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(54) DIE CAST ALUMINUM ALLOYS FOR STRUCTURAL COMPONENTS

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(57) ABSTRACT

An alloy composition comprising Al is described, wherein the alloy comprises a yield strength of at least about 130 MPa and a bend angle of at least about 20° at a 3 mm section thickness when as-cast and without further processing. Processes for forming the alloy are also described.

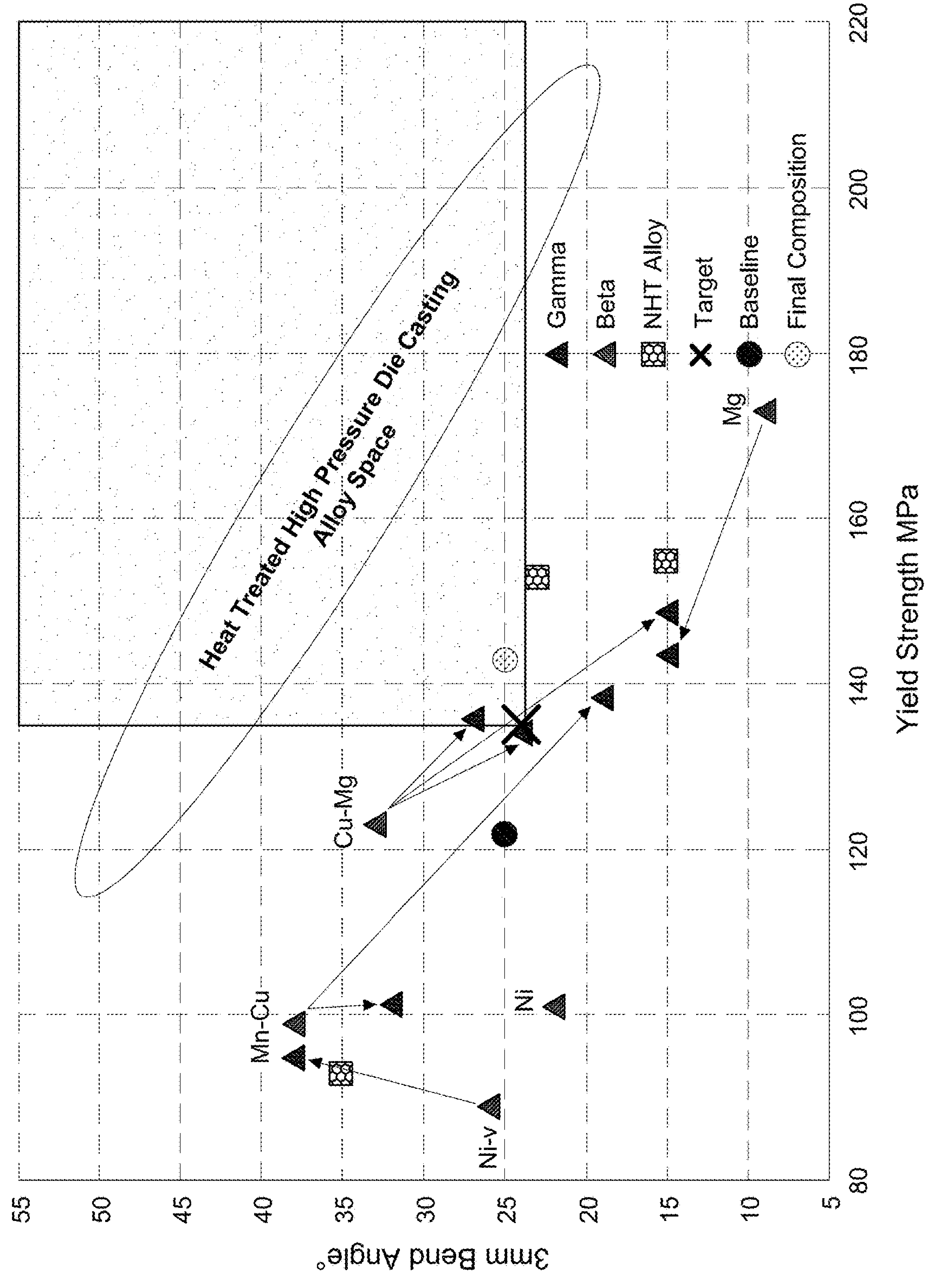
Heat Treated High Pressure Die Casting
Alloy Space
Gamma
Beta
NHT Alloy
Target
Baseline
Final Composition
Mg
Cu-Mg
Mn-Cu
Ni
Ni-v
Yield Strength MPa
80
100
120
140
160
180
200
220
3mm Bend Angle°
5
10
15
20
25
30
35
40
45
50
55

