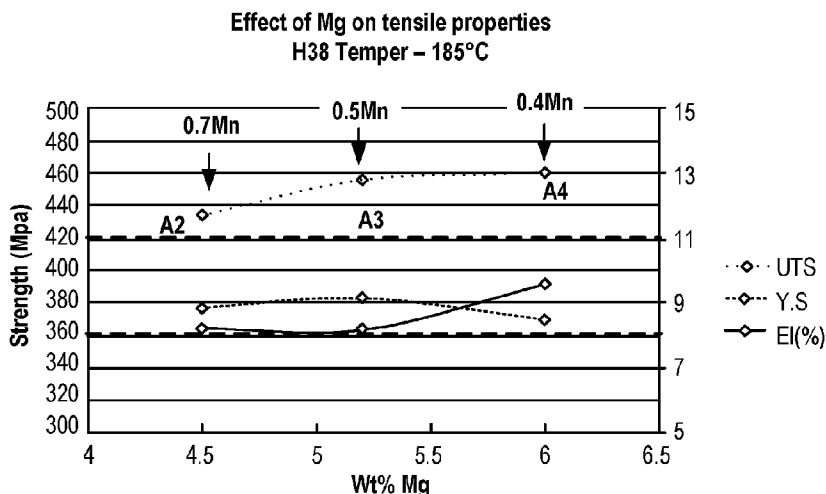




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(54) Title: HIGH STRENGTH 5XXX ALUMINUM ALLOYS AND METHODS OF MAKING THE SAME



(57) **Abrégé/Abstract:**

Described herein are aluminum-containing alloys. In an embodiment, an aluminum alloy comprises 0.05 - 0.30 wt. % Si, 0.08 - 0.50 wt. % Fe, 0 - 0.60 wt. % Cu, 0.31 - 0.60 wt. % Mn, 5.0- 7.0 wt. % Mg, 0 - 0.25 wt. % Cr, 0 - 0.20 wt. % Zn, 0 - 0.15 wt. % Ti, and up to 0.15 wt. % of impurities, with the remainder as Al, wherein the aluminum alloy, when in an H-temper, has an ultimate tensile strength greater than 420 Mpa. The alloys are highly formable, exhibit high strength and corrosion resistance, and are recyclable. The alloys can be used in electronics, transportation, industrial, and automotive applications, just to name a few. Also described herein are methods for producing metal ingots and products obtained by the methods.

ABSTRACT

Described herein are aluminum-containing alloys. In an embodiment, an aluminum alloy comprises 0.05 – 0.30 wt. % Si, 0.08 – 0.50 wt. % Fe, 0 – 0.60 wt. % Cu, 0.31 – 0.60 wt. % Mn, 5.0– 7.0 wt. % Mg, 0 – 0.25 wt. % Cr, 0 – 0.20 wt. % Zn, 0 – 0.15 wt. % Ti, and up to 0.15
5 wt. % of impurities, with the remainder as Al, wherein the aluminum alloy, when in an H-temper, has an ultimate tensile strength greater than 420 Mpa. The alloys are highly formable, exhibit high strength and corrosion resistance, and are recyclable. The alloys can be used in electronics, transportation, industrial, and automotive applications, just to name a few. Also described herein are methods for producing metal ingots and products obtained by the methods.

HIGH STRENGTH 5XXX ALUMINUM ALLOYS AND METHODS OF MAKING THE SAME

5

FIELD

Provided herein are aluminum alloy compositions and methods of making and
10 processing the same. In some cases, the alloys described herein exhibit high formability, high
strength, and corrosion resistance. The alloys described herein are also highly recyclable. The
alloys described herein can be used in electronics, transportation, industrial, automotive and
other applications.

15

BACKGROUND

Recyclable aluminum alloys that can be used in multiple applications, including
electronics and transportation applications, are desirable. Such alloys should exhibit high
strength, high formability, and corrosion resistance. However, producing such alloys has proven
to be a challenge, as hot rolling of compositions with the potential of exhibiting the desired
20 properties often results in edge cracking issues and the propensity for hot tearing.

SUMMARY

Provided herein are aluminum-containing 5XXX series alloys. The alloys exhibit
high strength, high formability, and corrosion resistance. The alloys can be used in electronics,
25 transportation, industrial, and automotive applications, just to name a few. The aluminum alloys
described herein comprise about 0.05 – 0.30 wt. % Si, 0.08 – 0.50 wt. % Fe, 0 – 0.60 wt. % Cu,
0 – 0.60 wt. % Mn, 4.0 – 7.0 wt. % Mg, 0 – 0.25 wt. % Cr, 0 – 0.20 wt. % Zn, 0 – 0.15 wt. % Ti,
and up to 0.15 wt. % of impurities, with the remainder as Al. Throughout this application, all
elements are described in weight percentage (wt. %) based on the total weight of the alloy. In
30 some examples, the aluminum alloy comprises about 0.05 – 0.30 wt. % Si, 0.1 – 0.50 wt. % Fe, 0
– 0.60 wt. % Cu, 0.10 – 0.60 wt. % Mn, 4.5 – 7.0 wt. % Mg, 0 – 0.25 wt. % Cr, 0 – 0.20 wt. %
Zn, 0 – 0.15 wt. % Ti, and up to 0.15 wt. % of impurities, with the remainder as Al. In some
examples, the aluminum alloy comprises about 0.10 – 0.20 wt. % Si, 0.20 – 0.35 wt. % Fe, 0.01
– 0.25 wt. % Cu, 0.20 – 0.55 wt. % Mn, 5.0 – 6.5 wt. % Mg, 0.01 – 0.25 wt. % Cr, 0.01 – 0.20

wt. % Zn, 0 – 0.1 wt. % Ti, and up to 0.15 wt. % of impurities, with the remainder as Al. In some examples, the aluminum alloy comprises about 0.10 – 0.15 wt. % Si, 0.20 – 0.35 wt. % Fe, 0.1 – 0.25 wt. % Cu, 0.20 – 0.50 wt. % Mn, 5.0 – 6.0 wt. % Mg, 0.05 – 0.20 wt. % Cr, 0.01 – 0.20 wt. % Zn, 0 – 0.05 wt. % Ti, and up to 0.15 wt. % of impurities, with the remainder as Al.

5 Optionally, the aluminum alloy comprises about 0.05 – 0.15 wt. % Si, 0.09 – 0.15 wt. % Fe, 0 – 0.05 wt. % Cu, 0 – 0.10 wt. % Mn, 4.0– 5.5 wt. % Mg, 0 – 0.20 wt. % Cr, 0 – 0.05 wt. % Zn, 0 – 0.05 wt. % Ti, and up to 0.15 wt. % of impurities, with the remainder as Al. The alloy can include α -AlFeMnSi particles. The alloy can be produced by casting (e.g., direct casting or continuous casting), homogenization, hot rolling, cold rolling, and annealing. Also provided

10 herein are products comprising the aluminum alloy as described herein. The products can include, but are not limited to, automotive body parts (e.g., inner panels), electronic device housings (e.g., outer casings of mobile phones and tablet bottom chassis), and transportation body parts.

Further provided herein are methods of processing an aluminum ingot or of producing a

15 metal product. The methods include the steps of casting an aluminum alloy as described herein to form an ingot; homogenizing the ingot to form a plurality of α -AlFeMnSi particles in the ingot; cooling the ingot to a temperature of 450 °C or less; hot rolling the ingot to produce a rolled product; optionally cold rolling the rolled product to an intermediate gauge; allowing the rolled product to self-anneal; and cold rolling the rolled product to a final gauge. Products (e.g.,

20 automotive body parts, electronic device housings, and transportation body parts) obtained according to the methods are also provided herein.

Other objects and advantages of the invention will be apparent from the following detailed description of non-limiting examples of the invention.

25 BRIEF DESCRIPTION OF THE FIGURES

Figure 1 is a flowchart depicting processing routes for making the alloys described herein.

Figure 2A is a graph showing the tensile strength for the prototype alloys described herein and for the comparison alloy. Figure 2B is a graph showing the yield strength for the

30 prototype alloys described herein and for the comparison alloy. Figure 2C is a graph showing the percent elongation for the prototype alloys described herein and for the comparison alloy. In Figures 2A, 2B, and 2C, “B” represents comparison alloy K5182 and “A1,” “A2,” “A3,” and “A4” represent the prototype alloys.

Figure 3A is a graph showing the effect of Mg on tensile properties with Alloys A2 (4.5 wt. % Mg), A3 (5.2 wt. % Mg), and A4 (6.0 wt. % Mg) in their O-tempered conditions prior to testing. Figure 3B is a graph showing the effect of Mg on tensile properties with Alloys A2, A3, and A4 in their H38-tempered conditions, where the stabilization was performed at 135 °C, prior to testing. Figure 3C is a graph showing the effect of Mg on tensile properties with Alloys A2, A3, and A4 in their H38-tempered conditions, where the stabilization was performed at 185 °C, prior to testing.

Figure 4 is a picture of exemplary alloys assigned a ranking value based on the surface appearance.

Figure 5 is a graph showing the amount of weight loss that occurs after stabilizing the samples at 135 °C (left bar for each sample), 185 °C (middle bar for each sample), and 350 °C (right bar for each sample) for Alloys K5182 (represented as “B”) and Alloys A1, A2, A3, and A4 and Alloy G.

Figure 6A is a picture of the Alloy G material after stabilization at a temperature range of from 100 – 130 °C. Figure 6B is a picture of Alloy A4 after stabilization at 135 °C.

Figure 7 is a group of pictures showing the effects of stabilization at 135 °C, stabilization at 185 °C, and full anneal at 350 °C on the microstructures for Alloys A1, A3, and A4.

Figure 8A is a graph of strength versus percentage cold work for Alloy A4 prepared at a stabilization temperature of 135 °C. Figure 8B is a graph of strength versus percentage cold work for Alloy A4 prepared at a stabilization temperature of 185 °C.

Figure 9 is a flowchart depicting processing routes for making the alloys described herein.

Figure 10A is a graph showing the acidic anodizing response of prototype alloy Example 1, comparative alloy AA5052, and comparative alloy AA5182. The graph shows the brightness (represented as “L”; left bar in each set), the white index (represented as “WI”; right bar in each set), and the yellow index (represented as “YI”; diamonds in graph).

Figure 10B is a graph showing the caustic anodizing response of prototype alloy Example 1, comparative alloy AA5052, and comparative alloy AA5182. The graph shows the brightness (represented as “L”; left bar in each set), the white index (represented as “WI”; right bar in each set), and the yellow index (represented as “YI”; diamonds in graph).

Figure 11 is a graph showing the tensile properties for prototype alloy Example 1, AA5052, and AA5182. The graph shows the yield strength (represented as “YS”; left bar in

each set), the ultimate tensile strength (represented as “UTS”; right bar in each set), the uniform elongation (represented as “Uni. El. (%)”; diamonds in graph), and the total elongation (represented as “Total El. (%)”; circles in graph).

