereof. Accordingly, V, Ni, Sc, Hf, Zr, Sn, Ga, Bi, Na, or Pb, may each be present in the alloys in amounts of about 0.05 wt. % or below, about 0.04 wt. % or below, about 0.03 wt. % or below, about 0.02 wt. % or below, or about 0.01 wt. % or below, for example. The sum of all impurities does not exceed about 0.50 wt. % (e.g., does not

exceed about 0.40 wt. %, about 0.30 wt. %, about 0.25 wt. %, about 0.20 wt. % about 0.15 wt. %, or about 0.10 wt. %). All expressed in wt. %. In some embodiments, the remaining percentage of the alloy is aluminum.

[0030] Optionally, the improved aluminum alloy may comprise recycled aluminum or aluminum alloys. As non-limiting examples, the improved aluminum alloy can comprise recycled 5xxx series aluminum alloy scrap, recycled 6xxx series aluminum alloy scrap, or both 5xxx series aluminum alloy scrap and 6xxx series aluminum alloy scrap. Recycled aluminum content, recycled aluminum, or recycled aluminum scrap as used herein refers to any aluminum and/or aluminum alloy that is reused or recovered from a prior use. Recycled aluminum content can include, but is broader than, used beverage cans content. In some aspects, the improved aluminum alloy can contain at least about 10 wt. % recycled content (e.g., at least about 15 wt. % recycled content, at least about 20 wt. % recycled content, at least about 25 wt. % recycled content, at least about 30 wt. % recycled content, at least about 35 wt. % recycled content, at least about 40 wt. % recycled content, at least about 45 wt. % recycled content, at least about 50 wt. % recycled content, at least about 55 wt. % recycled content, or at least about 60 wt. % recycled content).

[0031] In some aspects, the improved aluminum alloy can contain at least about 5 % used beverage cans (“UBC”) (e.g., at least about 8 wt. % UBC, at least about 10 wt. % UBC, at least about 15 wt. % UBC, at least about 20 wt. % UBC, at least about 25 wt. % UBC, at least about 30 wt. % UBC, at least about 35 wt. % UBC, at least about 40 wt. % UBC, at least about 45 wt. % UBC, at least about 50 wt. % UBC, at least about 55 wt. % UBC, or at least about 60 wt. % UBC). UBC scrap as used herein is collected metal from used beverage cans and similar products that can be recycled for use in further metal products. Aluminum UBC scrap is often a mixture of various aluminum alloys (e.g., from different alloys used for can bodies and can ends) and can often include foreign substances, such as rainwater, drink remainders, organic matter (e.g., paints and laminated films), and other materials. UBC scrap generally contains a mixture of metal from various alloys, such as metal from can bodies (e.g., 3104, 3004, or other 3xxx aluminum alloy) and can ends (e.g., 5182 or other 5xxx aluminum alloy). UBC scrap can be shredded and decoated or delacquered prior to being melted for use as liquid metal stock in casting a new metal product.

[0032] In various embodiments, the improved aluminum alloy may comprise a combined concentration of Fe, Cu, and Mn of greater than about 0.5 wt. %, (e.g., greater than about 0.6 wt. %, greater than about 0.7 wt. %, greater than about 0.8 wt. %, greater than about 0.9 wt. %.

greater than about 1.0 wt. %, greater than about 1.2 wt. %, greater than about 1.5 wt. %, greater than about 1.7 wt. %, greater than about 2.0 wt. %, greater than about 2.2 wt. %, greater than about 2.5 wt. %, greater than about 2.7 wt. %, greater than about 3.0 wt. %, from about 0.5 wt. % to about 3.0 wt. %, from about 0.5 wt. % to about 2.8 wt. %, from about 0.6 wt. % to about 2.5 wt. %, from about 0.7 wt. % to about 2.5 wt. %, from about 0.7 wt. % to about 2.2 wt. %, from about 0.9 wt. % to about 3.0 wt. %, or from about 1.0 wt. % to about 2.0 wt. %). As indicated, in other aspects, Fe, Cu, and Mn are not present or may be present at lower levels.

[0033] In a non-limiting example, the improved aluminum alloy may have a composition that includes from 0.5 wt. % to 1.6 wt. % Mg and from 0.2 wt. % to 0.5 wt. % Si.

[0034] In one example, the improved aluminum alloy may have a composition including from 0.5 wt. % to 1.6 wt. % Mg; from 0.2 wt. % to 0.5 wt. % Si; up to 1.0 wt. % Fe; up to 0.5 wt. % Cu; up to 0.5 wt. % Mn; up to 0.3 wt. % Cr; up to 0.3 wt. % Ti; up to 0.5 wt. % Zn; up to 0.25 wt. % impurities; and Al.

[0035] In another non-limiting example, the improved aluminum alloy may have a composition including from 0.6 wt. % to 1.5 wt. % Mg; from 0.3 wt. % to 0.45 wt. % Si; up to 0.5 wt. % Fe; up to 0.4 wt. % Cu; up to 0.4 wt. % Mn; up to 0.25 wt. % Cr; up to 0.15 wt. % Ti; up to 0.4 wt. % Zn; impurities up to 0.20 wt. %; and Al.

[0036] In another non-limiting example, the improved aluminum alloy may have a composition including from 0.7 wt. % to 1.5 wt. % Mg; from 0.25 wt. % to 0.45 wt. % Si; from 0.01 wt. % to 1.0 wt. % Fe; from 0.01 wt. % to 0.5 wt. % Cu; from 0.01 wt. % to 0.5 wt. % Mn; from 0.005 wt. % to 0.3 wt. % Cr; from 0.01 wt. % to 0.25 wt. % Ti; up to 0.4 wt. % Zn; impurities up to 0.20 wt. %; and Al.

[0037] The improved aluminum alloys as described herein may have an average grain diameter of from about 5 μm to about 50 μm (e.g., from about 8 μm to about 40 μm , from about 10 μm to about 30 μm , or from about 15 μm to about 25 μm), for example. In some embodiments, the grain sizes of the improved aluminum alloys described are suitable for skin applications.

[0038] In various embodiments, the improved aluminum alloys exhibit both high formability and age hardening. The improved aluminum alloys also demonstrate good tensile properties, bendability, and deep-drawability.

[0039] In some embodiments, the improved aluminum alloys may have yield strengths ($R_{p0.2}$) after bake hardening (e.g., after a paint bake cycle of 20 minutes at 185 °C to a T8x temper) of up to about 250 MPa, such as from about 80 MPa to about 240 MPa, such as from

about 150 MPa to about 230 MPa, such as from about 160 MPa to about 230 MPa, such as from about 165 MPa to about 220 MPa, or such as from about 170 MPa to about 210 MPa. Rp0.2 refers to the amount of stress that will result in a plastic strain of 0.2 %. In some examples, the yield strengths (Rp0.2) of the improved aluminum alloys can be about 100 MPa, about 110 MPa, about 120 MPa, about 130 MPa, about 140 MPa, about 150 MPa, about 160 MPa, about 170 MPa, about 180 MPa, about 190 MPa, about 200 MPa, about 210 MPa, about 220 MPa, about 230 MPa, or about 240 MPa.

[0040] In various embodiments, the improved aluminum alloys may have an ultimate tensile strength (Rm) after bake hardening (e.g., after a paint bake cycle of 20 minutes at 185 °C to a T8x temper) of up to about 300 MPa, such as from about 230 MPa to about 300 MPa, such as from about 240 MPa to about 300 MPa, or such as from about 240 MPa to about 290 MPa. Rm refers to the ultimate tensile strength. In some examples, the Rm of the improved aluminum alloys can be about 230 MPa, about 240 MPa, about 250 MPa, about 260 MPa, about 270 MPa, about 280 MPa, about 290 MPa, or about 300 MPa.