FIG. 1

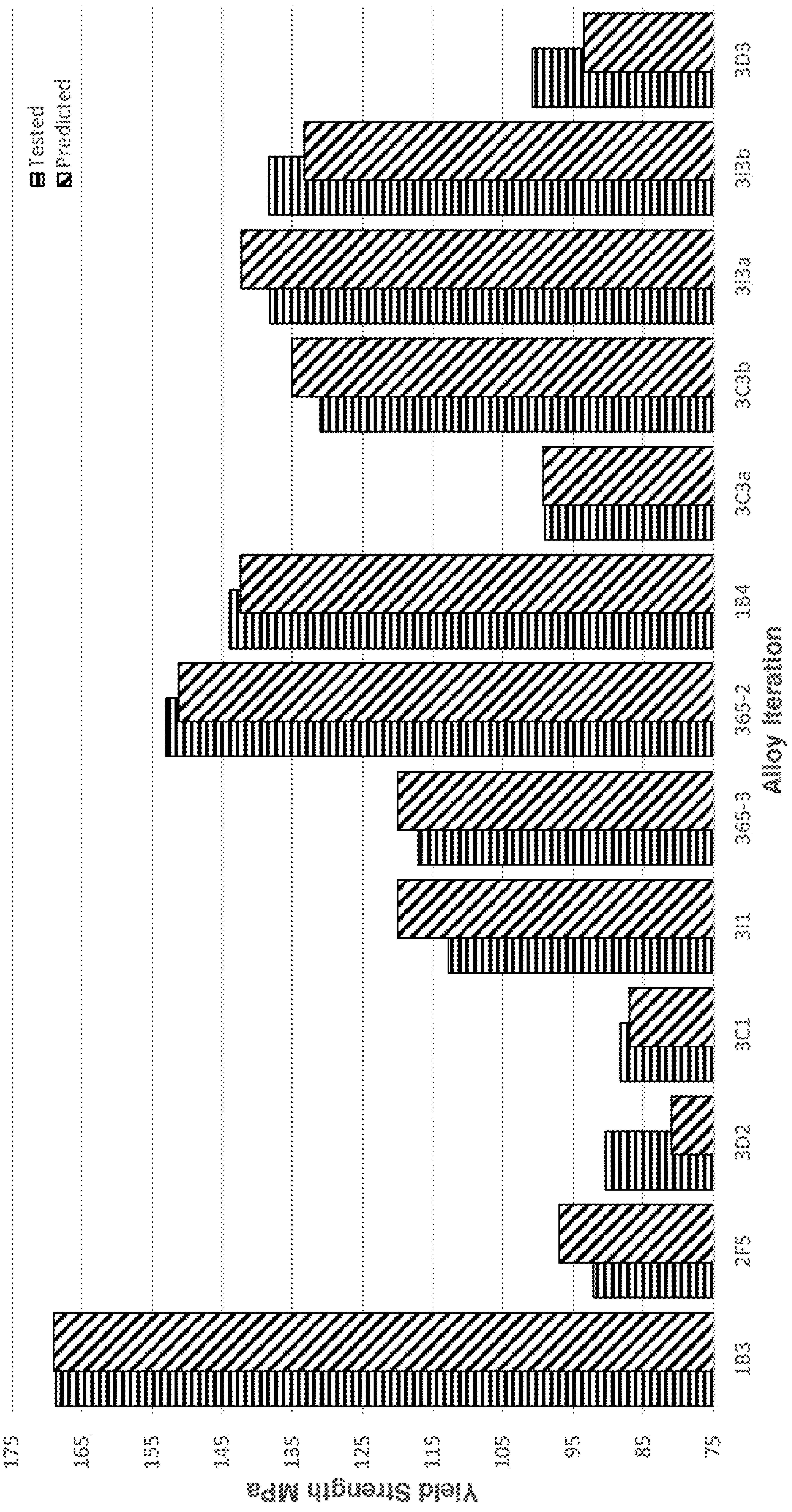
Yield Strength MPa
175
165
155
145
135
125
115
105
95
85
75
Tested
Predicted
1B3
2F5
3D2
3C1
3I1
365-3
365-2
1B4
3C3a
3C3b
3I3a
3I3b
3D3
Alloy Iteration

FIG. 2

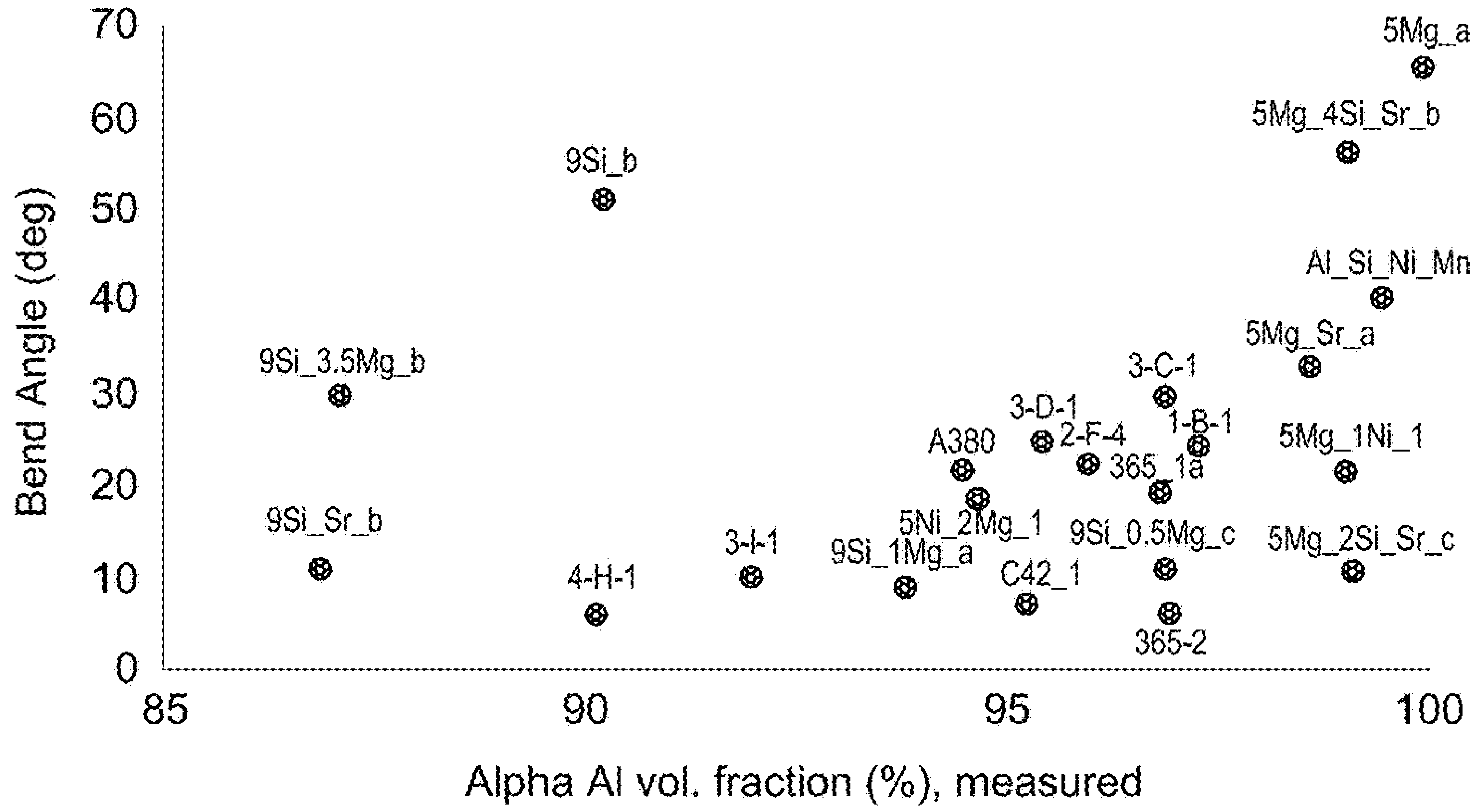
Bend Angle (deg)
70
60
50
40
30
20
10
0
85
90
95
100
Alpha Al vol. fraction (%), measured
5Mg_a
5Mg_4Si_Sr_b
9Si_b
Al_Si_Ni_Mn
9Si_3.5Mg_b
5Mg_Sr_a
3-C-1
3-D-1
A380
2-F-4
1-B-1
365_1a
5Mg_1Ni_1
5Ni_2Mg_1
9Si_Sr_b
3-I-1
9Si_1Mg_a
9Si_0.5Mg_c
5Mg_2Si_Sr_c
4-H-1
C42_1
365-2