5

DETAILED DESCRIPTION

Described herein are 5XXX series aluminum alloys which exhibit high strength and high formability. The alloys described herein are also insensitive to intergranular corrosion and are highly recyclable. In the soft annealed condition, these alloys exhibit high formability which allows for complex geometry applications. Surprisingly, the alloys described herein also exhibit high formability in other tempers as well. The high strength, high formability, and corrosion resistance properties are stable and are maintained throughout the life of any products prepared using the alloys. In other words, little or no ageing occurs during storage, processing, or service.

10

Alloy Composition

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The alloys described herein are aluminum-containing 5XXX series alloys. The alloys exhibit high strength, high formability, and corrosion resistance. The properties of the alloy are achieved due to the elemental composition of the alloy. Specifically, the alloy can have the following elemental composition as provided in Table 1.

Table 1

Element	Weight Percentage (wt. %)
Si	0.05 – 0.30
Fe	0.08 – 0.50
Cu	0 – 0.60
Mn	0 – 0.60
Mg	4.0 – 7.0
Cr	0 – 0.25
Zn	0 – 0.20
Ti	0 – 0.15
Others	0 – 0.05 (each) 0 – 0.15 (total)
Al	Remainder

In some examples, the alloy can have the following elemental composition as provided in Table 2.

Table 2

Element	Weight Percentage (wt. %)
Si	0.10 – 0.20
Fe	0.20 – 0.35
Cu	0.01 – 0.25
Mn	0.2 – 0.55
Mg	5.0 – 6.5
Cr	0.01 – 0.25
Zn	0.01 – 0.20
Ti	0 – 0.1
Others	0 – 0.05 (each) 0 – 0.15 (total)
Al	Remainder

5

In some examples, the alloy can have the following elemental composition as provided in Table 3.

Table 3

Element	Weight Percentage (wt. %)
Si	0.10 – 0.15
Fe	0.20 – 0.35
Cu	0.1 – 0.25
Mn	0.20 – 0.50
Mg	5.0 – 6.0
Cr	0.05 – 0.20
Zn	0.01 – 0.20
Ti	0 – 0.05
Others	0 – 0.05 (each) 0 – 0.15 (total)
Al	Remainder

In some examples, the alloy can have the following elemental composition as provided in Table 4.

Table 4

Element	Weight Percentage (wt. %)
Si	0.05 – 0.15
Fe	0.09 – 0.15
Cu	0 – 0.05
Mn	0 – 0.10
Mg	4.0 – 5.5
Cr	0 – 0.20
Zn	0 – 0.05
Ti	0 – 0.05
Others	0 – 0.05 (each) 0 – 0.15 (total)
Al	Remainder

5

In some examples, the alloy described herein includes silicon (Si) in an amount of from 0.05 % to 0.30 % (e.g., from 0.10 % to 0.20 %, from 0.10 % to 0.15 %, or from 0.05 % to 0.15 %) based on the total weight of the alloy. For example, the alloy can include 0.05 %, 0.06 %, 0.07 %, 0.08 %, 0.09 %, 0.10 %, 0.11 %, 0.12 %, 0.13 %, 0.14 %, 0.15 %, 0.16 %, 0.17 %, 0.18 %, 0.19 %, 0.20 %, 0.21 %, 0.22 %, 0.23 %, 0.24 %, 0.25 %, 0.26 %, 0.27 %, 0.28 %, 0.29 %, or 0.30 % Si. All expressed in wt. %.

In some examples, the alloy described herein also includes iron (Fe) in an amount of from 0.08 % to 0.50 % (e.g., from 0.1 % to 0.50 %, from 0.20 % to 0.35 %, or from 0.09 % to 0.15 %) based on the total weight of the alloy. For example, the alloy can include 0.08 %, 0.09 %, 0.10 %, 0.11 %, 0.12 %, 0.13 %, 0.14 %, 0.15 %, 0.16 %, 0.17 %, 0.18 %, 0.19 %, 0.20 %, 0.21 %, 0.22 %, 0.23 %, 0.24 %, 0.25 %, 0.26 %, 0.27 %, 0.28 %, 0.29 %, 0.30 %, 0.31 %, 0.32 %, 0.33 %, 0.34 %, 0.35 %, 0.36 %, 0.37 %, 0.38 %, 0.39 %, 0.40 %, 0.41 %, 0.42 %, 0.43 %, 0.44 %, 0.45 %, 0.46 %, 0.47 %, 0.48 %, 0.49 %, or 0.50 % Fe. All expressed in wt. %.

In some examples, the alloy described includes copper (Cu) in an amount of up to 0.60 % (e.g., from 0.01 % to 0.25 %, from 0.1 % to 0.25 %, or from 0 % to 0.05 %) based on the total

weight of the alloy. For example, the alloy can include 0.01 %, 0.02 %, 0.03 %, 0.04 %, 0.05 %, 0.06 %, 0.07 %, 0.08 %, 0.09 %, 0.10 %, 0.11 %, 0.12 %, 0.13 %, 0.14 %, 0.15 %, 0.16 %, 0.17 %, 0.18 %, 0.19 %, 0.20 %, 0.21 %, 0.22 %, 0.23 %, 0.24 %, 0.25 %, 0.26 %, 0.27 %, 0.28 %, 0.29 %, 0.30 %, 0.31 %, 0.32 %, 0.33 %, 0.34 %, 0.35 %, 0.36 %, 0.37 %, 0.38 %, 0.39 %, 0.40 %, 0.41 %, 0.42 %, 0.43 %, 0.44 %, 0.45 %, 0.46 %, 0.47 %, 0.48 %, 0.49 %, 0.50 %, 0.51 %, 0.52 %, 0.53 %, 0.54 %, 0.55 %, 0.56 %, 0.57 %, 0.58 %, 0.59 %, or 0.60 % Cu. In some cases, Cu is not present in the alloy (i.e., 0 %). All expressed in wt. %.

In some examples, the alloy described herein can include manganese (Mn) in an amount of up to 0.60 % (e.g., from 0.10 % to 0.60 %, from 0.40 % to 0.55 %, from 0.40 % to 0.50 %, or from 0 % to 0.1 %) based on the total weight of the alloy. For example, the alloy can include 0.01 %, 0.02 %, 0.03 %, 0.04 %, 0.05 %, 0.06 %, 0.07 %, 0.08 %, 0.09 %, 0.10 %, 0.11 %, 0.12 %, 0.13 %, 0.14 %, 0.15 %, 0.16 %, 0.17 %, 0.18 %, 0.19 %, 0.20 %, 0.21 %, 0.22 %, 0.23 %, 0.24 %, 0.25 %, 0.26 %, 0.27 %, 0.28 %, 0.29 %, 0.30 %, 0.31 %, 0.32 %, 0.33 %, 0.34 %, 0.35 %, 0.36 %, 0.37 %, 0.38 %, 0.39 %, 0.40 %, 0.41 %, 0.42 %, 0.43 %, 0.44 %, 0.45 %, 0.46 %, 0.47 %, 0.48 %, 0.49 %, 0.50 %, 0.51 %, 0.52 %, 0.53 %, 0.54 %, 0.55 %, 0.56 %, 0.57 %, 0.58 %, 0.59 %, or 0.60 % Mn. In some cases, Mn is not present in the alloy (i.e., 0 %). All expressed in wt. %. When present, the Mn content results in the precipitation of α -AlFeMnSi particles during homogenization, which can result in additional dispersoid strengthening.

In some examples, the alloy described herein can include magnesium (Mg) in an amount of from 4.0 to 7.0 % (e.g., from 4.5 % to 7.0 %, from 5.0 % to 6.5 %, from 5.0 % to 6.0 %, or from 4.0 % to 5.5 %). In some examples, the alloy can include 4.0 %, 4.1 %, 4.2 %, 4.3 %, 4.4 %, 4.5 %, 4.6 %, 4.7 %, 4.8 %, 4.9 %, 5.0 %, 5.1 %, 5.2 %, 5.3 %, 5.4 %, 5.5 %, 5.6 %, 5.7 %, 5.8 %, 5.9 %, 6.0 %, 6.1 %, 6.2 %, 6.3 %, 6.4 %, 6.5 %, 6.6 %, 6.7 %, 6.8 %, 6.9 %, or 7.0 % Mg. All expressed in wt. %. The inclusion of Mg in the alloys described herein in an amount of from 5.0 to 7.0 % is referred to as a “high Mg content.” Mg can be included in the alloys described herein to serve as a solid solution strengthening element for the alloy. As described further below, and as demonstrated in the Examples, the high Mg content results in the desired strength and formability, without compromising the corrosion resistance of the materials.

In some examples, the alloy described herein includes chromium (Cr) in an amount of up to 0.25 % (e.g., from 0.01 % to 0.25 % or from 0.05 % to 0.20 %) based on the total weight of the alloy. For example, the alloy can include 0.01 %, 0.02 %, 0.03 %, 0.04 %, 0.05 %, 0.06 %, 0.07 %, 0.08 %, 0.09 %, 0.10 %, 0.11 %, 0.12 %, 0.13 %, 0.14 %, 0.15 %, 0.16 %, 0.17 %, 0.18

%, 0.19 %, 0.20 %, 0.21 %, 0.22 %, 0.23 %, 0.24 %, or 0.25 % Cr. In some cases, Cr is not present in the alloy (i.e., 0 %). All expressed in wt. %.

In some examples, the alloy described herein includes zinc (Zn) in an amount of up to 0.20 % (e.g., from 0.01 % to 0.20 % or from 0 % to 0.05 %) based on the total weight of the alloy. For example, the alloy can include 0.01 %, 0.02 %, 0.03 %, 0.04 %, 0.05 %, 0.06 %, 0.07 %, 0.08 %, 0.09 %, 0.10 %, 0.11 %, 0.12 %, 0.13 %, 0.14 %, 0.15 %, 0.16 %, 0.17 %, 0.18 %, 0.19 %, or 0.20 % Zn. In some cases, Zn is not present in the alloy (i.e., 0 %). All expressed in wt. %.

In some examples, the alloy described herein includes titanium (Ti) in an amount of up to 0.15 % (e.g., from 0 % to 0.1 % or from 0 % to 0.05 %) based on the total weight of the alloy. For example, the alloy can include 0.01 %, 0.02 %, 0.03 %, 0.04 %, 0.05 %, 0.06 %, 0.07 %, 0.08 %, 0.09 %, 0.10 %, 0.11 %, 0.12 %, 0.13 %, 0.14 %, or 0.15 % Ti. In some cases, Ti is not present in the alloy (i.e., 0 %). All expressed in wt. %.

Optionally, the alloy compositions described herein can further include other minor elements, sometimes referred to as impurities, in amounts of 0.05% or below, 0.04% or below, 0.03% or below, 0.02% or below, or 0.01% or below each. These impurities may include, but are not limited to, V, Zr, Ni, Sn, Ga, Ca, or combinations thereof. Accordingly, V, Zr, Ni, Sn, Ga, or Ca may be present in alloys in amounts of 0.05% or below, 0.04% or below, 0.03% or below, 0.02% or below, or 0.01% or below. In some cases, the sum of all impurities does not exceed 0.15% (e.g., 0.10%). All expressed in wt. %. The remaining percentage of the alloy is aluminum.