[0041] In some embodiments, the improved aluminum alloys as described herein may have a yield strength (Rp0.2) before bake hardening (T4 temper) of from about 80 MPa to about 140 MPa (e.g., from about 80 MPa to about 130 MPa, from about 80 MPa to about 120 MPa, or from about 85 MPa to about 110 MPa). In various embodiments, the improved aluminum alloys as described herein can have an Rm before bake hardening (T4 temper) of from about 170 MPa to about 280 MPa (e.g., from about 180 MPa to about 270 MPa, from about 170 MPa to about 250 MPa, from about 190 MPa to about 230 MPa, or from about 190 MPa to about 220 MPa).

[0042] In addition to being age-hardenable, the improved aluminum alloys may exhibit high formability, including deep-drawability and bendability.

[0043] In various embodiments, the improved aluminum alloys can have a total elongation (as measured by ISO/EN A80) in any individual direction or in all directions (longitudinal (L), diagonal (D), and/or transverse (T)) of at least about 20 % (e.g., at least about 21 %, at least about 22 %, at least about 23 %, at least about 24 %, at least about 25 %, at least about 26 %, at least about 27 %, at least about 28 %, at least about 29 %, at least about 30 %, at least about 31 %, at least about 32 %, at least about 33 %, at least about 34 %, at least about 35 %, at least about 36 %, at least about 37 %, at least about 38 %, at least about 39 %, or at least about 40 %). In terms of ranges, the aluminum alloys can have an elongation of from about 20 % to about 40 % (e.g., from about 22 % to about 38 %, from about 23 % to about 36 %, from about 24 % to about 34 %, from about 25 % to about 33 %, from about 25 % to about 32 %, from

about 25 % to about 31 %, from about 25 % to about 30 %, or from about 25 % to about 29 %).

[0044] In various embodiments, the improved aluminum alloys may have a uniform elongation (Ag) (as measured by ISO/EN Ag) in any individual direction or in all directions (longitudinal (L), diagonal (D), and/or transverse (T)) of at least about 18 % (e.g., at least about 19 %, at least about 20 %, at least about 21 %, at least about 22 %, at least about 23 %, at least about 24 %, at least about 25 %, at least about 26 %, at least about 27 %, at least about 28 %, at least about 29 %, or at least about 30 %). In terms of ranges, the aluminum alloys can have an elongation of from about 18 % to about 30 % (e.g., from about 22 % to about 38 %, from about 23 % to about 36 %, from about 24 % to about 34 %, from about 25 % to about 33 %, from about 25 % to about 32 %, from about 25 % to about 31 %, from about 25 % to about 30 %, or from about 25 % to about 29 %).

[0045] In some aspects, the improved aluminum alloys may have an r (10-15) value in any individual direction or in all directions (longitudinal (L), diagonal (D), and/or transverse (T)) of at least about 0.45 (e.g., of at least about 0.46, of at least about 0.47, of at least about 0.48, of at least about 0.49, of at least about 0.50, of at least about 0.51, of at least about 0.52, of at least about 0.53, of at least about 0.54, of at least about 0.55, of at least about 0.56, of at least about 0.57, of at least about 0.58, of at least about 0.59, of at least about 0.60, of at least about 0.61, of at least about 0.62, of at least about 0.63, of at least about 0.64, of at least about 0.65, of at least about 0.66, of at least about 0.67, of at least about 0.68, of at least about 0.69, of at least about 0.70, of at least about 0.71, of at least about 0.72, of at least about 0.73, of at least about 0.74, of at least about 0.75, of at least about 0.76, of at least about 0.77, of at least about 0.78, of at least about 0.79, or of at least about 0.80). In certain embodiments, the improved aluminum alloy can have an r (10-15) value in any direction or all directions (longitudinal (L), diagonal (D), and/or transverse (T)) of from about 0.45 to about 0.80 (e.g., from about 0.45 to about 0.75, from about 0.47 to about 0.72, from about 0.50 to about 0.70, or from about 0.52 to about 0.68).

[0046] In some aspects, the improved aluminum alloys may have an n (10-20) value in any direction or all directions (longitudinal (L), diagonal (D), and/or transverse (T)) of at least about 0.20 (e.g., of at least about 0.21, of at least about 0.22, of at least about 0.23, of at least about 0.24, of at least about 0.25, of at least about 0.26, of at least about 0.27, of at least about 0.28, of at least about 0.29, or of at least about 0.30). In terms of ranges, the improved aluminum alloy can have an n (10-20) value in any individual direction or in all directions (longitudinal

(L), diagonal (D), and/or transverse (T)) of from about 0.20 to about 0.30 (e.g., of from about 0.21 to about 0.29 or of from about 0.22 to about 0.28).

[0047] In various embodiments, the improved aluminum alloys may have strong bendability properties. In some embodiments, the improved aluminum alloys may have a minimum R/t ratio or f-factor at 10% elongation of about 0.60 or less, for example. As described, the bendability is assessed based on the R/t ratio, where R is the radius of the tool (die) used and t is the thickness of the material. A lower R/t ratio indicates better bendability of the material. In certain embodiments, the improved aluminum alloys may have an f-factor at 10% elongation of less than about 0.85 (e.g., less than about 0.80, less than about 0.75, less than about 0.70, less than about 0.65, less than about 0.60, less than about 0.59, less than about 0.58, less than about 0.57, less than about 0.56, less than about 0.55, less than about 0.54, less than about 0.53, less than about 0.52, less than about 0.51, less than about 0.50, less than about 0.49, less than about 0.48, less than about 0.47, less than about 0.46, less than about 0.45, less than about 0.44, less than about 0.43, less than about 0.42, less than about 0.41, less than about 0.40, less than about 0.39, less than about 0.38, less than about 0.37, less than about 0.36, less than about 0.35, less than about 0.34, less than about 0.33, less than about 0.32, less than about 0.31, or less than about 0.30). In terms of ranges, the aluminum alloys can have an f-factor at 10% elongation of from about 0.30 to about 0.85 (e.g., from about 0.30 to 0.80, from about 0.30 to about 0.75, from about 0.30 to about 0.70, from about 0.30 to about 0.65, from about 0.35 to about 0.58, from about 0.35 to about 0.55, from about 0.35 to about 0.50, from about 0.35 to about 0.45, or from about 0.37 to about 0.45).

[0048] In various embodiments, the at least one metal product with the improved aluminum alloy may be monolithic. However, in other embodiments, the at least one metal product may be a clad metal product, and in such embodiments, the improved aluminum alloy may include the improved aluminum alloy as a core layer and/or a cladding layer, and another aluminum alloy may be utilized as a cladding layer and/or the core layer. In such embodiments, the other aluminum alloy of the cladding layer and/or the core layer may be a 1xxx series aluminum alloy, a 2xxx series aluminum alloy, a 3xxx series aluminum alloy, a 4xxx series aluminum alloy, a 5xxx series aluminum alloy, a 6xxx series aluminum alloy, a 7xxx series aluminum alloy, or an 8xxx series aluminum alloy.

[0049] Non-limiting examples of 1xxx series aluminum alloys can include AA1100, AA1100A, AA1200, AA1200A, AA1300, AA1110, AA1120, AA1230, AA1230A, AA1235, AA1435, AA1145, AA1345, AA1445, AA1150, AA1350, AA1350A, AA1450, AA1370,

AA1275, AA1185, AA1285, AA1385, AA1188, AA1190, AA1290, AA1193, AA1198, and AA1199.