FIG. 3A

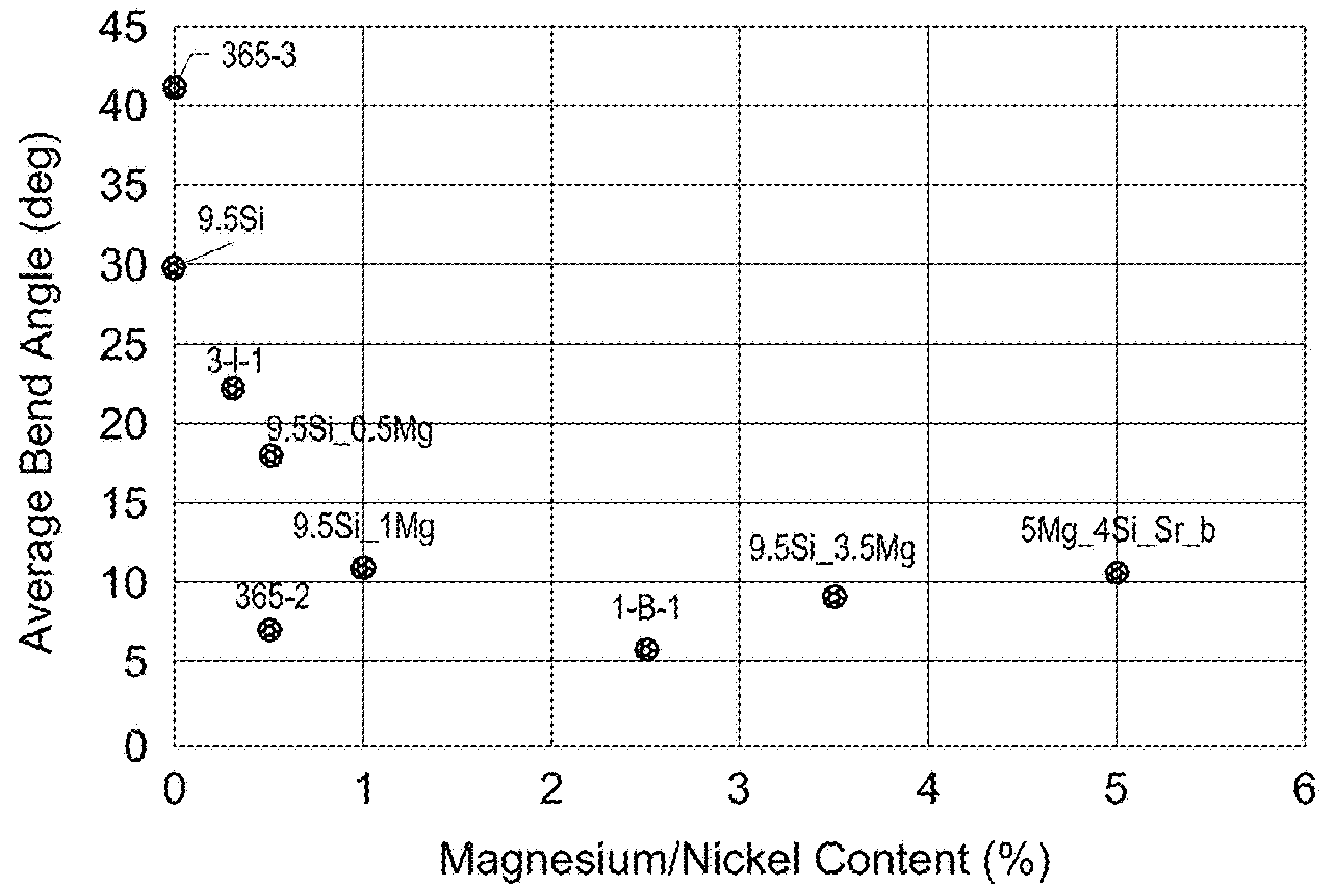
Average Bend Angle (deg)
45
40
35
30
25
20
15
10
5
0
0
1
2
3
4
5
6
Magnesium/Nickel Content (%)
365-3
9.5Si
3-I-1
9.5Si_0.5Mg
9.5Si_1Mg
9.5Si_3.5Mg
5Mg_4Si_Sr_b
365-2
1-B-1