Methods of Making

The alloys described herein can be cast into ingots using a Direct Chill (DC) process or can be cast using a Continuous Casting (CC) process. The casting process is performed according to standards commonly used in the aluminum industry as known to one of skill in the art. The CC process may include, but is not limited to, the use of twin belt casters, twin roll casters, or block casters. In some examples, the casting process is performed by a CC process to form a slab, a strip, or the like. In some examples, the casting process is a DC casting process to form a cast ingot.

The cast ingot, slab, or strip can then be subjected to further processing steps. Optionally, the further processing steps can be used to prepare sheets. Such processing steps include, but are not limited to, a homogenization step, a hot rolling step, an optional first cold

rolling step to produce an intermediate gauge, an annealing step, and a second cold rolling step to a final gauge. The processing steps are described below in relation to a cast ingot. However, the processing steps can also be used for a cast slab or strip, using modifications as known to those of skill in the art.

5 The homogenization is carried out to precipitate α -AlFeMnSi particles. The α -AlFeMnSi particles can result in the formation of dispersoids during subsequent strengthening processes. In the homogenization step, an ingot prepared from the alloy compositions described herein is heated to attain a peak metal temperature of at least 470 °C (e.g., at least 475 °C, at least 480 °C, at least 485 °C, at least 490 °C, at least 495 °C, at least 500 °C, at least 505 °C, at least 510 °C, at least 515 °C, at least 520 °C, at least 525 °C, or at least 530 °C). In some examples, the ingot is heated to a temperature ranging from 500 °C to 535 °C. The heating rate to the peak metal temperature is sufficiently low to allow time for Al_3Mg_8 phase dissolution. For example, the heating rate to the peak metal temperature can be 50 °C/hour or less, 40 °C/hour or less, or 30 °C/hour or less. The ingot is then allowed to soak (i.e., held at the indicated temperature) for a period of time during the first stage. In some cases, the ingot is allowed to soak for up to 5 hours (e.g., from 30 minutes to 5 hours, inclusively). For example, the ingot can be soaked at the temperature of at least 500 °C for 30 minutes, 1 hour, 2 hours, 3 hours, 4 hours, or 5 hours.

 Optionally, the homogenization step described herein can be a two-stage homogenization process. In these cases, the homogenization process can include the above-described heating and soaking steps, which can be referred to as the first stage, and can further include a second stage. In the second stage of the homogenization process, the ingot temperature is increased to a temperature higher than the temperature used for the first stage of the homogenization process. The ingot temperature can be increased, for example, to a temperature at least five degrees Celsius higher than the ingot temperature during the first stage of the homogenization process. For example, the ingot temperature can be increased to a temperature of at least 475 °C (e.g., at least 480 °C, at least 485 °C, at least 490 °C, at least 495 °C, at least 500 °C, at least 505 °C, at least 510 °C, at least 515 °C, at least 520 °C, at least 525 °C, at least 530 °C, or at least 535 °C). The heating rate to the second stage homogenization temperature can be 5 °C/hour or less, 3 °C/hour or less, or 2.5 °C/hour or less. The ingot is then allowed to soak for a period of time during the second stage. In some cases, the ingot is allowed to soak for up to 5 hours (e.g., from 15 minutes to 5 hours, inclusively). For example, the ingot can be soaked at the temperature of

at least 475 °C for 30 minutes, 1 hour, 2 hours, 3 hours, 4 hours, or 5 hours. Following homogenization, the ingot can be allowed to cool to room temperature in the ambient air.

The homogenization step should be performed fully to eliminate low melting constituents and prevent edge cracking. Incomplete homogenization causes massive edge cracks which originate from segregation of Mg_5Al_8 precipitates. Therefore, in some cases, Mg_5Al_8 is minimized or eliminated prior to hot rolling, which can improve fabricability.

Following the homogenization step, a hot rolling step can be performed. To avoid ingot cracking during the hot rolling step, the ingot temperature can be reduced to a temperature lower than the eutectic melting temperature of the Mg_5Al_8 precipitates (i.e., 450 °C). Therefore, prior to the start of hot rolling, the homogenized ingot can be allowed to cool to approximately 450 °C or less. The ingots can then be hot rolled to a 12 mm thick gauge or less. For example, the ingots can be hot rolled to a 10 mm thick gauge or less, 9 mm thick gauge or less, 8 mm thick gauge or less, 7 mm thick gauge or less, 6 mm thick gauge or less, 5 mm thick gauge or less, 4 mm thick gauge or less, 3 mm thick gauge or less, 2 mm thick gauge or less, or 1 mm thick gauge or less. In some examples, the ingots can be hot rolled to a 2.8 mm thick gauge. The hot rolled gauge can then undergo an annealing process at a temperature of from about 300 °C to 450 °C.

Optionally, a cold rolling step can then be performed to result in an intermediate gauge. The rolled gauge can then undergo an annealing process at a temperature of from about 300 °C to about 450 °C, with a soak time of approximately 1 hour and controlled cooling to room temperature at a rate of about 50 °C/hour. Alternatively, a batch annealing process or a continuous annealing process can be performed. Following the annealing process, the rolled gauge can be cold rolled to a final gauge thickness of from 0.2 mm to 7 mm. The cold rolling can be performed to result in a final gauge thickness that represents an overall gauge reduction by 20 %, 50 %, 75 %, or 85 %. In some cases, the resulting sheet can be stabilized by holding the sheet at a temperature of from 100 °C – 250 °C (e.g., 135 °C, 160 °C, 185 °C, or 200 °C) for a period of time from 30 minutes to 2 hours (e.g., 1 hour).

The resulting sheets have the combination of desired properties described herein, including high strength, insensitivity to intergranular corrosion, and high formability under a variety of temper conditions, including O-temper and H3X-temper conditions, where H3X tempers include H32, H34, H36, or H38. Under O-temper conditions, the alloys can exhibit an ultimate tensile strength of greater than 310 MPa, a yield strength of greater than 160 MPa, and a

percent elongation of greater than 22 %. Under H3X-temper conditions, the alloys can exhibit an ultimate tensile strength of greater than 420 MPa, a yield strength of greater than 360 MPa, and a percent elongation of greater than 12 %.

The alloys and methods described herein can be used in automotive, electronics, and transportation applications, among others. In some cases, the alloys can be used in O-temper, H2X, F, T4, T6, and in H3X temper for applications that require alloys with high formability. As mentioned above, the H3X tempers include H32, H34, H36, or H38. In some cases, the alloys are useful in applications where the processing and operating temperature is 150 °C or lower. For example, the alloys and methods described herein can be used to prepare automobile body parts, such as inner panels. The alloys and methods described herein can also be used to prepare housings for electronic devices, including mobile phones and tablet computers. In some cases, the alloys can be used to prepare housings for the outer casing of mobile phones (e.g., smart phones) and tablet bottom chassis.

The following examples will serve to further illustrate the present invention without, at the same time, however, constituting any limitation thereof. On the contrary, it is to be clearly understood that resort may be had to various embodiments, modifications and equivalents thereof which, after reading the description herein, may suggest themselves to those of ordinary skill in the art without departing from the spirit of the invention.

Example 1

Alloys were prepared as described herein with or without the optional cold rolling to intermediate gauge step (see Figure 1). Specifically, the ingots were preheated from room temperature to 525 °C and allowed to soak for three hours. In the processing route without the optional cold rolling to intermediate gauge step, the ingots were then hot rolled to a 2.8 mm thick gauge, annealed at 450 °C for 1 hour followed by cooling to room temperature at a rate of 50 °C/hour, and then cold rolled to a final gauge thickness representing an overall gauge reduction by 85 %. The resulting sheets were allowed to stabilize at either 135 °C or at 185 °C for 1 hour. In the processing route with the optional cold rolling to intermediate gauge step, the ingots were hot rolled to a 2.8 mm thick gauge, cold rolled to an intermediate gauge, annealed at 300 to 450 °C for 1 hour, and then cold rolled to a final gauge thickness representing an overall gauge reduction by 50 % or 75 %. The resulting sheets were allowed to stabilize at either 135 °C

or at 185 °C for 1 hour. The annealing process can be a controlled heating and cooling as described above, or alternatively can be a batch annealing or continuous annealing step.

Example 2

5 Five alloys were prepared or obtained for tensile elongation testing (see Table 5). Alloy K5182, A1, A2, A3, and A4 were prepared according to the methods described herein. Specifically, the ingots having the alloy composition shown below in Table 5 were heated to 525 °C and soaked for 3 hours. The ingots were then hot rolled to a 2.8 mm thick gauge, cold rolled to an intermediate gauge, and annealed at 300 to 450 °C for 1 hour followed by cooling to
10 room temperature at a rate of 50 °C/hour.

Cold rolling was then carried out to a final gauge thickness of from approximately 0.43 mm to 0.46 mm (overall gauge reduction by 50 % or by 75 %). The resulting sheets were allowed to stabilize at either 135 °C or at 185 °C for 1 hour. The elemental compositions of the tested alloys are shown in Table 5, with the balance being aluminum. The elemental
15 compositions are provided in weight percentages. Alloy K5182 is an existing alloy commercially available from Novelis, Inc. (Atlanta, GA). Alloys A1, A2, A3, and A4 are prototype alloys prepared for the tensile, bendability, and corrosion resistance tests described below.

Table 5

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
K5182	0.1	0.27	0.06	0.40	4.5	0.01	0.01	0.01
A1	0.1	0.27	0.20	0.50	4.5	0.15	0.20	0.015
A2	0.25	0.27	0.20	0.70	4.5	0.10	0.20	0.015
A3	0.1	0.27	0.20	0.50	5.2	0.15	0.20	0.015
A4	0.1	0.27	0.06	0.40	6.0	0.01	0.01	0.01

20 All expressed in wt. %.

Recyclability

The recyclability was estimated for each of the alloys from Table 5. The recycle content and prime content are listed below in Table 6. The recycle content is an estimate and was calculated using known models, which blend scrap chemistries from different sources.

Table 6

	K5182	A1	A2	A3	A4
Recycle Content	38 %	92 %	79 %	92 %	38 %
Prime Content	39 %	5 %	14 %	5 %	39 %

Mechanical Properties

Tensile strength, yield strength, and elongation data were obtained for each alloy from Table 5. The testing was performed according to ASTM B557. The tensile strength, yield strength, and elongation data obtained from the four prototype alloys and from K5182 were compared, as shown in Figures 2A, 2B, and 2C, respectively. The data obtained from K5182 was included as a baseline comparison and is labeled in Figures 2A-2C as “B.” All alloys were in their O-tempered conditions prior to tensile testing.

The four prototype alloys and K5182 from Table 5 were prepared under O-temper conditions, H38-temper conditions with stabilization at 135 °C, and H38-temper conditions with stabilization at 185 °C. The tensile strength, yield strength, and elongation data were obtained and are shown in Table 7. The testing was performed according to ASTM B557.