[0050] Non-limiting exemplary 2xxx series aluminum alloys can include AA2001, A2002, AA2004, AA2005, AA2006, AA2007, AA2007A, AA2007B, AA2008, AA2009, AA2010, AA2011, AA2011A, AA2111, AA2111 A, AA211 IB, AA2012, AA2013, AA2014, AA2014A, AA2214, AA2015, AA2016, AA2017, AA2017A, AA2117, AA2018, AA2218, AA2618, AA2618A, AA2219, AA2319, AA2419, AA2519, AA2021, AA2022, AA2023, AA2024, AA2024A, AA2124, AA2224, AA2224A, AA2324, AA2424, AA2524, AA2624, AA2724, AA2824, AA2025, AA2026, AA2027, AA2028, AA2028A, AA2028B, AA2028C, AA2029, AA2030, AA2031, AA2032, AA2034, AA2036, AA2037, AA2038, AA2039, AA2139, AA2040, AA2041, AA2044, AA2045, AA2050, AA2055, AA2056, AA2060, AA2065, AA2070, AA2076, AA2090, AA2091, AA2094, AA2095, AA2195, AA2295, AA2196, AA2296, AA2097, AA2197, AA2297, AA2397, AA2098, AA2198, AA2099, and AA2199.

[0051] Non-limiting exemplary 3xxx series aluminum alloys can include AA3002, AA3102, AA3003, AA3103, AA3103A, AA3103B, AA3203, AA3403, AA3004, AA3004A, AA3104, AA3204, AA3304, AA3005, AA3005A, AA3105, AA3105A, AA3105B, AA3007, AA3107, AA3207, AA3207A, AA3307, AA3009, AA3010, AA3110, AA3011, AA3012, AA3012A, AA3013, AA3014, AA3015, AA3016, AA3017, AA3019, AA3020, AA3021, AA3025, AA3026, AA3030, AA3130, and AA3065.

[0052] Non-limiting exemplary 4xxx series aluminum alloys can include AA4045, AA4004, AA4104, AA4006, AA4007, AA4008, AA4009, AA4010, AA4013, AA4014, AA4015, AA4015A, AA4115, AA4016, AA4017, AA4018, AA4019, AA4020, AA4021, AA4026, AA4032, AA4043, AA4043A, AA4143, AA4343, AA4643, AA4943, AA4044, AA4145, AA4145A, AA4046, AA4047, AA4047A, and AA4147.

[0053] Non-limiting exemplary 5xxx series aluminum alloys can include AA5182, AA5183, AA5005, AA5005A, AA5205, AA5305, AA5505, AA5605, AA5006, AA5106, AA5010, AA5110, AA5110A, AA5210, AA5310, AA5016, AA5017, AA5018, AA5018A, AA5019, AA5019A, AA5119, AA5119A, AA5021, AA5022, AA5023, AA5024, AA5026, AA5027, AA5028, AA5040, AA5140, AA5041, AA5042, AA5043, AA5049, AA5149, AA5249, AA5349, AA5449, AA5449A, AA5050, AA5050A, AA5050C, AA5150, AA5051, AA5051A, AA5151, AA5251, AA5251A, AA5351, AA5451, AA5052, AA5252, AA5352, AA5154, AA5154A, AA5154B, AA5154C, AA5254, AA5354, AA5454, AA5554, AA5654, AA5654A,

AA5754, AA5854, AA5954, AA5056, AA5356, AA5356A, AA5456, AA5456A, AA5456B, AA5556, AA5556A, AA5556B, AA5556C, AA5257, AA5457, AA5557, AA5657, AA5058, AA5059, AA5070, AA5180, AA5180A, AA5082, AA5182, AA5083, AA5183, AA5183A, AA5283, AA5283A, AA5283B, AA5383, AA5483, AA5086, AA5186, AA5087, AA5187, and AA5088.

[0054] Non-limiting exemplary 6xxx series aluminum alloys can include AA6101, AA6101A, AA6101B, AA6201, AA6201A, AA6401, AA6501, AA6002, AA6003, AA6103, AA6005, AA6005A, AA6005B, AA6005C, AA6105, AA6205, AA6305, AA6006, AA6106, AA6206, AA6306, AA6008, AA6009, AA6010, AA6110, AA6110A, AA6011, AA6111, AA6012, AA6012A, AA6013, AA6113, AA6014, AA6015, AA6016, AA6016A, AA6116, AA6018, AA6019, AA6020, AA6021, AA6022, AA6023, AA6024, AA6025, AA6026, AA6027, AA6028, AA6031, AA6032, AA6033, AA6040, AA6041, AA6042, AA6043, AA6151, AA6351, AA6351A, AA6451, AA6951, AA6053, AA6055, AA6056, AA6156, AA6060, AA6160, AA6260, AA6360, AA6460, AA6460B, AA6560, AA6660, AA6061, AA6061A, AA6261, AA6361, AA6162, AA6262, AA6262A, AA6063, AA6063A, AA6463, AA6463A, AA6763, AA6963, AA6064, AA6064A, AA6065, AA6066, AA6068, AA6069, AA6070, AA6081, AA6181, AA6181A, AA6082, AA6082A, AA6182, AA6091, and AA6092.

[0055] Non-limiting exemplary 7xxx series aluminum alloys can include AA7011, AA7019, AA7020, AA7021, AA7039, AA7072, AA7075, AA7085, AA7108, AA7108A, AA7015, AA7017, AA7018, AA7019A, AA7024, AA7025, AA7028, AA7030, AA7031, AA7033, AA7035, AA7035A, AA7046, AA7046A, AA7003, AA7004, AA7005, AA7009, AA7010, AA7011, AA7012, AA7014, AA7016, AA7116, AA7122, AA7023, AA7026, AA7029, AA7129, AA7229, AA7032, AA7033, AA7034, AA7036, AA7136, AA7037, AA7040, AA7140, AA7041, AA7049, AA7049A, AA7149, AA7204, AA7249, AA7349, AA7449, AA7050, AA7050A, AA7150, AA7250, AA7055, AA7155, AA7255, AA7056, AA7060, AA7064, AA7065, AA7068, AA7168, AA7175, AA7475, AA7076, AA7178, AA7278, AA7278A, AA7081, AA7181, AA7185, AA7090, AA7093, AA7095, and AA7099.

[0056] Non-limiting exemplary 8xxx series aluminum alloys can include AA8005, AA8006, AA8007, AA8008, AA8010, AA8011, AA8011A, AA8111, AA8211, AA8112, AA8014, AA8015, AA8016, AA8017, AA8018, AA8019, AA8021, AA8021A, AA8021B, AA8022, AA8023, AA8024, AA8025, AA8026, AA8030, AA8130, AA8040, AA8050, AA8150, AA8076, AA8076A, AA8176, AA8077, AA8177, AA8079, AA8090, AA8091, and AA8093.

[0057] The thickness of the core layer may be from about 30 % to about 99 % of the thickness of the clad aluminum alloy products described herein, e.g., from about 40 % to 99 %, from about 50 % to 99 %, from about 55 % to 99 %, from about 60 % to 98 %, from about 70 % to 98 %, from about 75 % to 95 %, or from about 80 % to 90 %. For example, in a clad aluminum alloy product having a thickness of about 1000 microns, the core layer may have a thickness of about 300 microns to about 990 microns. Optionally, the core layer may have a thickness in the range of about 0.1 mm to about 5 mm (e.g., about 0.5 mm to about 3 mm, from about 0.7 mm to about 2.5 mm, or about 0.8 mm to about 2 mm). For example, the thickness of the core layer can be about 0.5 mm, about 0.6 mm, about 0.7 mm, about 0.8 mm, about 0.9 mm, about 1.0 mm, about 1.1 mm, about 1.2 mm, about 1.3 mm, about 1.4 mm, about 1.5 mm, about 1.6 mm, about 1.7 mm, about 1.8 mm, about 1.9 mm, about 2.0 mm, about 2.1 mm, about 2.2 mm, about 2.3 mm, about 2.4 mm, about 2.5 mm, about 2.6 mm, about 2.7 mm, about 2.8 mm, about 2.9 mm, or about 3.0 mm.