FIG. 3B

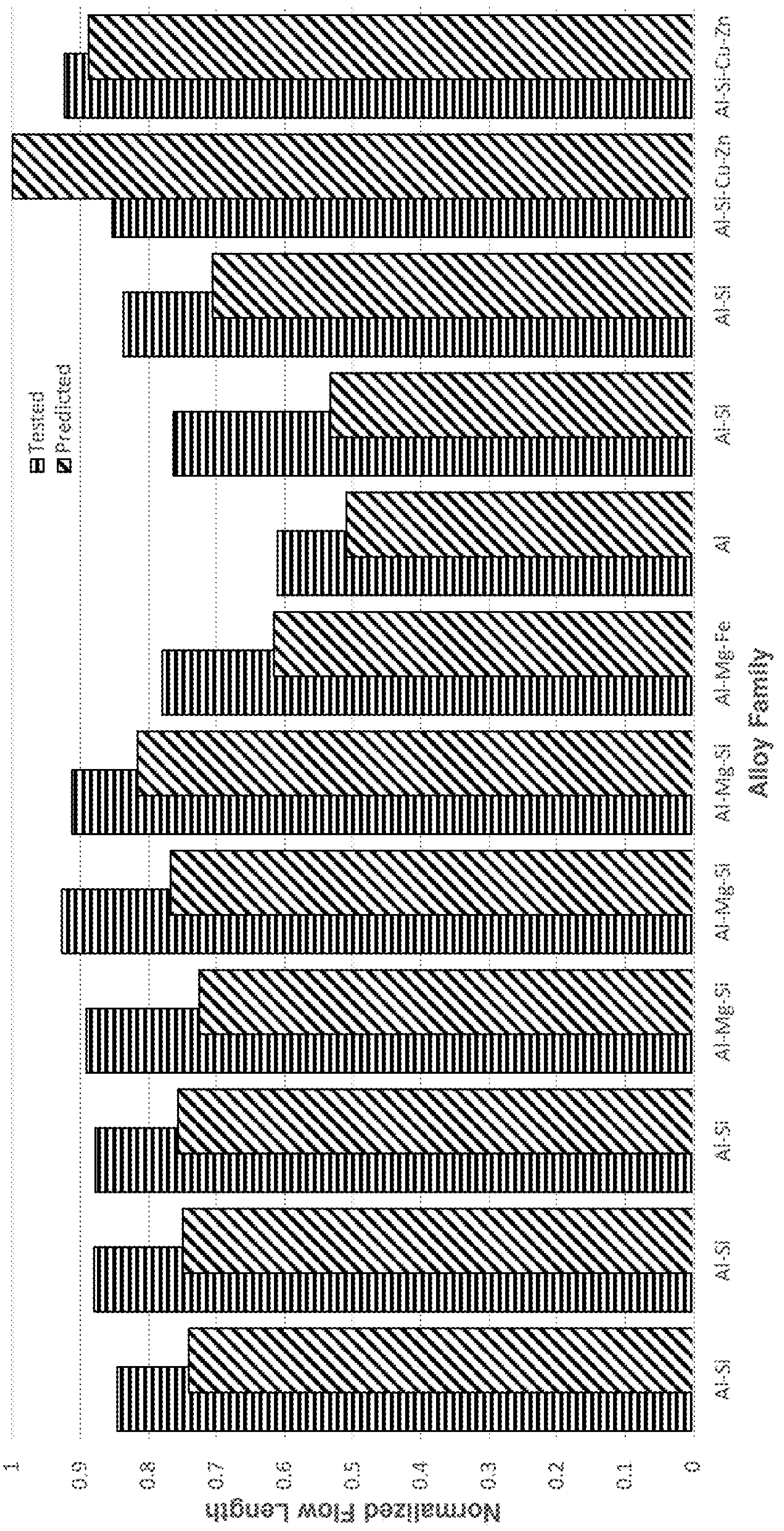
Normalized Flow Length
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
▤ Tested
▨ Predicted
Al-Si
Al-Si
Al-Si
Al-Mg-Si
Al-Mg-Si
Al-Mg-Si
Al-Mg-Fe
Al
Al-Si
Al-Si
Al-Si-Cu-Zn
Al-Si-Cu-Zn
Alloy Family