Table 7

Alloy	Temper	UTS(MPa)	YS(MPa)	El(%)
Baseline	O-temper	300	152	23
A1		314	162	23
A2		313	164	22
A3		332	168	22
A4		337	166	26
Baseline	H38 (135 °C)	419	362	8
A1		453	395	7.7
A2		455	404	7.0
A3		480	415	8.4
A4		482	407	8.5
Baseline	H38 (185 °C)	402	336	9.2
A1		431	368	8.8
A2		434	377	8.2
A3		456	383	8.2
A4		460	370	9.6

To determine the effect of Mg content in the alloys on the mechanical properties in the resulting sheets, the mechanical properties for Alloys A2, A3, and A4 were compared. Alloys A2, A3, and A4 contain 4.5, 5.2, and 6.0 wt. %, respectively. Figure 3A shows the effect of Mg

on tensile properties with Alloys A2, A3, and A4 in their O-tempered conditions prior to testing. Figure 3B shows the effect of Mg on tensile properties with Alloys A2, A3, and A4 in their H38-tempered conditions, where the stabilization was performed at 135 °C, prior to testing. Figure 3C shows the effect of Mg on tensile properties with Alloys A2, A3, and A4 in their H38-tempered conditions, where the stabilization was performed at 185 °C, prior to testing. The tensile strengths of Alloys A3 and A4, which contain 5.2 wt. % and 6.0 wt. % Mg, respectively, were consistently higher than that of Alloy A2, which contains Mg in an amount of 4.5 wt. %.

Bendability

The bendability was determined for each of the prototype alloys, for the comparison material K5182, and for Alloy G, which is commercially available as Alloy GM55 from Sumitomo (Japan). The bendability was determined by measuring the hemming ability under a 90-180° bend and a radius of 0.5 mm. The samples were then ranked on a scale from 1 to 4 based on the surface appearance at the bend area. A ranking of “1” indicates a good surface appearance with no cracks. A ranking of “4” indicates that the samples contained short and/or long cracks at the bend area. Exemplary pictures of surface areas for alloys for each of the available ranking values are provided in Figure 4. The results are shown for each of the alloys in their O-tempered conditions; H38-tempered conditions, where the stabilization was performed at 135 °C; and H38-tempered conditions, where the stabilization was performed at 185 °C (see Table 8).

Table 8

Alloy	Temper	Rating
K5182	O-temper	1
A1		1
A2		1
A3		1
A4		1
K5182	H38 (135C)	3
A1		4
A2		4
A3		4
A4		4
K5182	H38 (185C)	3
A1		4
A2		4
A3		4
A4		4
Alloy G	H38	1

Corrosion Resistance

Corrosion resistance was determined for each of the prototype alloys A1 – A4, K5182, and Alloy G using the intergranular corrosion test NAMLT (“Nitric Acid Mass Loss Test,” ASTM-G67). The amount of weight loss that occurs after stabilizing the samples at 135 °C, 185 °C, and 350 °C (which represents a full anneal) are depicted in Figure 5. As shown in Figure 5, weight loss results after subjecting the samples to stabilization temperatures of 135 °C and 185 °C for 1 hour. Figure 6A shows the effects of subjecting the Alloy G material to stabilization at a temperature ranging from 100 – 130 °C. Figure 6B shows the effects of subjecting the Alloy A4 material to stabilization at 135 °C. The effects of stabilization at 135 °C, stabilization at 185 °C, and full anneal at 350 °C are also shown for Alloys A1, A3, and A4 in Figure 7.

Effect of Cold Working Percentage on Mechanical Properties

To determine the effect of the cold working percentage on mechanical properties, the mechanical properties of Alloys A1, A4, and Alloy G were compared. Alloys A1 and A4 were prepared under cold work percentage of 50% or 75%, and the tensile strength, yield strength, percent elongation, and hemming were determined. The results are shown in Table 9.

Table 9

Alloy	Condition	Stabilization temp	Gauge(mm)	UTS(MPa)	YS(MPa)	EL%	Hemming test
A1	75% CW	135 °C	0.435	432	373	8	4
	50% CW		0.448	402	332	8	1
A4	75% CW		0.437	457	373	10	3
	50% CW		0.452	423	327	11	1
A1	75% CW	185 °C	0.453	418	354	7	3
	50% CW		0.455	399	323	9	1
A4	75% CW		0.434	444	352	9	3
	50% CW		0.456	415	315	13	1
Alloy G	H3X		0.397	394	313	10	1

For Alloy A4, the strength versus the percentage cold work (CW) was plotted for the materials prepared at a stabilization temperature of 135 °C (Figure 8A) and 185 °C (Figure 8B). The process modification with 50 % CW significantly affected the mechanical properties of Alloy A4, which is a high Mg content alloy. The mechanical properties are higher than Alloy G, and the bendability was also good as demonstrated by the hemming testing.

Example 3

Alloys as described herein were prepared according to one of the processes shown in Figure 9. In a first process, the cast ingots were preheated from room temperature to 515 °C and allowed to soak for 1 hour. The total time lapsed for the preheating and soaking averaged 10 hours. The ingots were then hot rolled at 340 °C for 1 hour to a 4.5 mm thick gauge, annealed at 300 °C for 3 hours to result in a 1.0 mm thick gauge, and then cold rolled to a final gauge thickness of 0.7 mm, representing a 30% gauge reduction from the annealed gauge. The resulting sheets were allowed to stabilize at 135 °C for 1 hour. In a second process, the cast ingots were preheated, soaked, and hot rolled as described above for the first process. The

annealing step was performed at 330 °C for 1 hour to result in a 2.0 mm thick gauge, and then cold rolled to a final gauge thickness of 0.7 mm, representing a 65% gauge reduction from the annealed gauge. The resulting sheets were allowed to stabilize at 160 °C for 1 hour.

In a third process, the cast ingots were preheated from room temperature to 480 °C and allowed to soak for 2 hours. The ingots were then heated to a second temperature of 525 °C and allowed to soak for 2 additional hours. The total time lapsed for the preheating, soaking, heating, and additional soaking steps averaged 14 hours. The ingots were then hot rolled at 340 °C for 1 hour to a 10.5 mm thick gauge, annealed at 330 °C for 1 hour to result in a 1.0 mm thick gauge, and then cold rolled to a final gauge thickness of 0.7 mm, representing a 30% gauge reduction from the annealed gauge. The resulting sheets were allowed to stabilize at 160 °C for 1 hour. In a fourth process, the cast ingots were preheated, soaked, heated, soaked, and hot rolled as described above for the third process. The annealing step was performed at 330 °C for 1 hour to result in a 2.0 mm thick gauge, and then cold rolled to a final gauge thickness of 0.7 mm, representing a 65% gauge reduction from the annealed gauge. The resulting sheets were allowed to stabilize at 200 °C for 1 hour. The processes described above resulted in alloys in their H32 tempered conditions.

Example 4

Prototype alloy Example 1 was prepared for anodizing quality testing and tensile property testing. The elemental composition of Example 1 is shown in Table 10, with the balance being aluminum, and values are provided in weight percentages. Example 1 was prepared according to the methods described herein. Alloys AA5052 and AA5182 were obtained and were also tested for anodizing quality and tensile properties. Alloy AA5182 is an existing alloy commercially available from Novelis, Inc. (Atlanta, GA). Alloy AA5052 is an alloy that was prepared in the laboratory.

Table 10

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
Example 1	0.05-0.15	0.09-0.15	~ 0.05	~ 0.10	4.0-5.5	~ 0.20	~ 0.005	~ 0.05

Anodizing Quality

The anodizing responses under acidic and caustic conditions were obtained for prototype alloy Example 1, for comparative alloy AA5182, and for comparative alloy AA5052. Specifically, the brightness (represented as “L”), the white index (represented as “WI”), and the yellow index (represented as “YT”) for the alloys were determined. As illustrated in Figures 10A-10B, the prototype alloy showed improved anodizing qualities, such as lower YI values, which may be due to the reduced size and number density of intermetallic particles in the alloy sample.

10 Mechanical Properties

Yield strength, ultimate tensile strength, uniform elongation, and total elongation data were obtained for prototype alloy Example 1, for comparative alloy AA5182, and for comparative alloy AA5052. The testing was performed according to ASTM B557. The tensile strength, yield strength, and elongation data obtained from the alloys were compared, as shown in Figure 11. The strength and formability values of prototype alloy Example 1 were higher than those of AA5052 and comparable to those of AA5182.

Various embodiments of the invention have been described in fulfillment of the various objectives of the invention. It should be recognized that these embodiments are merely illustrative of the principles of the present invention. Numerous modifications and adaptations thereof will be readily apparent to those of ordinary skill in the art without departing from the spirit and scope of the invention as defined in the following claims.

WHAT IS CLAIMED IS:

1. An aluminum alloy comprising 0.05 – 0.30 wt. % Si, 0.08 – 0.50 wt. % Fe, 0 – 0.60 wt. % Cu, 0.31 – 0.60 wt. % Mn, 5.0– 7.0 wt. % Mg, 0 – 0.25 wt. % Cr, 0 – 0.20 wt. % Zn, 0 – 0.15 wt. % Ti, and up to 0.15 wt. % of impurities, with the remainder as Al, wherein the aluminum alloy, when in an H-temper, has an ultimate tensile strength greater than 420 MPa.
2. The aluminum alloy of claim 1, comprising 0.05 – 0.30 wt. % Si, 0.1 – 0.50 wt. % Fe, 0 – 0.60 wt. % Cu, 0.31 – 0.60 wt. % Mn, 5.0– 7.0 wt. % Mg, 0 – 0.25 wt. % Cr, 0 – 0.20 wt. % Zn, 0 – 0.15 wt. % Ti, and up to 0.15 wt. % of impurities, with the remainder as Al.
3. The aluminum alloy of claim 1, comprising 0.10 – 0.20 wt. % Si, 0.20 – 0.35 wt. % Fe, 0.01 – 0.25 wt. % Cu, 0.31 – 0.55 wt. % Mn, 5.0 – 6.5 wt. % Mg, 0.01 – 0.25 wt. % Cr, 0.01 – 0.20 wt. % Zn, 0 – 0.1 wt. % Ti, and up to 0.15 wt. % of impurities, with the remainder as Al.
4. The aluminum alloy of claim 1, comprising 0.10 – 0.15 wt. % Si, 0.20 – 0.35 wt. % Fe, 0.1 – 0.25 wt. % Cu, 0.31 – 0.50 wt. % Mn, 5.0 – 6.0 wt. % Mg, 0.05 – 0.20 wt. % Cr, 0.01 – 0.20 wt. % Zn, 0 – 0.05 wt. % Ti, and up to 0.15 wt. % of impurities, with the remainder as Al.
5. The aluminum alloy of any one of claims 1-4, wherein the alloy includes α -AlFeMnSi particles.
6. The aluminum alloy of any one of claims 1-5, wherein the alloy is produced by direct chill casting.
7. The aluminum alloy of any one of claims 1-6, wherein the alloy is produced by homogenization, hot rolling, cold rolling, and annealing.