[0058] The thickness of each clad layer may be from about 1 % to about 25 % of the total thickness of the clad aluminum alloy products described herein (e.g., from about 1 % to about 12 %, or about 10 %). For example, in an aluminum alloy product having a thickness of 1000 microns, each clad layer can have a thickness of about 10 microns to about 250 microns. Optionally, each clad layer can have a thickness in the range of about 0.05 mm to about 0.80 mm (e.g., about 0.10 mm to about 0.80 mm, about 0.10 mm to about 0.60 mm, or about 0.20 mm to about 0.50 mm).

[0059] The clad aluminum alloy products may contain one clad layer or more than one clad layer. In some cases, the clad aluminum alloy products contain only a first clad layer. In some cases, the clad aluminum alloy products contain a first clad layer and a second clad layer. In some cases, the first clad layer and the second clad layer are identical in composition. In other cases, the first clad layer and the second clad layer differ in composition.

[0060] In embodiments where both metal products of the at least two metal products are not the improved aluminum alloy, the other metal product may include a different aluminum alloy, such as a 1xxx series aluminum alloy, a 2xxx series aluminum alloy, a 3xxx series aluminum alloy, a 4xxx series aluminum alloy, a 5xxx series aluminum alloy, a 6xxx series aluminum alloy, a 7xxx series aluminum alloy, or an 8xxx series aluminum alloy. In these embodiments, the other metal product may be a monolithic metal product, clad metal product, and/or other metal product as desired.

[0061] FIG. 1 illustrates an example of a laser welding system 10 for joining at least two metal products 12, 14 according to embodiments, of which at least one of the at least two metal products (e.g., the metal product 12) includes the improved aluminum alloy. In some cases, both the two metal products 12, 14 included the improved aluminum alloy.

[0062] The at least two metal products 12, 14 may be various metal products as desired. As non-limiting examples, the metal products 12, 14 may be a sheet, a plate, a shate, an automotive structural part, an automotive non-structural part, an aerospace structural part, an aerospace non-structural part, a marine structural part, a marine non-structural part, combinations thereof, and/or products with other shapes or profiles as desired. As such, the shape and configuration of the at least two metal products 12, 14 should not be considered limiting.

[0063] The metal product 12 may include a first side 22, a second side 24, and at least one edge 26. Similarly, the metal product 14 may include a first side 28, a second side 30, and at least one edge 32. The metal products 12, 14 may be arranged in various configurations relative to each other within the laser welding system 10 during a laser welding operation. As a non-limiting example, FIG. 1 illustrates the metal products 12, 14 in a vertically overlapping configuration such that the second side 24 of the metal product 12 faces the first side 28 of the metal product 14; however, in other embodiments, the metal products 12, 14 may be arranged such that the second side 30 faces the first side 22, such that the second side 24 faces the second side 30, such that the first side 22 faces the first side 28, in an end-to-end configuration and/or other configuration as desired.

[0064] In certain embodiments, the at least one metal product 12, 14 with the improved aluminum alloy may allow for laser welding and/or formation of a weld 34 at a reduced distance 36 from the edge 26 (and/or the edge 32 if the welding region is on the metal product 14). As discussed in greater detail below with reference to FIGS. 2 and 3, the reduced distance 36 may include both a reduced distance for any weld formation as well as a reduced critical edge distance. As mentioned, the critical edge distance is the minimum distance between an edge of the metal product (e.g., the edge 26 of the metal product 12) and the weld 34 without the occurrence of centerline cracks.

[0065] The laser welding system 10 generally includes a laser tool 16 for generating a laser beam 18. When the metal products 12, 14 are arranged in the laser welding system 10, a welding region 20 may be defined on one or more sides of the metal products 12, 14 that is most proximate to the laser tool 16. In the embodiment illustrated in FIG. 1, the welding region 20 is defined on the first side 22. During a laser welding process, the laser tool 16 may direct

the laser beam 18 to the welding region 20 to form the weld 34 that joins the metal products 12, 14. In certain embodiments, the laser tool 16 may traverse the welding region 20 via movement of the laser tool 16, movement of the metal products 12, 14 relative to the laser tool 16, or both types of movement. Various aspects of the laser welding system 10 may be controlled during a laser welding operation, such as but not limited to an angle of the laser beam 18, movement of the laser beam 18 along the weld region 20, an intensity of the laser beam 18, a number of laser beams 18, a location of the weld region 20, combinations thereof, and/or other characteristics as desired.

[0066] FIGS. 2 and 3 are graphs illustrating the improved weldability and resistance to cracking during laser welding of metal products with the improved aluminum alloy (represented by evenly dotted lines 201, 301) compared to traditional aluminum alloys. The improved aluminum alloy may have an improved resistance to cracking during laser welding (similar to current 5xxx series aluminum alloys and unlike current 6xxx series aluminum alloys) while exhibiting high formability and age hardening (similar to current 6xxx series aluminum alloys and unlike current 5xxx series aluminum alloys).

[0067] In FIGS. 2 and 3, the evenly dotted lines 201, 301 represent weld formation in five samples of a metal product with the improved aluminum alloy, the solid lines 203, 303 represent weld formation in five samples of a metal product formed with a 6016 aluminum alloy, the evenly dashed lines 205, 305 represent weld formation in five samples of a metal product with a 6014 aluminum alloy, and the dash-dot lines 207, 307 represent weld formation in five samples of a metal product with a 5182 aluminum alloy. In these examples, other than the different aluminum alloys, the laser welding on the metal products was the same and was performed without filler wire.

[0068] FIG. 2 is a graph illustrating ratios of samples welds with centerline cracks and illustrates a minimum distance at which crack-free welding was obtained for each aluminum alloy as well as the critical edge distance for each aluminum alloy. As illustrated by the line 201 (the improved aluminum alloy), crack-free welding was achieved in the metal product with the improved aluminum alloy at a distance of 2 mm from the edge of the metal product, and the critical edge distance was 5 mm from the edge of the metal product. As illustrated by the line 203 (the comparative 6016 aluminum alloy), crack-free welding was achieved in the metal product with the comparative 6016 aluminum alloy at a distance of 3 mm from the edge of the metal product, and the critical edge distance was 7 mm from the edge of the metal product. As illustrated by the line 205 (the 6014 comparative aluminum alloy), crack-free welding was

achieved in the metal product with the comparative 6014 aluminum alloy at a distance of 3 mm from the edge of the metal product, and the critical edge distance was 6 mm from the edge of the metal product. As illustrated by the line 207 (the 5182 aluminum alloy), crack-free welding was achieved in the metal product with the comparative 5182 aluminum alloy at a distance of 2 mm from the edge of the metal product, and the critical edge distance was 5 mm from the edge of the metal product. As illustrated by these results, the improved aluminum alloy and the comparative 5182 aluminum alloy had similar results - crack-free welding was achieved closer to the edge with the comparative 5182 aluminum alloy as well as the improved aluminum alloy compared to the comparative 6014 aluminum alloy and the comparative 6016 aluminum alloy, and the critical edge distance of the comparative 5182 aluminum alloy and the improved aluminum alloy was less than that of the comparative 6014 aluminum alloy and the comparative 6016 aluminum alloy.