FIG. 4

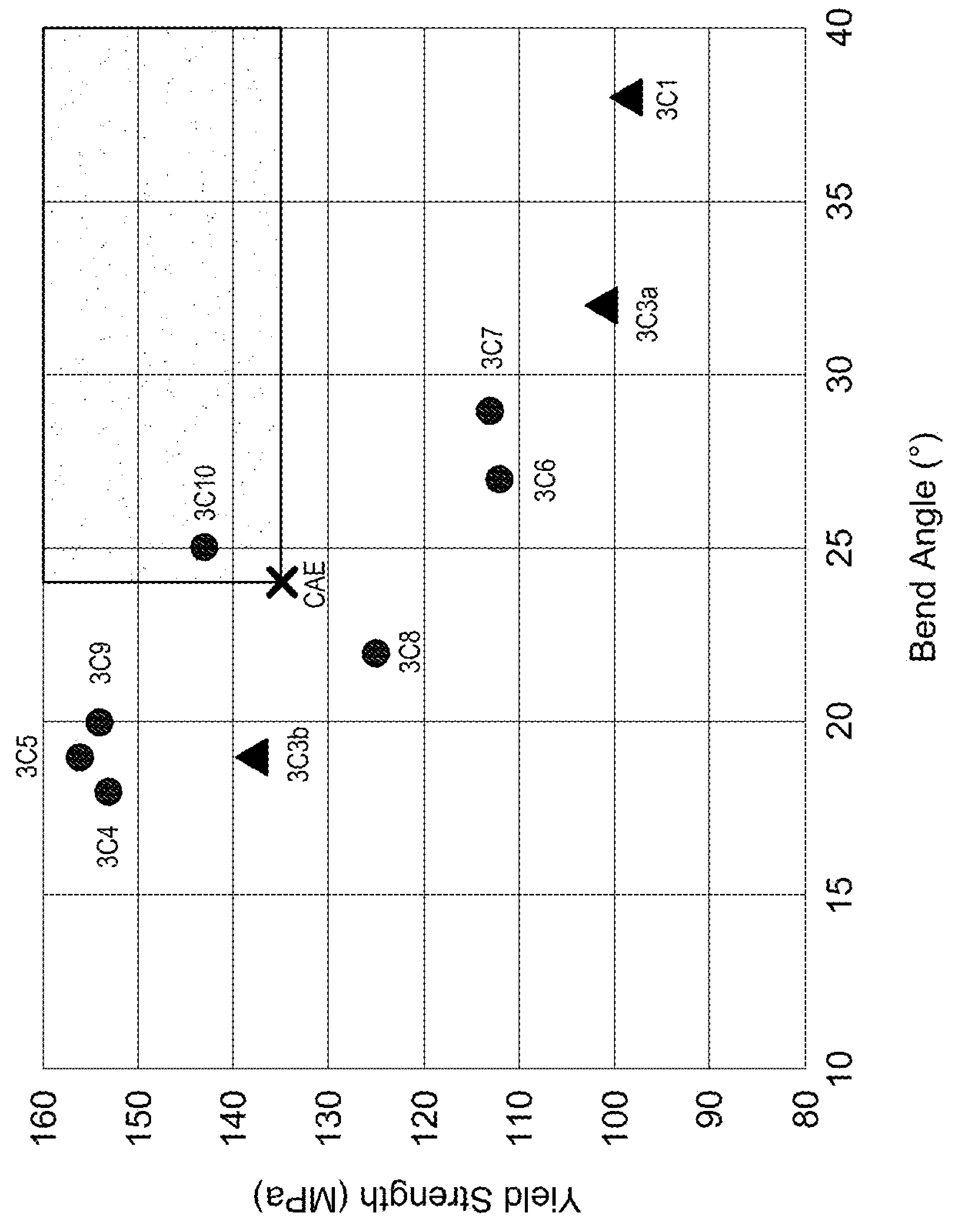
Yield Strength (MPa)
160
150
140
130
120
110
100
90
80
Bend Angle (°)
10
15
20
25
30
35
40
3C5
3C4
3C9
3C3b
3C8
CAE
3C10
3C6
3C7
3C3a
3C1

FIG. 5

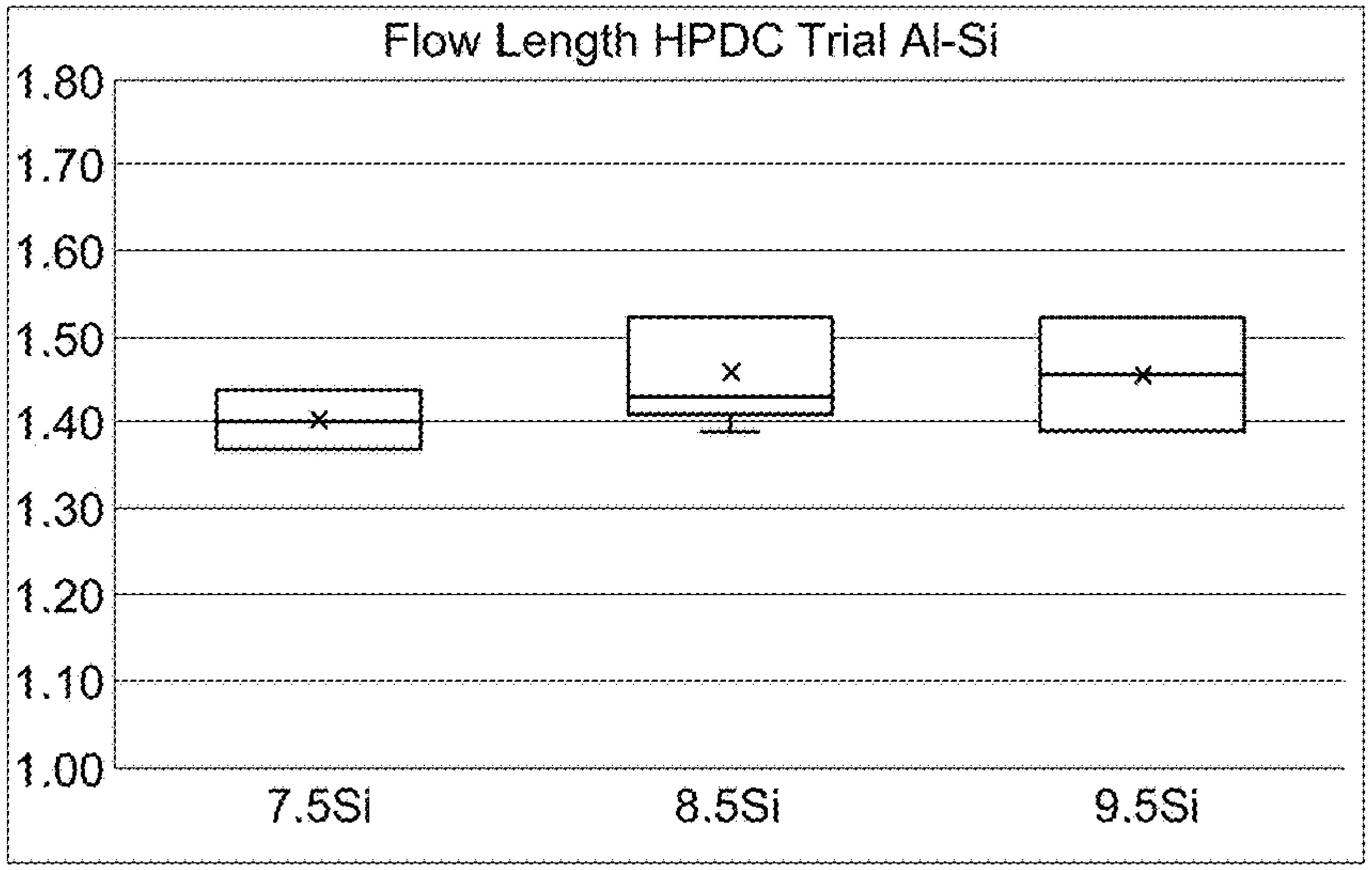
Flow Length HPDC Trial Al-Si
3mm Cast Length n meters
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
7.5Si
8.5Si
9.5Si