8. An automotive body part comprising the aluminum alloy as claimed in any one of claims 1-7.
9. The automotive body part of claim 8, wherein the automotive body part comprises an inner panel.
10. An electronic device housing comprising the aluminum alloy as claimed in any one of claims 1-7.
11. The electronic device housing of claim 10, wherein the electronic device housing comprises an outer casing of a mobile phone or a tablet bottom chassis.
12. A transportation body part comprising the aluminum alloy as claimed in any one of claims 1-7.
13. A method of producing a metal product, comprising:
 - direct chill casting an aluminum alloy to form an ingot, wherein the aluminum alloy comprises 0.05 – 0.30 wt. % Si, 0.08 – 0.50 wt. % Fe, 0 – 0.60 wt. % Cu, 0.31 – 0.6 wt. % Mn, 5.0– 7.0 wt. % Mg, 0 – 0.25 wt. % Cr, 0 – 0.20 wt. % Zn, 0 – 0.15 wt. % Ti, and up to 0.15 wt. % of impurities, with the remainder as Al, wherein the aluminum alloy, when in an H-temper, has an ultimate tensile strength greater than 420 MPa;
 - homogenizing the ingot to form a plurality of α -AlFeMnSi particles in the ingot;
 - cooling the ingot to a temperature of 450 °C or less;
 - hot rolling the ingot to produce a rolled product;
 - allowing the rolled product to self-anneal; and
 - cold rolling the rolled product to a final gauge.
14. The method of claim 13, further comprising cold rolling the rolled product to an intermediate gauge after the hot rolling step.

15. A metal product, wherein the metal product is prepared by a method comprising the method as claimed in claim 13 or 14.
16. The metal product of claim 15, wherein the metal product is an automotive body part.
17. The metal product of claim 16, wherein the automotive body part comprises an inner panel.
18. The metal product of claim 15, wherein the metal product is an electronic device housing.
19. The metal product of claim 18, wherein the electronic device housing comprises an outer casing of a mobile phone or a tablet bottom chassis.
20. The metal product of claim 15, wherein the metal product is a transportation body part.

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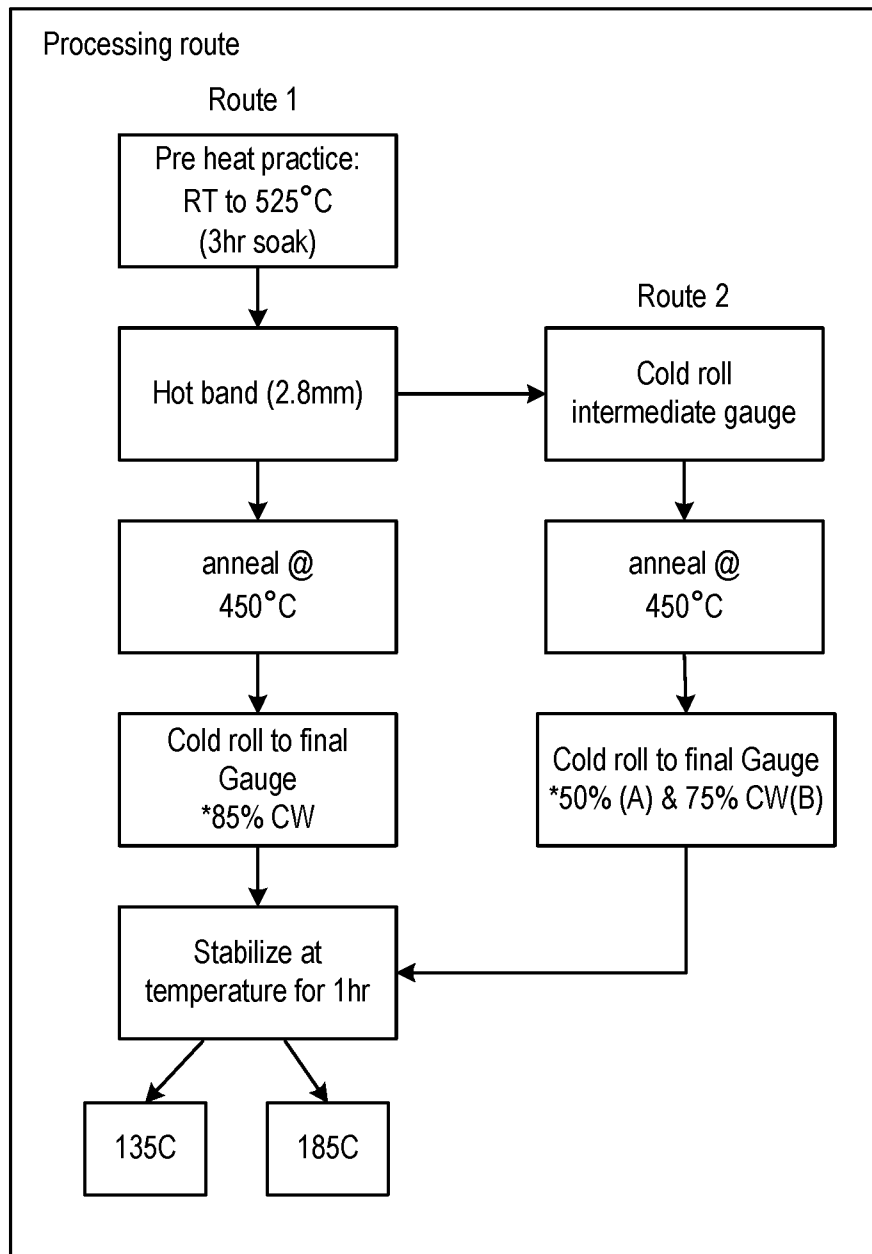
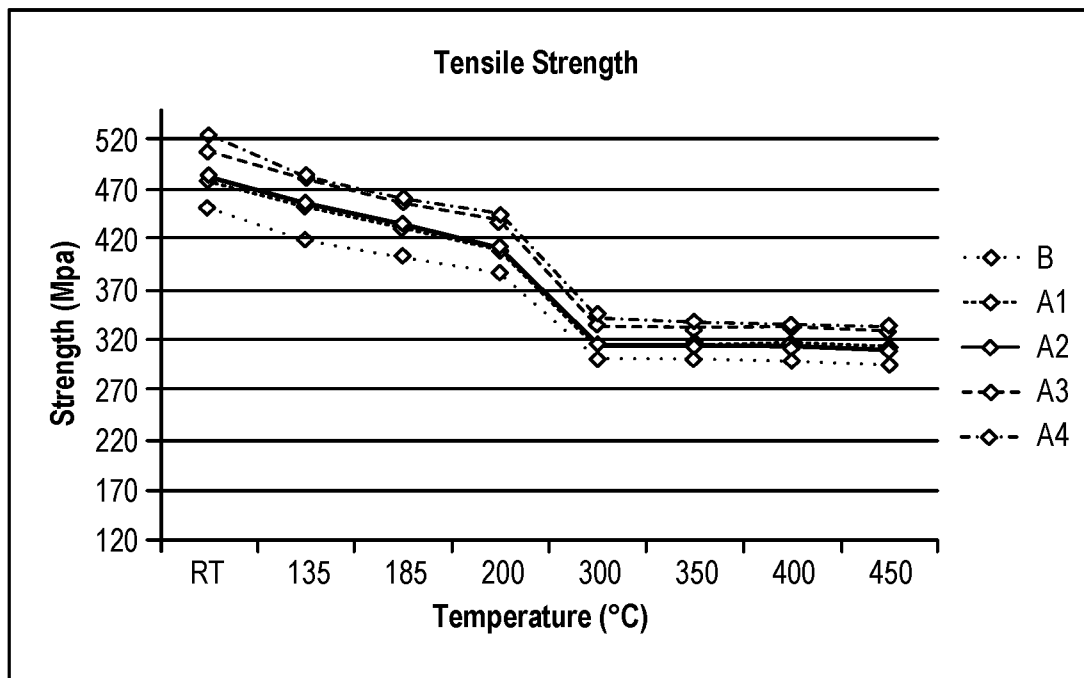
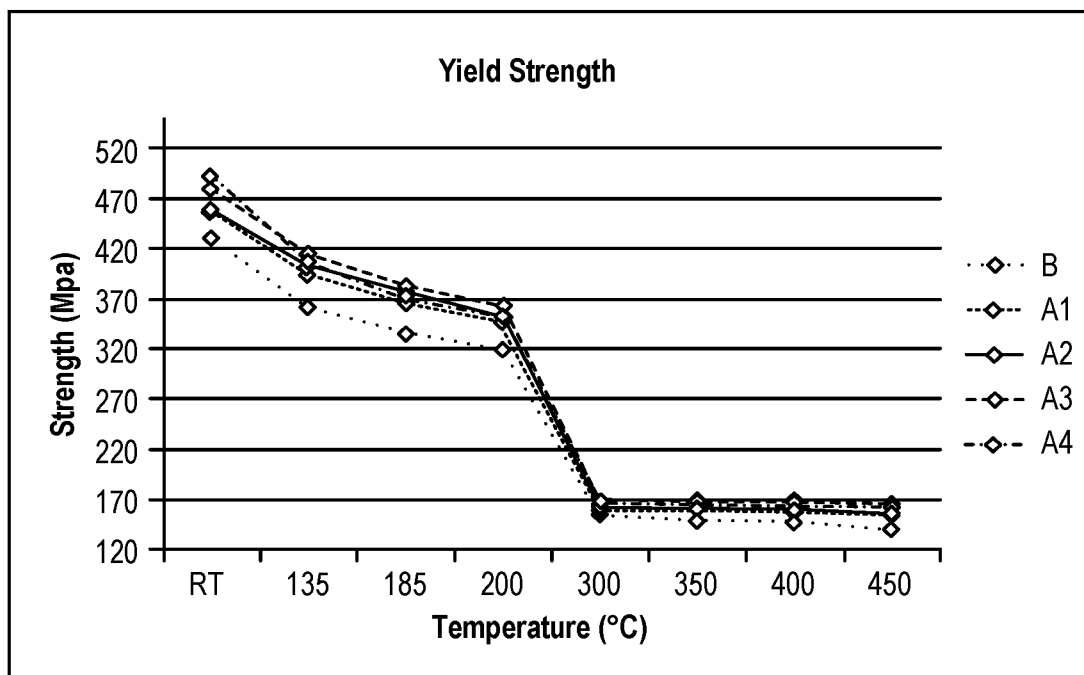