[0069] FIG. 3 is a graph illustrating an amount of transverse cracks per millimeter. In this example, a transverse crack was a crack in the weld that was greater than or equal to 0.5 mm. As illustrated by comparing lines 301 (the improved aluminum alloy), 303 (the comparative 6016 aluminum alloy), 305 (the comparative 6014 aluminum alloy), and 307 (the comparative 5182 aluminum alloy), the metal product with the improved aluminum alloy (line 301) had the least amount of transverse cracks both at a minimum distance from the edge of the metal product (2 mm) as well as at locations farther from the edge. The metal product with the comparative 5182 aluminum alloy (line 307) had the next fewest number of transverse cracks at a minimum distance from the edge of the metal product (2 mm) and locations farther from the edge. The metal product with the comparative 6016 aluminum alloy (line 303) had more transverse cracks at a greater minimum distance from the edge (3 mm), and the metal product with the comparative 6014 aluminum alloy (line 305) generally had the most transverse cracks and at a greater minimum distance from the edge (3 mm).

[0070] As collectively illustrated by FIGS. 2 and 3, the metal product with the improved aluminum alloy behaved similar to the comparative 5182 aluminum alloy in terms of hot cracking during laser welding. The metal product with the improved aluminum alloy had a smaller critical edge distance and less transverse cracks compared to the comparative 6014 aluminum alloy and the comparative 6016 aluminum alloy, thereby illustrating improved weldability of the metal product with the improved aluminum alloy.

Illustrations

[0071] A collection of exemplary embodiments is provided below, including at least some explicitly enumerated as an “Illustration” providing additional description of a variety of example embodiments in accordance with the concepts described herein. These illustrations are not meant to be mutually exclusive, exhaustive, or restrictive; and the disclosure not limited to these example illustrations but rather encompasses all possible modifications and variations within the scope of the issued claims and their equivalents.

[0072] Illustration 1. A method of laser welding metal products, the method comprising: supplying at least two metal products, wherein a first metal product of the at least two metal products comprises an aluminum alloy comprising: from 0.5 wt. % to 1.6 wt. % Mg; from 0.2 wt. % to 0.5 wt. % Si; up to 1.0 wt. % Fe; up to 0.5 wt. % Cu; up to 0.5 wt. % Mn; up to 0.3 wt. % Cr; up to 0.3 wt. % Ti; up to 0.5 wt. % Zn; up to 0.25 wt. % impurities; and Al; and laser welding the at least two metal products.

[0073] Illustration 2. The method of any preceding or subsequent illustration or combination of illustrations, wherein laser welding the at least two metal products is without filler wire.

[0074] Illustration 3. The method of any preceding or subsequent illustration or combination of illustrations, wherein laser welding comprises remote laser welding the at least two metal products while the at least two metal products are in an end-to-end configuration or a vertically overlapping configuration.

[0075] Illustration 4. The method of any preceding or subsequent illustration or combination of illustrations, wherein laser welding comprises forming a weld in the first metal product at a distance of about 2 mm from an edge of the first metal product.

[0076] Illustration 5. The method of any preceding or subsequent illustration or combination of illustrations, wherein laser welding comprises forming a weld in the first metal product at a centerline crack critical edge distance, which is a minimum distance between an edge of the first metal product and the weld without the occurrence of centerline cracks in the weld, wherein the centerline crack critical edge distance is about 5 mm from the edge of the first metal product.

[0077] Illustration 6. The method of any preceding or subsequent illustration or combination of illustrations, wherein a second metal product of the at least two metal products comprises an aluminum alloy.

[0078] Illustration 7. The method of any preceding or subsequent illustration or combination of illustrations, wherein the aluminum alloy of the second metal product is different from the aluminum alloy of the first metal product.

[0079] Illustration 8. The method of any preceding or subsequent illustration or combination of illustrations, wherein the second metal product comprises a 1xxx series aluminum alloy, a 2xxx series aluminum alloy, a 3xxx series aluminum alloy, a 4xxx series aluminum alloy, a 5xxx series aluminum alloy, a 6xxx series aluminum alloy, a 7xxx series aluminum alloy, or an 8xxx series aluminum alloy.

[0080] Illustration 9. The method of any preceding or subsequent illustration or combination of illustrations, wherein the Mg and Si are present in the aluminum alloy of the first metal product in a ratio of from 5:1 to 2:1 of Mg to Si by weight.

[0081] Illustration 10. The method of any preceding or subsequent illustration or combination of illustrations, wherein: the amount of Mg in the aluminum alloy of the first metal product is from 1.1 wt. % to 1.5 wt. %; the amount of Si in the aluminum alloy of the first metal product is from 0.25 wt. % to 0.45 wt. %; the amount of Fe in the aluminum alloy of the first metal product is from 0.01 wt. % to 1.0 wt. %; the amount of Cu in the aluminum alloy of the first metal product is from 0.01 wt. % to 0.5 wt. %; the amount of Mn in the aluminum alloy of the first metal product is from 0.01 wt. % to 0.5 wt. %; the amount of Cr in the aluminum alloy of the first metal product is from 0.005 wt. % to 0.3 wt. %; the amount of Ti in the aluminum alloy of the first metal product is from 0.01 wt. % to 0.25 wt. %; the amount of Zn in the aluminum alloy of the first metal product is up to 0.4 wt. %; and the amount of impurities in the aluminum alloy of the first metal product is up to 0.20 wt. %.

[0082] Illustration 11. The method of any preceding or subsequent illustration or combination of illustrations, wherein the aluminum alloy of the first metal product, when in a T8x temper, has a yield strength (Rp0.2) of from 160 MPa to 230 MPa when tested according to ISO 6892-1 (2016).

[0083] Illustration 12. The method of any preceding or subsequent illustration or combination of illustrations, wherein the aluminum alloy of the first metal product has a bake hardening value from 70 MPa to 140 MPa.

[0084] Illustration 13. The method of any preceding or subsequent illustration or combination of illustrations, wherein the aluminum alloy of the first metal product comprises at least 40 wt. % recycled content.

[0085] Illustration 14. The method of any preceding or subsequent illustration or combination of illustrations, wherein the aluminum alloy of the first metal product comprises at least 40 wt. % UBC.

[0086] Illustration 15. The method of any preceding or subsequent illustration or combination of illustrations, wherein the impurities in the aluminum alloy of the first metal product comprise at least one of V, Ni, Sc, Hf, Zr, Sn, Ga, Bi, Na, or Pb.

[0087] Illustration 16. The method of any preceding or subsequent illustration or combination of illustrations, wherein each impurity in the aluminum alloy of the first metal product is present in an amount of less than 0.03 wt. %.

[0088] Illustration 17. The method of any preceding or subsequent illustration or combination of illustrations, wherein the combined concentration of Fe, Mn, and Cu in the aluminum alloy of the first metal product is between 0.7 wt. % and 3.0 wt. %.

[0089] Illustration 18. The method of any preceding or subsequent illustration or combination of illustrations, wherein the first metal product is a clad product, and wherein the aluminum alloy is a core layer in the clad product.

[0090] Illustration 19. The method of any preceding or subsequent illustration or combination of illustrations, wherein the first metal product is a monolithic metal sheet.

[0091] Illustration 20. The method of any preceding or subsequent illustration or combination of illustrations, wherein: the amount of Mg in the aluminum alloy of the first metal product is from 0.6 wt. % to 1.5 wt. %; the amount of Si in the aluminum alloy of the first metal product is from 0.3 wt. % to 0.45 wt. %; the amount of Fe in the aluminum alloy of the first metal product is up to 0.5 wt. %; the amount of Cu in the aluminum alloy of the first metal product is up to 0.4 wt. %; the amount of Mn in the aluminum alloy of the first metal product is up to 0.4 wt. %; the amount of Cr in the aluminum alloy of the first metal product is up to 0.25 wt. %; the amount of Ti in the aluminum alloy of the first metal product is up to 0.15 wt. %; the amount of Zn in the aluminum alloy of the first metal product is up to 0.4 wt. %; and the amount of impurities in the aluminum alloy of the first metal product is up to 0.20 wt. %.