FIG. 6A

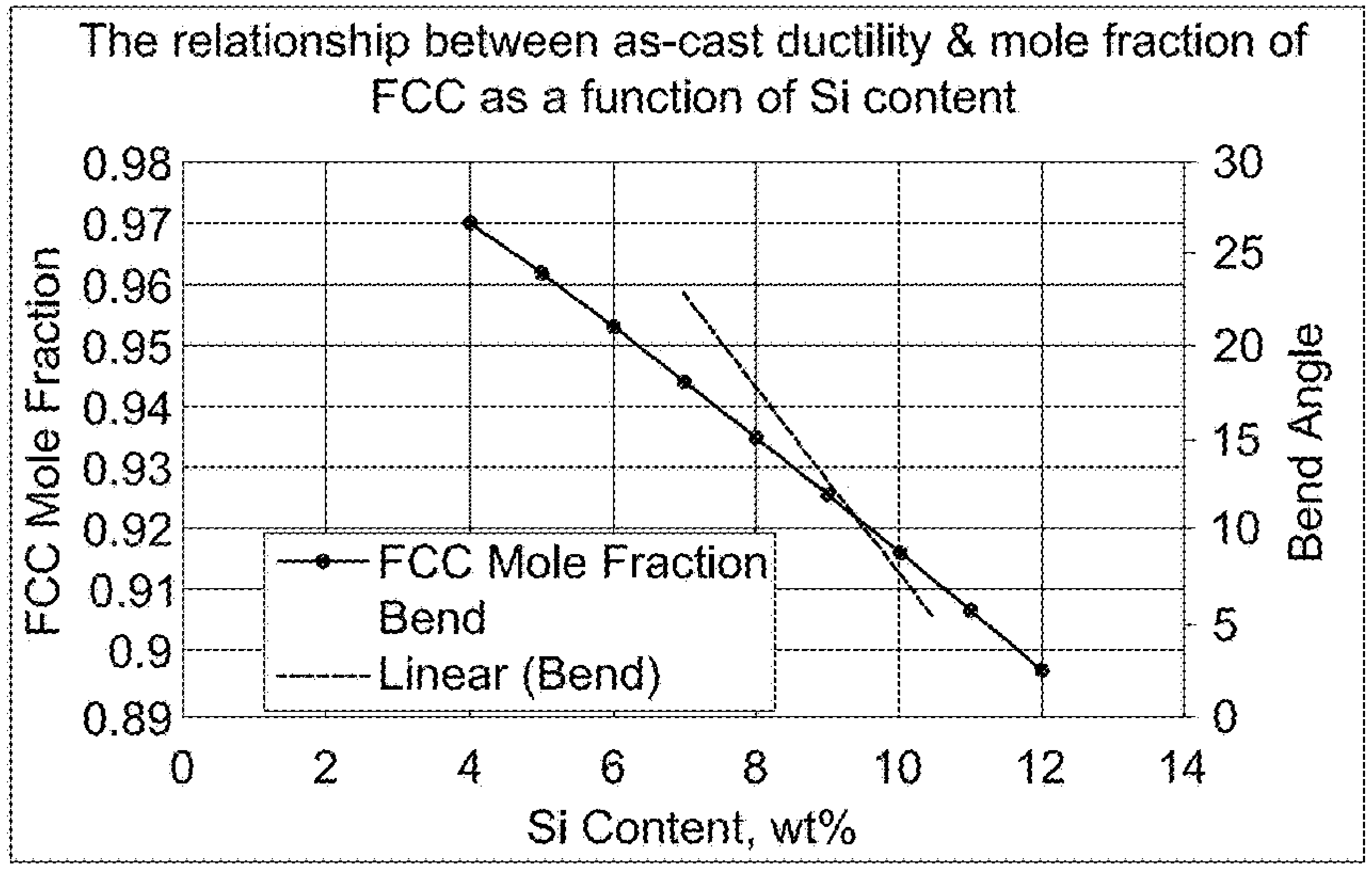
The relationship between as-cast ductility & mole fraction of FCC as a function of Si content
FCC Mole Fraction
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
0.9
0.89
Bend Angle
30
25
20
15
10
5
0
0
2
4
6
8
10
12
14
Si Content, wt%
FCC Mole Fraction
Bend
Linear (Bend)