Figure 1

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**Figure 2A****Figure 2B**

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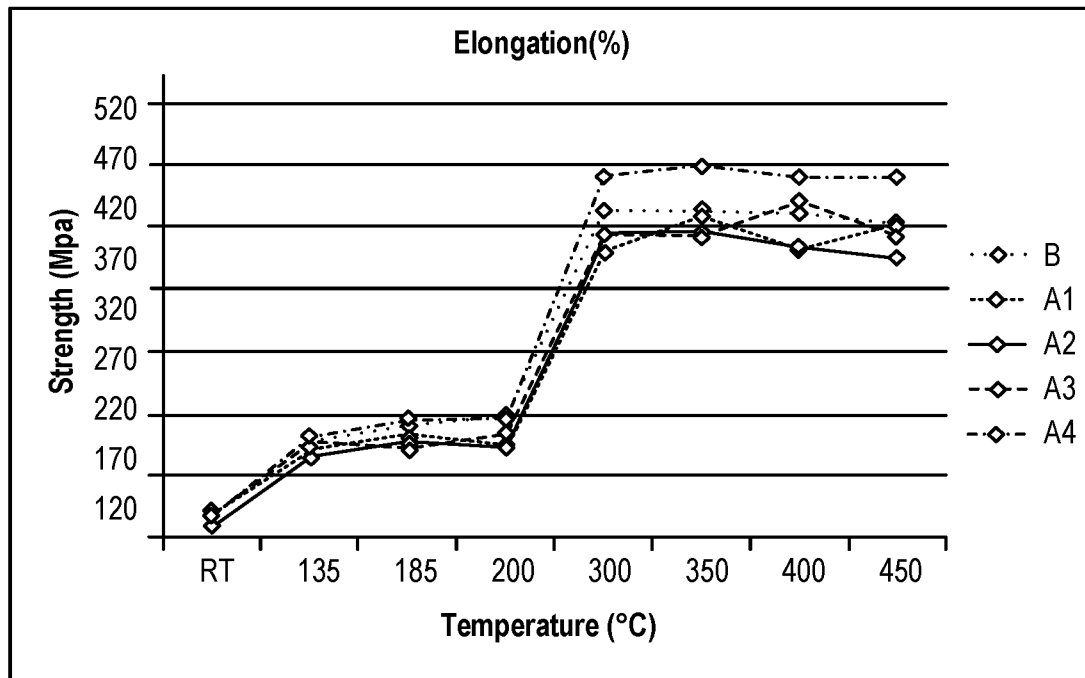


Figure 2C

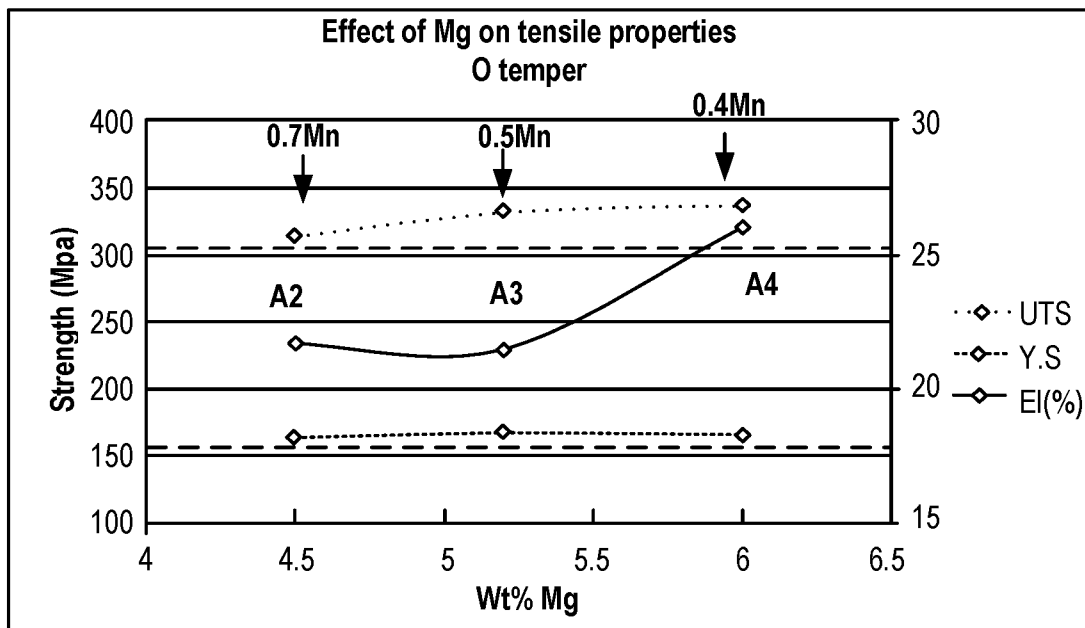


Figure 3A

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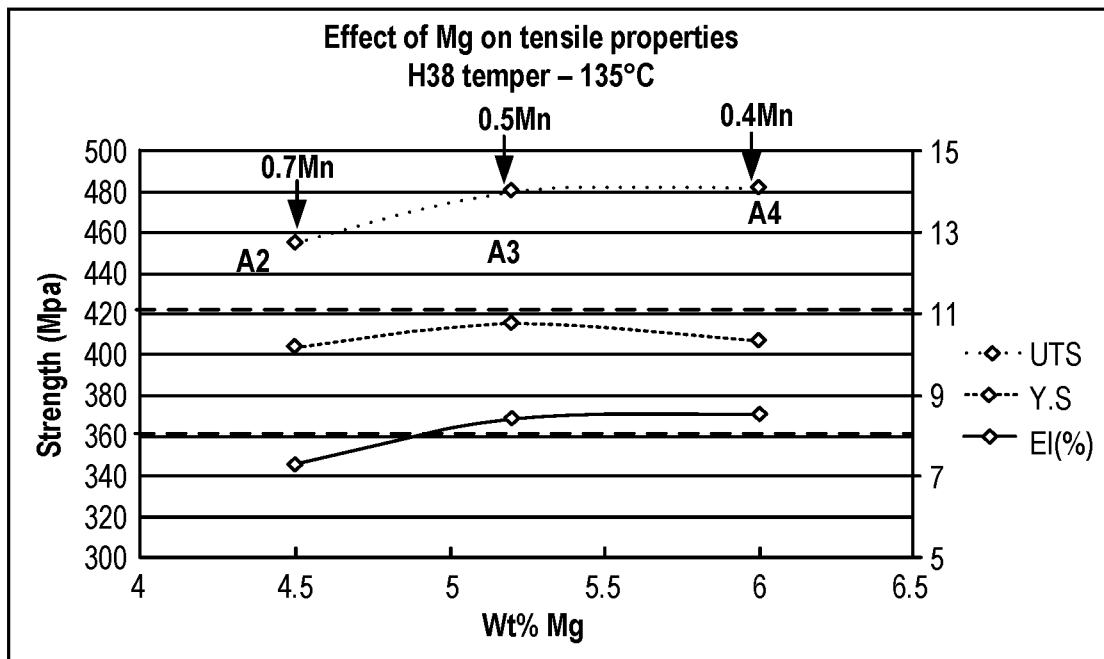


Figure 3B

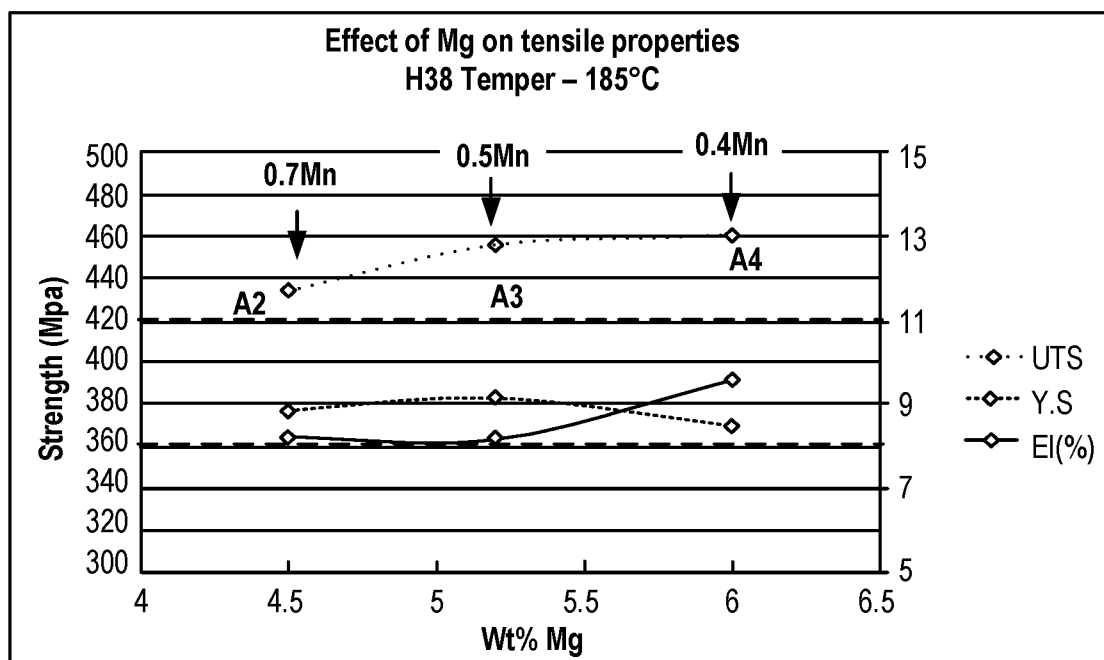


Figure 3C

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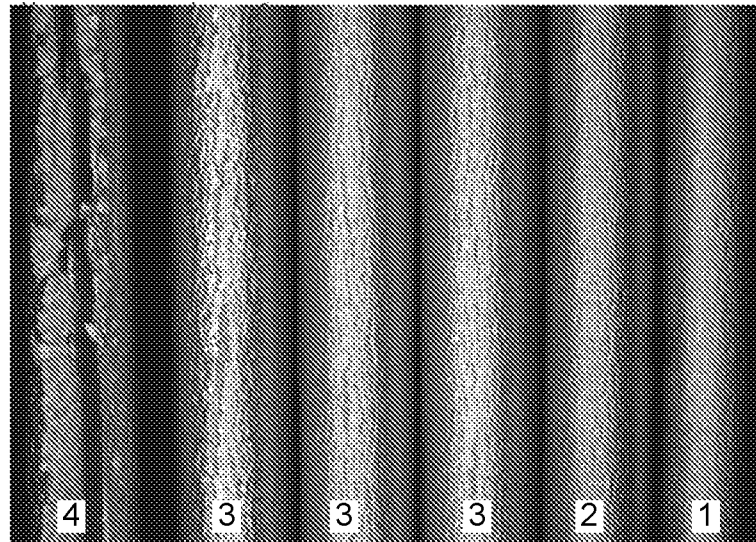