[0092] Illustration 21. A laser-welded component obtained by the method of any preceding or subsequent illustration or combination of illustrations.

[0093] Illustration 22. An automotive component comprising the laser-welded component of any preceding or subsequent illustration or combination of illustrations.

[0094] In this description, reference is made to alloys identified by AA numbers and other related designations, such as “series” or “5xxx.” For an understanding of the number designation system most commonly used in naming and identifying aluminum and its alloys, see “International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys” or “Registration Record of Aluminum Association

Alloy Designations and Chemical Compositions Limits for Aluminum Alloys in the Form of Castings and Ingot,” both published by The Aluminum Association.

[0095] As used herein, a plate generally has a thickness of greater than about 15 mm. For example, a plate may refer to an aluminum product having a thickness of greater than 15 mm, greater than 20 mm, greater than 25 mm, greater than 30 mm, greater than 35 mm, greater than 40 mm, greater than 45 mm, greater than 50 mm, or greater than 100 mm.

[0096] As used herein, a shate (also referred to as a sheet plate) generally has a thickness of from about 4 mm to about 15 mm. For example, a shate may have a thickness of 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm, 11 mm, 12 mm, 13 mm, 14 mm, or 15 mm.

[0097] As used herein, a sheet generally refers to an aluminum product having a thickness of less than about 4 mm. For example, a sheet may have a thickness of less than 4 mm, less than 3 mm, less than 2 mm, less than 1 mm, less than 0.5 mm, less than 0.3 mm, or less than 0.1 mm.

[0098] Reference is made in this application to alloy temper or condition. For an understanding of the alloy temper descriptions most commonly used, see “American National Standards (ANSI) H35 on Alloy and Temper Designation Systems.” An F condition or temper refers to an aluminum alloy as fabricated. A W condition or temper refers to an aluminum alloy solution heat treated at a temperature greater than a solvus temperature of the aluminum alloy and then quenched. An O condition or temper refers to an aluminum alloy after annealing. An Hxx condition or temper, also referred to herein as an H temper, refers to a non-heat treatable aluminum alloy after cold rolling with or without thermal treatment (e.g., annealing). Suitable H tempers include HX1, HX2, HX3 HX4, HX5, HX6, HX7, HX8, or HX9 tempers. A TI condition or temper refers to an aluminum alloy cooled from hot working and naturally aged (e.g., at room temperature). A T2 condition or temper refers to an aluminum alloy cooled from hot working, cold worked, and naturally aged. A T3 condition or temper refers to an aluminum alloy solution heat treated, cold worked, and naturally aged. A T4 condition or temper refers to an aluminum alloy solution heat treated and naturally aged. A T5 condition or temper refers to an aluminum alloy cooled from hot working and artificially aged (at elevated temperatures). A T6 condition or temper refers to an aluminum alloy solution heat treated and artificially aged. A T7 condition or temper refers to an aluminum alloy solution heat treated and artificially overaged. A T8x condition or temper refers to an aluminum alloy solution heat treated, cold worked, and artificially aged. A T9 condition or temper refers to an aluminum alloy solution heat treated, artificially aged, and cold worked.

[0099] All ranges disclosed herein are to be understood to encompass any and all subranges subsumed therein. For example, a stated range of “1 to 10” should be considered to include any and all subranges between (and inclusive of) the minimum value of 1 and the maximum value of 10; that is, all subranges beginning with a minimum value of 1 or more, e.g., 1 to 6.1, and ending with a maximum value of 10 or less, e.g., 5.5 to 10. The term “about” includes the exact value.

[0100] As used herein, the meaning of “a,” “an,” and “the” includes singular and plural references unless the context clearly dictates otherwise.

[0101] As used herein, “clad layer,” “cladding layer,” or “clad aluminum alloy layer” refers to a material that is or will be used as a cladding on a core layer. A “core layer” or “core aluminum alloy layer” refers to the inner material that can be the major component in a clad product (e.g., at least 50 % or more of the clad product). A “clad product” or “clad aluminum alloy product” refers to the combination of at least one clad layer on a core layer.

[0102] As used herein, used beverage cans (UBC) refers to any used beverage can scrap known in the art, for example those described in the Scrap Specifications Circular (2018) published by the Institute of Scrap Recycling Industries, Inc., including shredded aluminum UBC scrap, densified aluminum UBC scrap, baled aluminum UBC scrap, and/or briquetted aluminum UBC scrap.

[0103] Throughout the application, the aluminum alloys and aluminum alloy products and their components are described in terms of their elemental composition in weight percent (wt. %). In some aspects, the remainder for the alloy is aluminum, with a maximum wt. % of 0.50 % for the sum of all impurities (e.g., a maximum of 0.45 wt. %, a maximum of 0.40 wt. %, a maximum of 0.35 wt. %, a maximum of 0.30 wt. %, a maximum of 0.25 wt. %, a maximum of 0.20 wt. %, a maximum of 0.15 wt. %, and/or a maximum of 0.10 wt. %).

[0104] The subject matter of embodiments of the present disclosure is described here with specificity to meet statutory requirements, but this description is not necessarily intended to limit the scope of the claims. The claimed subject matter may be embodied in other ways, may include different elements or steps, and may be used in conjunction with other existing or future technologies. This description should not be interpreted as implying any particular order or arrangement among or between various steps or elements except when the order of individual steps or arrangement of elements is explicitly described. Directional references such as “up,” “down,” “top,” “bottom,” “left,” “right,” “vertical,” “horizontal,” “lateral,” “longitudinal,”

“front,” and “back,” among others, are intended to refer to the orientation as illustrated and described in the figure (or figures) to which the components and directions are referencing.

[0105] The terms “comprising,” “having,” “including,” and “containing” are to be construed as open-ended terms (i.e., meaning “including, but not limited to,”) unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, or gradients thereof, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., “such as”) provided herein, is intended merely to better illuminate embodiments of the invention, and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

[0106] As noted previously, the Mariaux reference is incorporated by reference in its entirety.

[0107] The above-described aspects are merely possible examples of implementations, merely set forth for a clear understanding of the principles of the present disclosure. Many variations and modifications can be made to the above-described embodiment(s) without departing substantially from the spirit and principles of the present disclosure. All such modifications and variations are intended to be included herein within the scope of the present disclosure, and all possible claims to individual aspects or combinations of elements or steps are intended to be supported by the present disclosure. Moreover, although specific terms are employed herein, as well as in the claims that follow, they are used only in a generic and descriptive sense, and not for the purposes of limiting the described embodiments, nor the claims that follow.