FIG. 6B

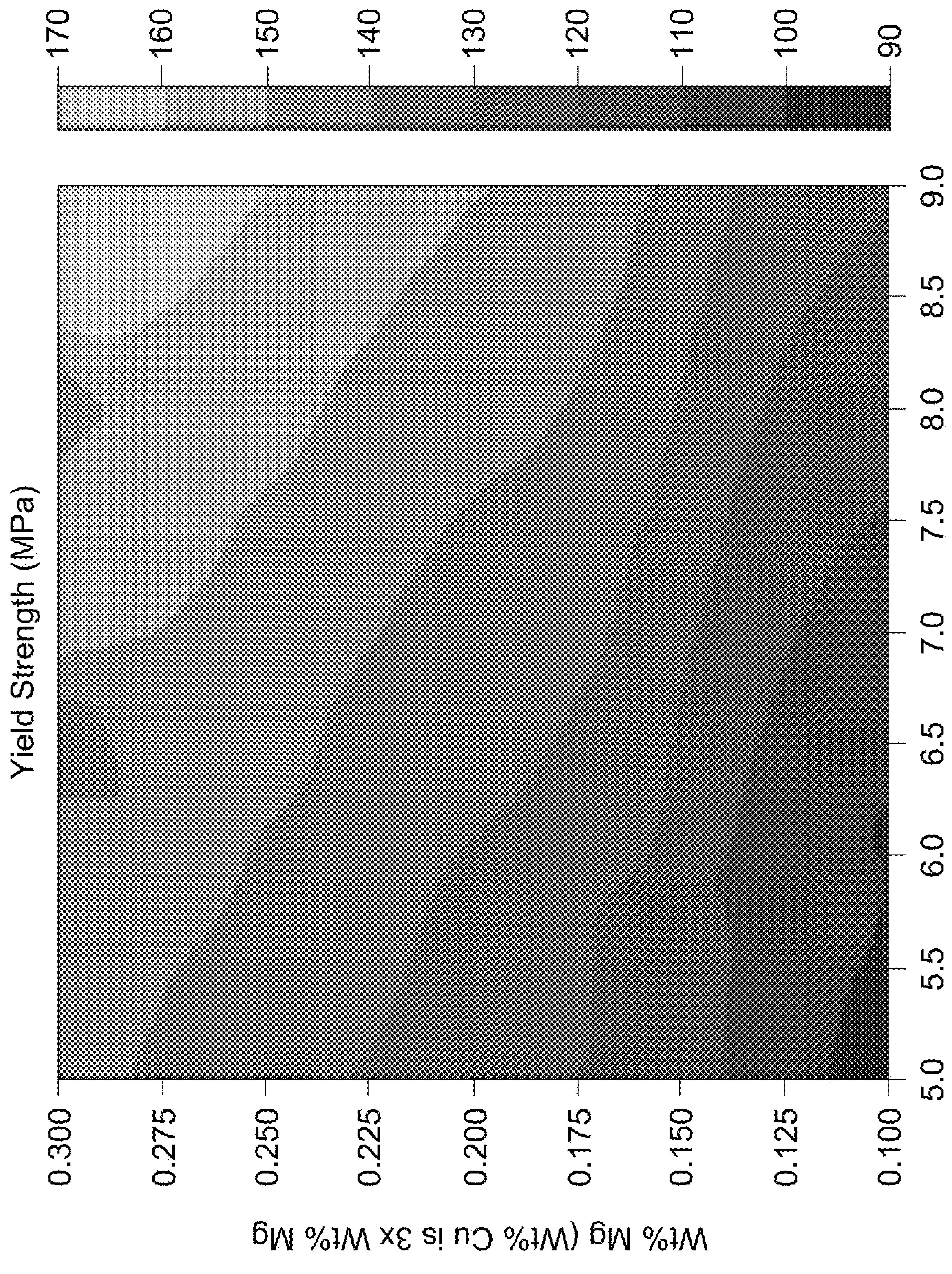
Yield Strength (MPa)
Wt% Mg (Wt% Cu is 3x Wt% Mg
0.300
0.275
0.250
0.225
0.200
0.175
0.150
0.125
0.100
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
170
160
150
140
130
120
110
100
90

FIG. 7

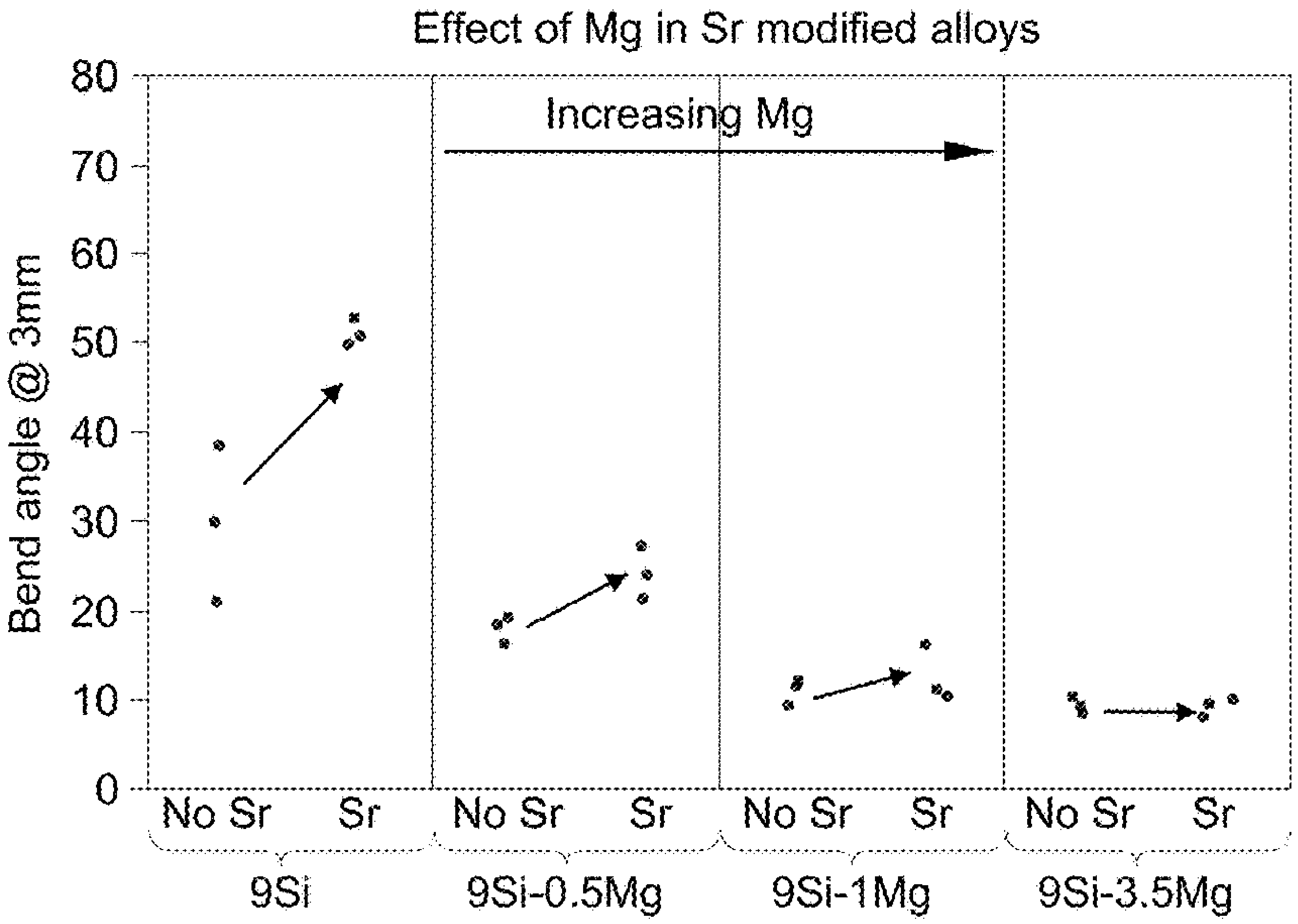
Effect of Mg in Sr modified alloys
Increasing Mg
Bend angle @ 3mm
80
70
60
50
40
30
20
10
0
No Sr
Sr
No Sr
Sr
No Sr
Sr
No Sr
Sr
9Si
9Si-0.5Mg
9Si-1Mg
9Si-3.5Mg