Figure 4

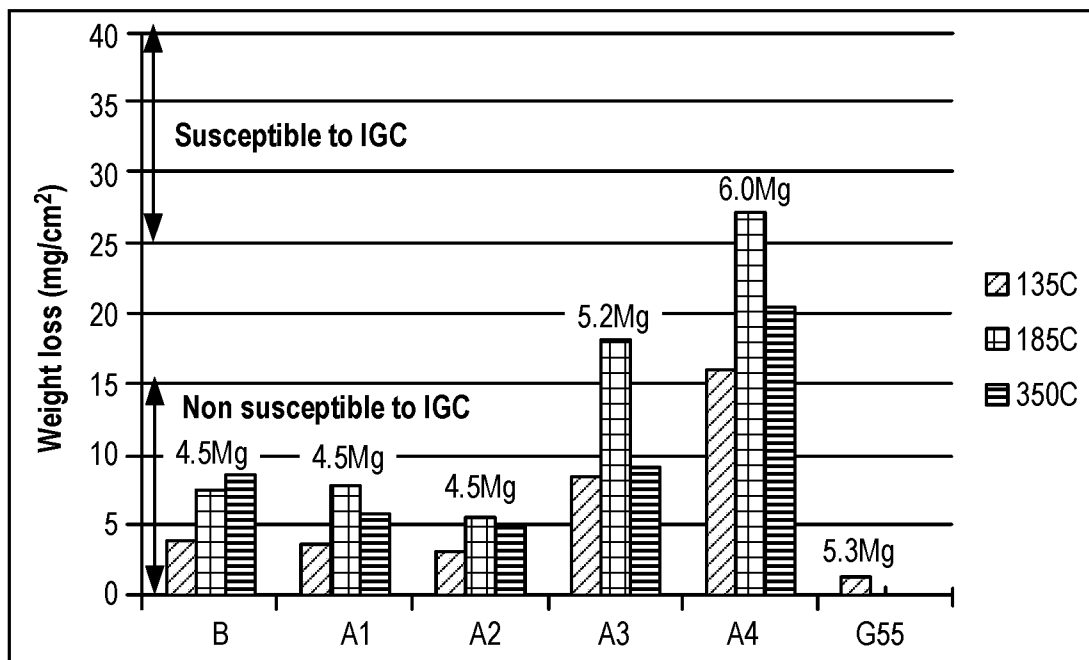


Figure 5

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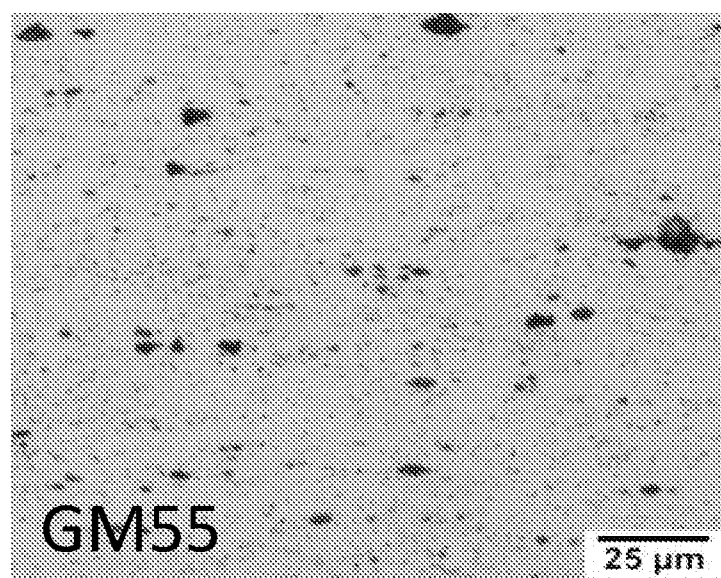


Figure 6A

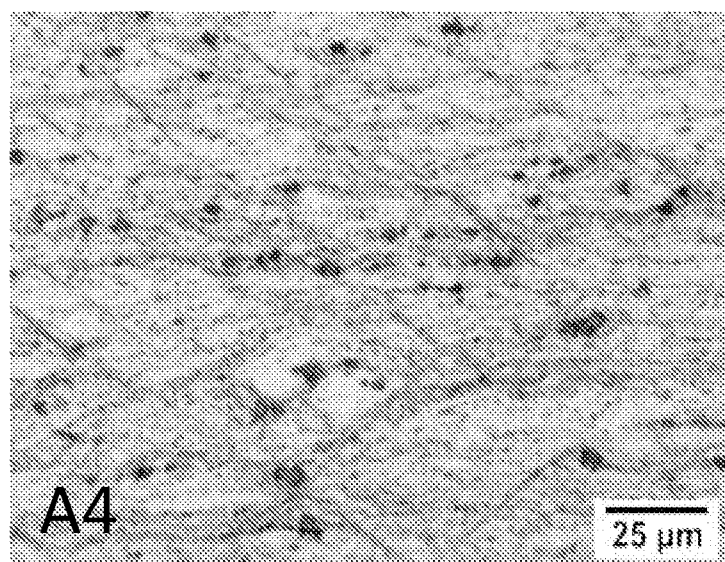


Figure 6B

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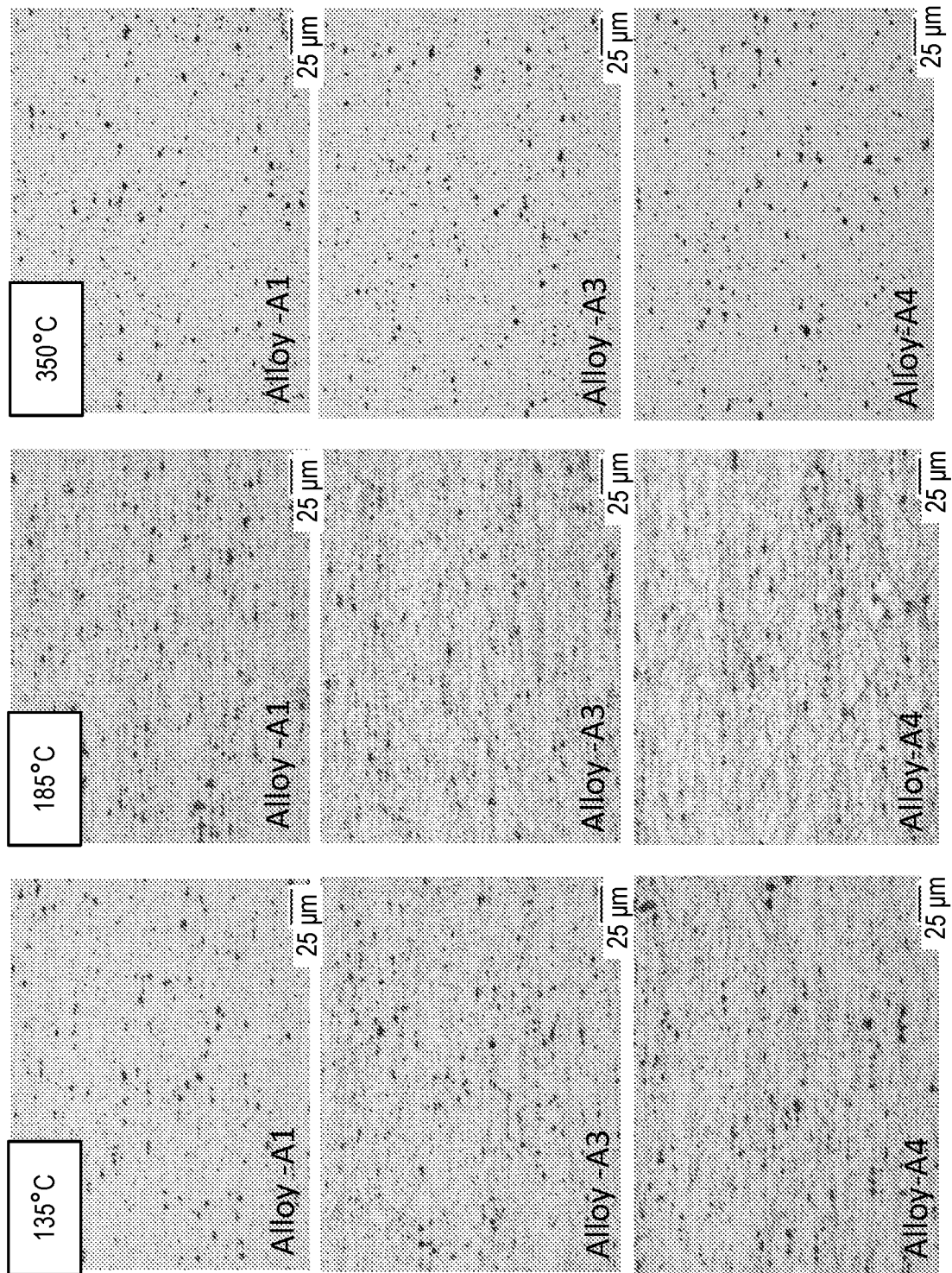


Figure 7

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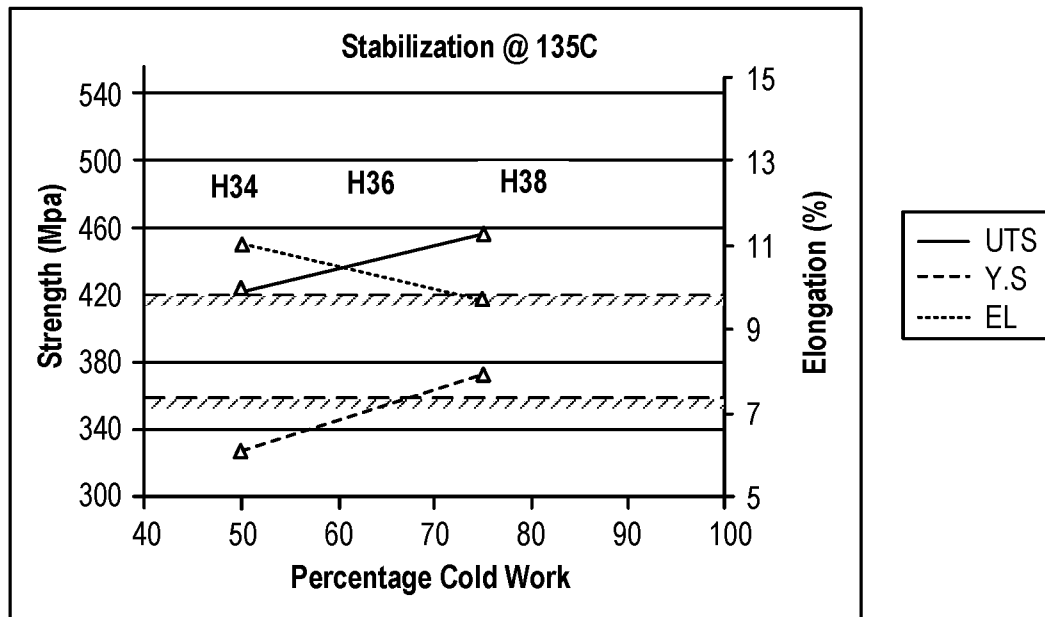