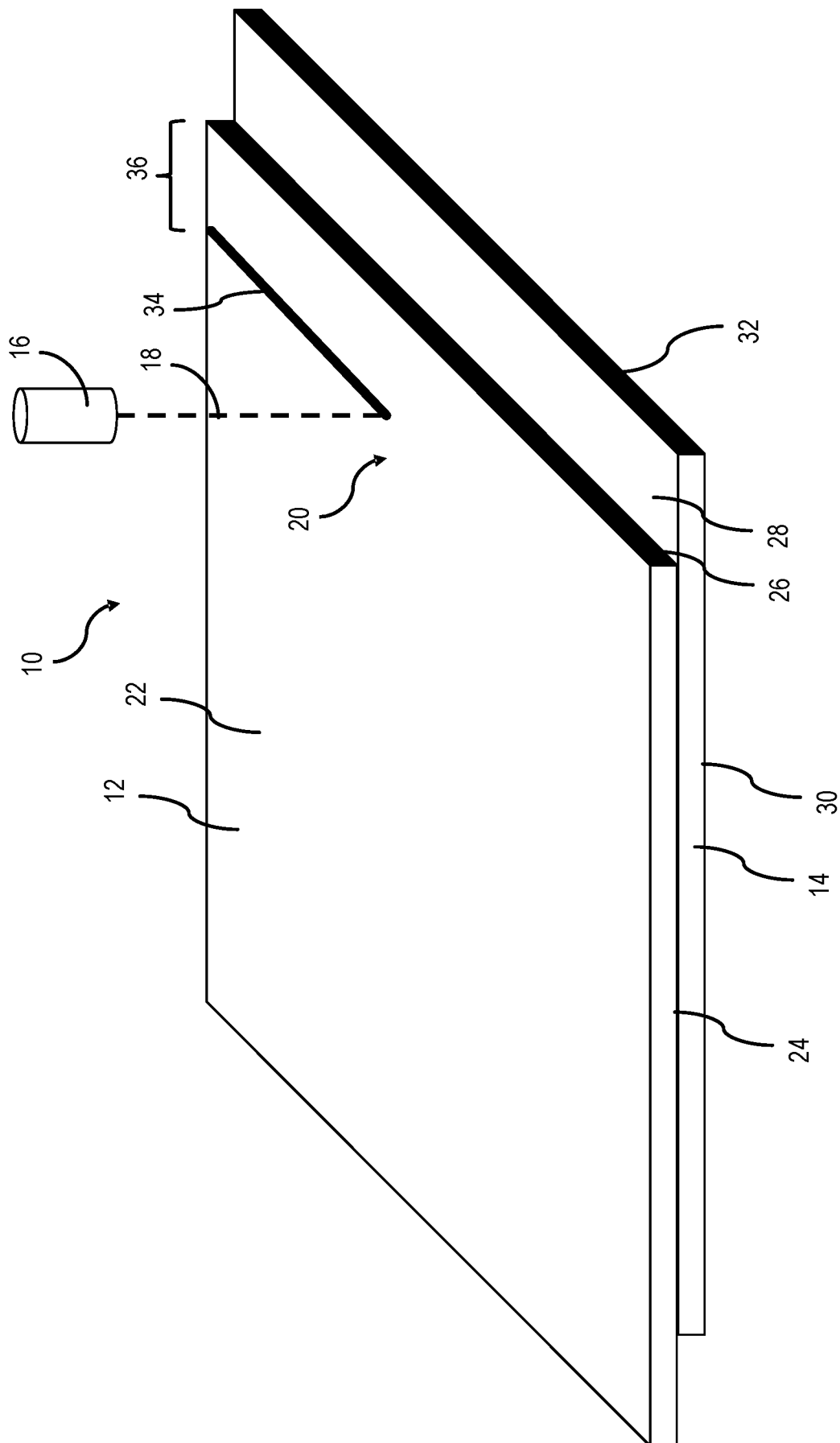
CLAIMS

That which is claimed:

1. A method of laser welding metal products, the method comprising:
supplying at least two metal products, wherein a first metal product of the at least two metal products comprises an aluminum alloy comprising:
from 0.5 wt. % to 1.6 wt. % Mg;
from 0.2 wt. % to 0.5 wt. % Si;
up to 1.0 wt. % Fe;
up to 0.5 wt. % Cu;
up to 0.5 wt. % Mn;
up to 0.3 wt. % Cr;
up to 0.3 wt. % Ti;
up to 0.5 wt. % Zn;
up to 0.25 wt. % impurities; and
Al; and
laser welding the at least two metal products.
2. The method of claim 1, wherein laser welding the at least two metal products is without filler wire.
3. The method of claim 1, wherein laser welding comprises remote laser welding the at least two metal products while the at least two metal products are in an end-to-end configuration or a vertically overlapping configuration.
4. The method of claim 1, wherein laser welding comprises forming a weld in the first metal product at a distance of about 2 mm from an edge of the first metal product.
5. The method of claim 1, wherein laser welding comprises forming a weld in the first metal product at a centerline crack critical edge distance, which is a minimum distance between an edge of the first metal product and the weld without the occurrence of centerline cracks in the weld, wherein the centerline crack critical edge distance is about 5 mm from the edge of the first metal product.

6. The method of claim 1, wherein a second metal product of the at least two metal products comprises an aluminum alloy.
7. The method of claim 6, wherein the aluminum alloy of the second metal product is different from the aluminum alloy of the first metal product.
8. The method of claim 6, wherein the second metal product comprises a 1xxx series aluminum alloy, a 2xxx series aluminum alloy, a 3xxx series aluminum alloy, a 4xxx series aluminum alloy, a 5xxx series aluminum alloy, a 6xxx series aluminum alloy, a 7xxx series aluminum alloy, or an 8xxx series aluminum alloy.
9. The method of claim 1, wherein:
 - the amount of Mg in the aluminum alloy of the first metal product is from 0.6 wt. % to 1.5 wt. %;
 - the amount of Si in the aluminum alloy of the first metal product is from 0.3 wt. % to 0.45 wt. %;
 - the amount of Fe in the aluminum alloy of the first metal product is up to 0.5 wt. %;
 - the amount of Cu in the aluminum alloy of the first metal product is up to 0.4 wt. %;
 - the amount of Mn in the aluminum alloy of the first metal product is up to 0.4 wt. %;
 - the amount of Cr in the aluminum alloy of the first metal product is up to 0.25 wt. %;
 - the amount of Ti in the aluminum alloy of the first metal product is up to 0.15 wt. %;
 - the amount of Zn in the aluminum alloy of the first metal product is up to 0.4 wt. %;
 - and
 - the amount of impurities in the aluminum alloy of the first metal product is up to 0.20 wt. %.
10. The method of claim 1, wherein the Mg and Si are present in the aluminum alloy of the first metal product in a ratio of from 5:1 to 2:1 of Mg to Si by weight.
11. The method of claim 1, wherein the aluminum alloy of the first metal product, when in a T8x temper, has a yield strength (Rp0.2) of from 160 MPa to 230 MPa when tested according to ISO 6892-1 (2016).

12. The method of claim 1, wherein the aluminum alloy of the first metal product has a bake hardening value from 70 MPa to 140 MPa.
13. The method of claim 1, wherein the aluminum alloy of the first metal product comprises at least 40 wt. % recycled content.
14. The method of claim 1, wherein the aluminum alloy of the first metal product comprises at least 40 wt. % UBC.
15. The method of claim 1, wherein the impurities in the aluminum alloy of the first metal product comprise at least one of V, Ni, Sc, Hf, Zr, Sn, Ga, Bi, Na, or Pb.
16. The method of claim 1, wherein each impurity in the aluminum alloy of the first metal product is present in an amount of less than 0.03 wt. %.
17. The method of claim 1, wherein the combined concentration of Fe, Mn, and Cu in the aluminum alloy of the first metal product is between 0.7 wt. % and 3.0 wt. %.
18. The method of claim 1, wherein the first metal product is a clad product, and wherein the aluminum alloy is a core layer in the clad product.
19. The method of claim 1, wherein the first metal product is a monolithic metal sheet.
20. The method of claim 1, wherein:
 - the amount of Mg in the aluminum alloy of the first metal product is from 1.1 wt. % to 1.5 wt. %;
 - the amount of Si in the aluminum alloy of the first metal product is from 0.25 wt. % to 0.45 wt. %;
 - the amount of Fe in the aluminum alloy of the first metal product is from 0.01 wt. % to 1.0 wt. %;
 - the amount of Cu in the aluminum alloy of the first metal product is from 0.01 wt. % to 0.5 wt. %;