Figure 8A

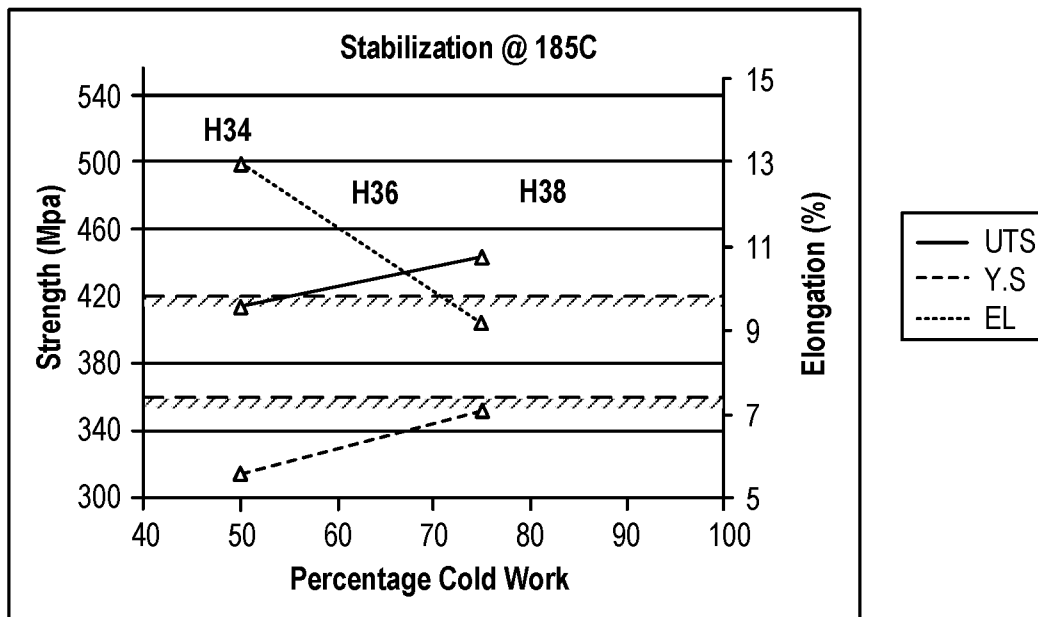


Figure 8B

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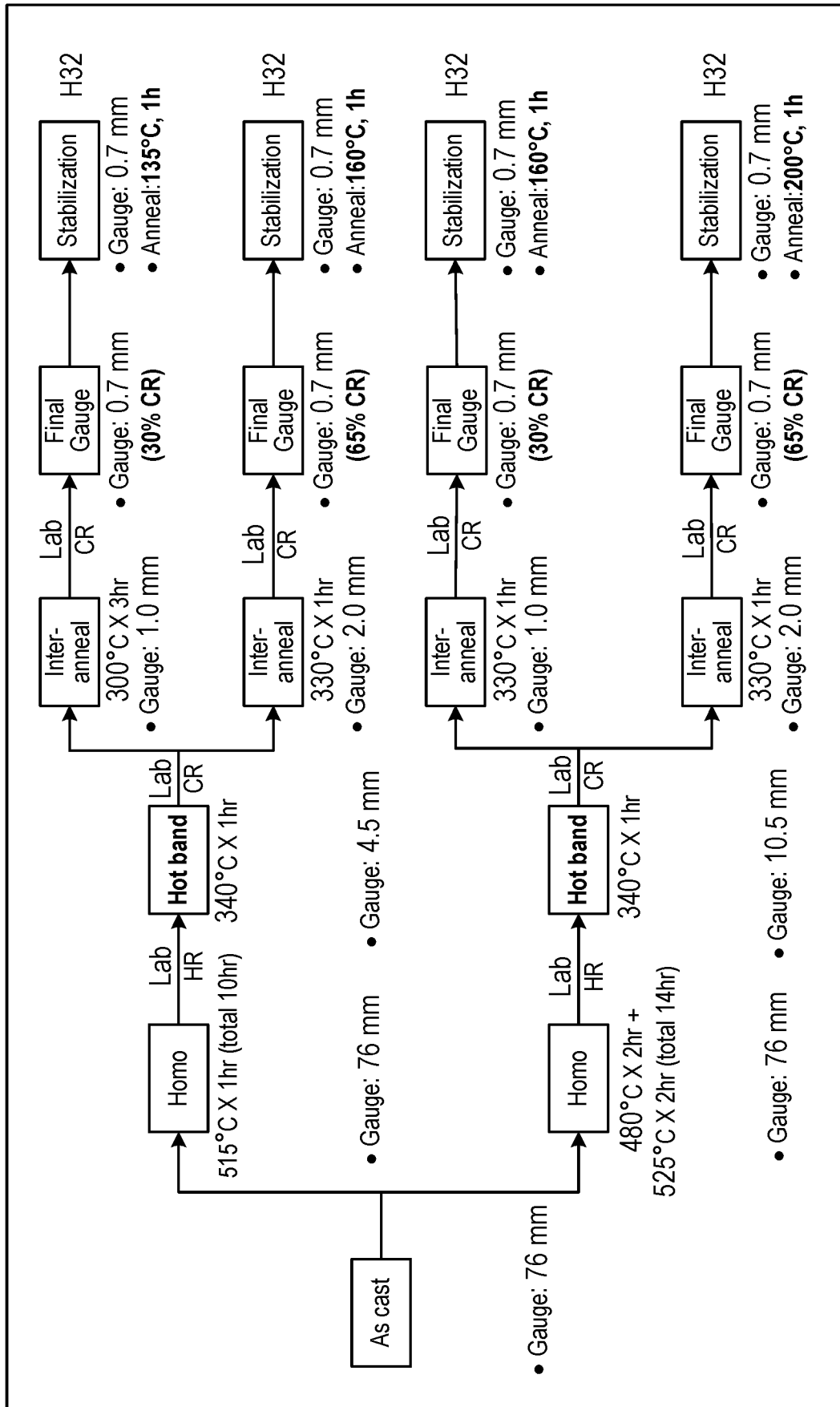


Figure 9

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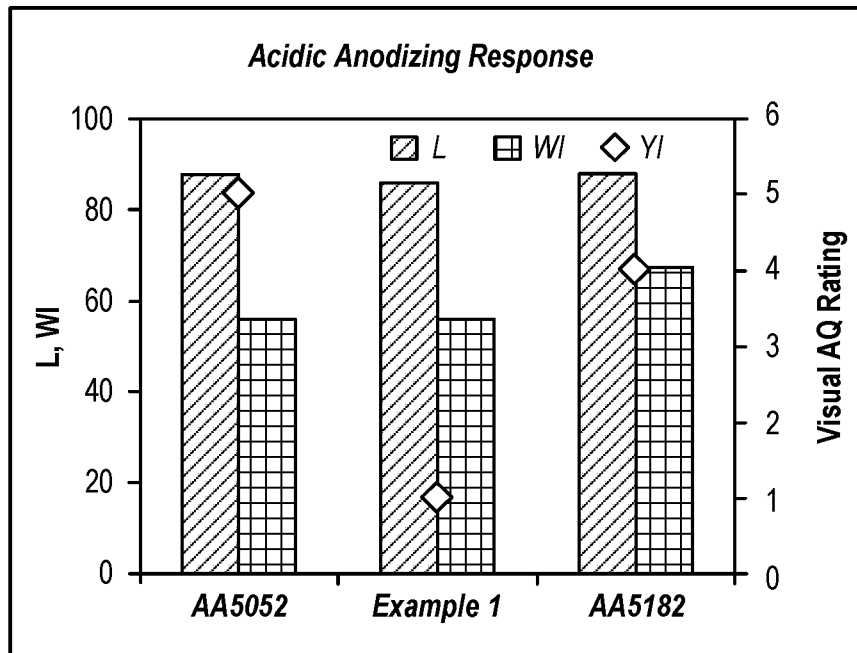


Figure 10A

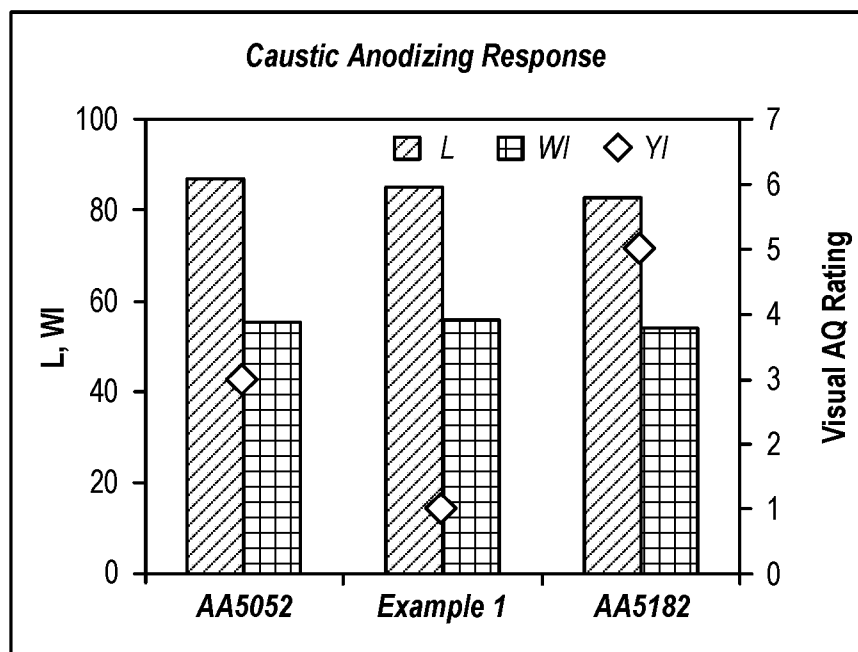


Figure 10B

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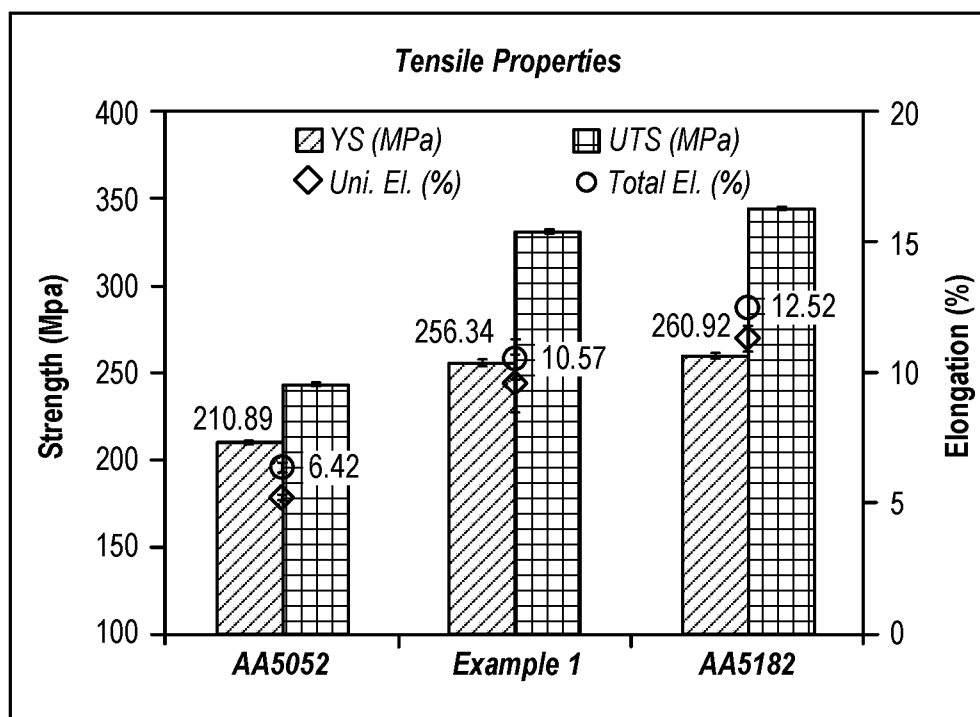


Figure 11

Effect of Mg on tensile properties
H38 Temper – 185°C