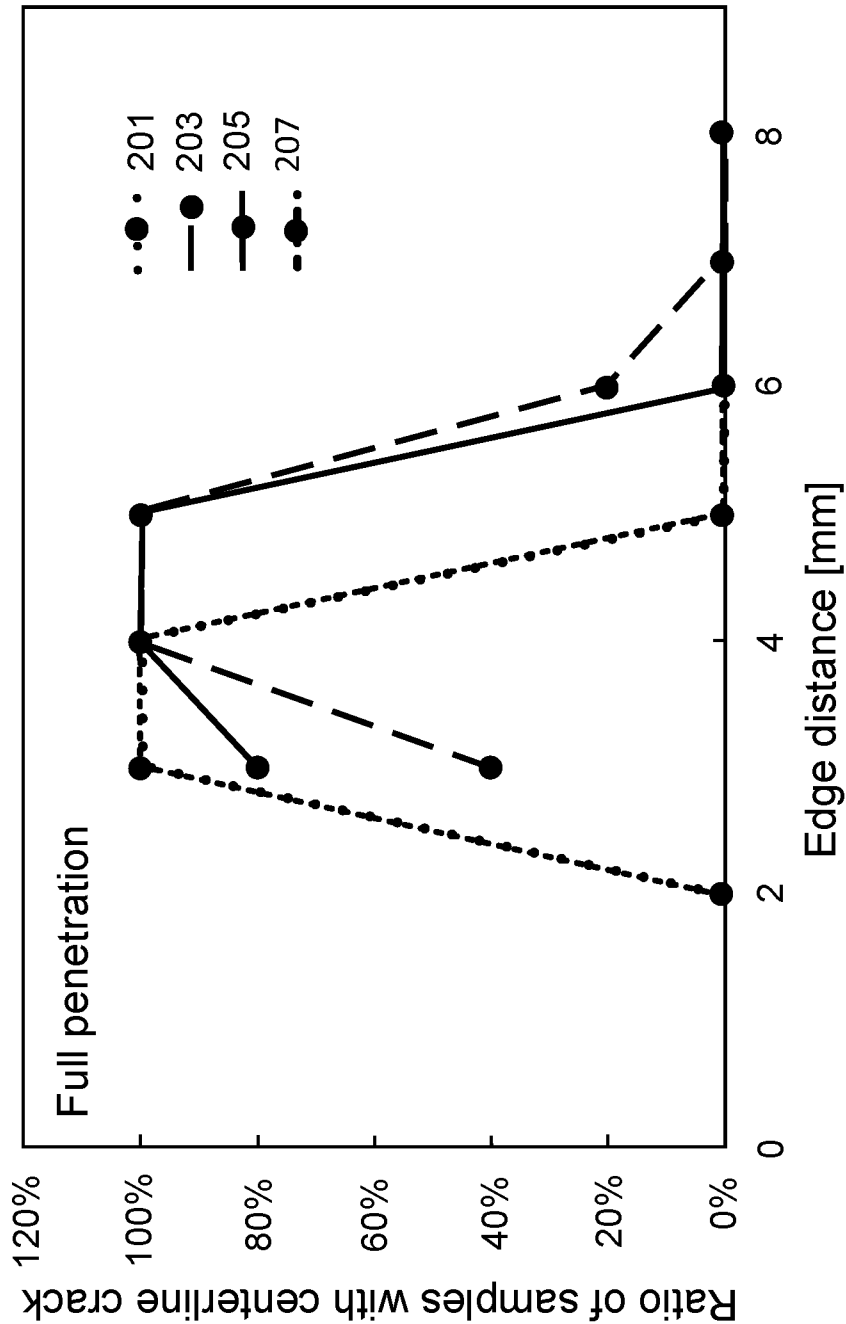


FIG. 2

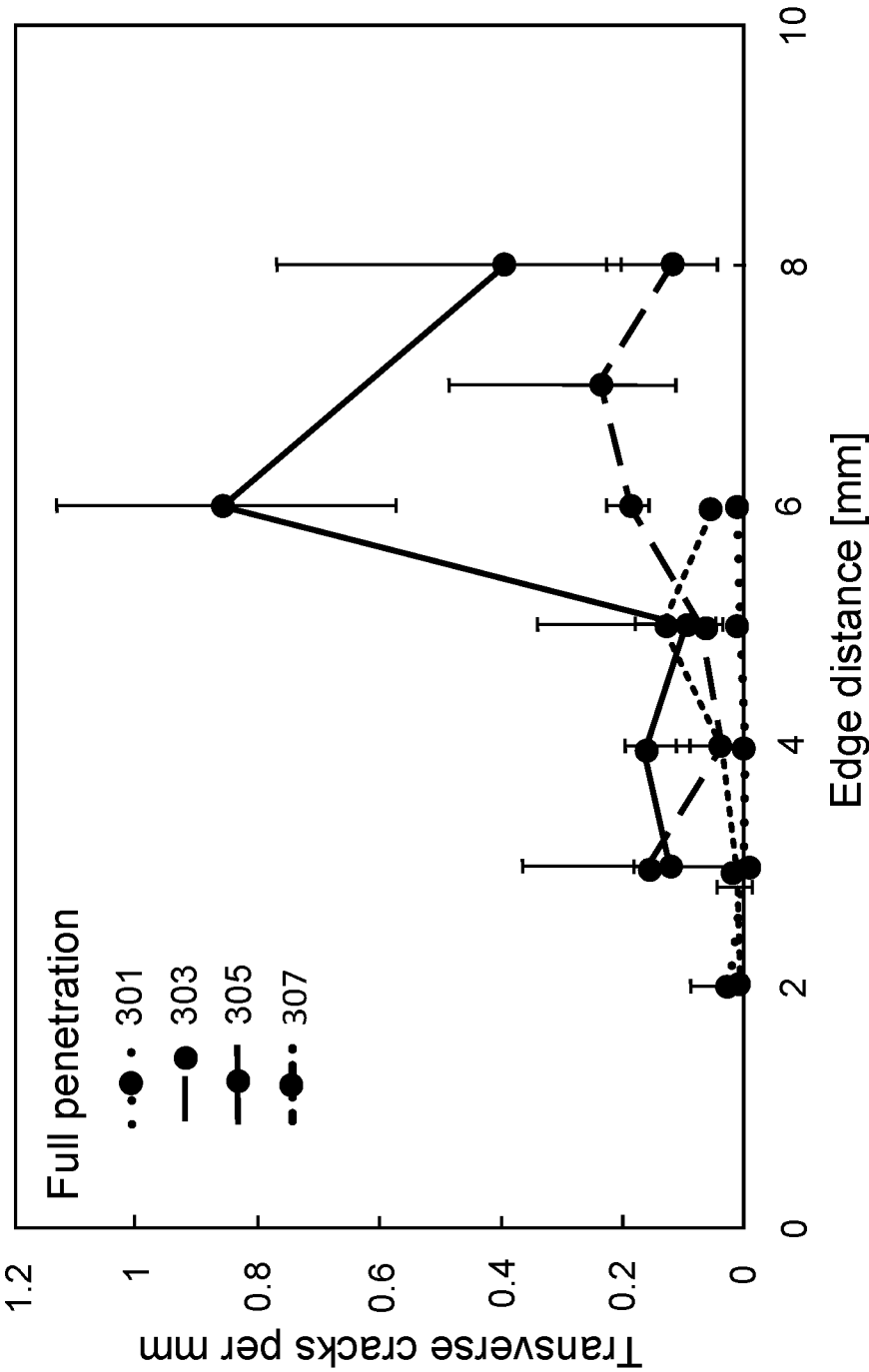


FIG. 3

INV. B23K35/28	C22C21/08	B23K103/10
ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) B23K C22C		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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☐ 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 October 2024		Date of mailing of the international search report 04/11/2024
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Mikloweit, Alexander

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