FIG. 8A

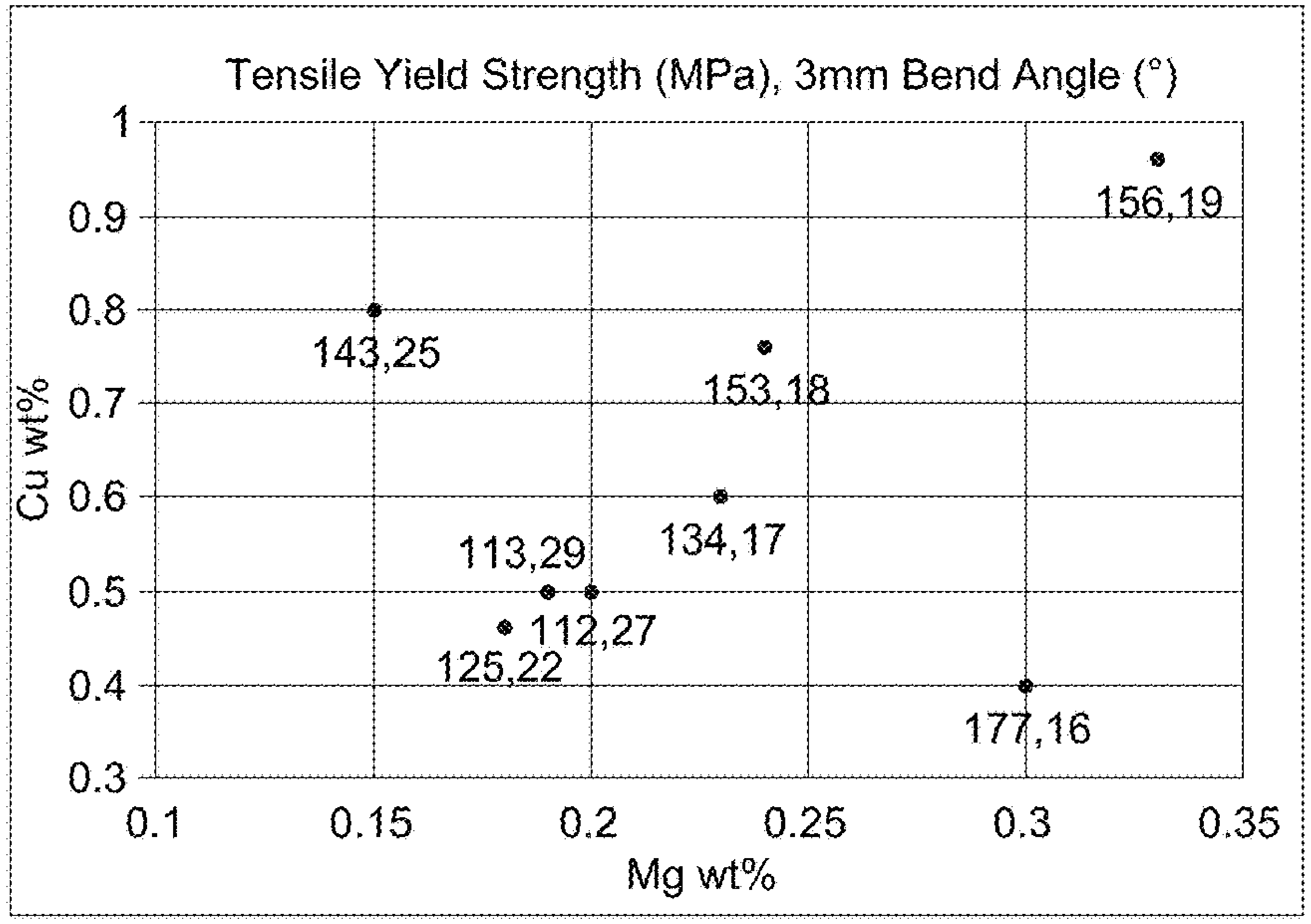
Tensile Yield Strength (MPa), 3mm Bend Angle (°)
Cu wt%
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.1
0.15
0.2
0.25
0.3
0.35
Mg wt%
156,19
143,25
153,18
134,17
113,29
112,27
125,22
177,16

FIG. 8B

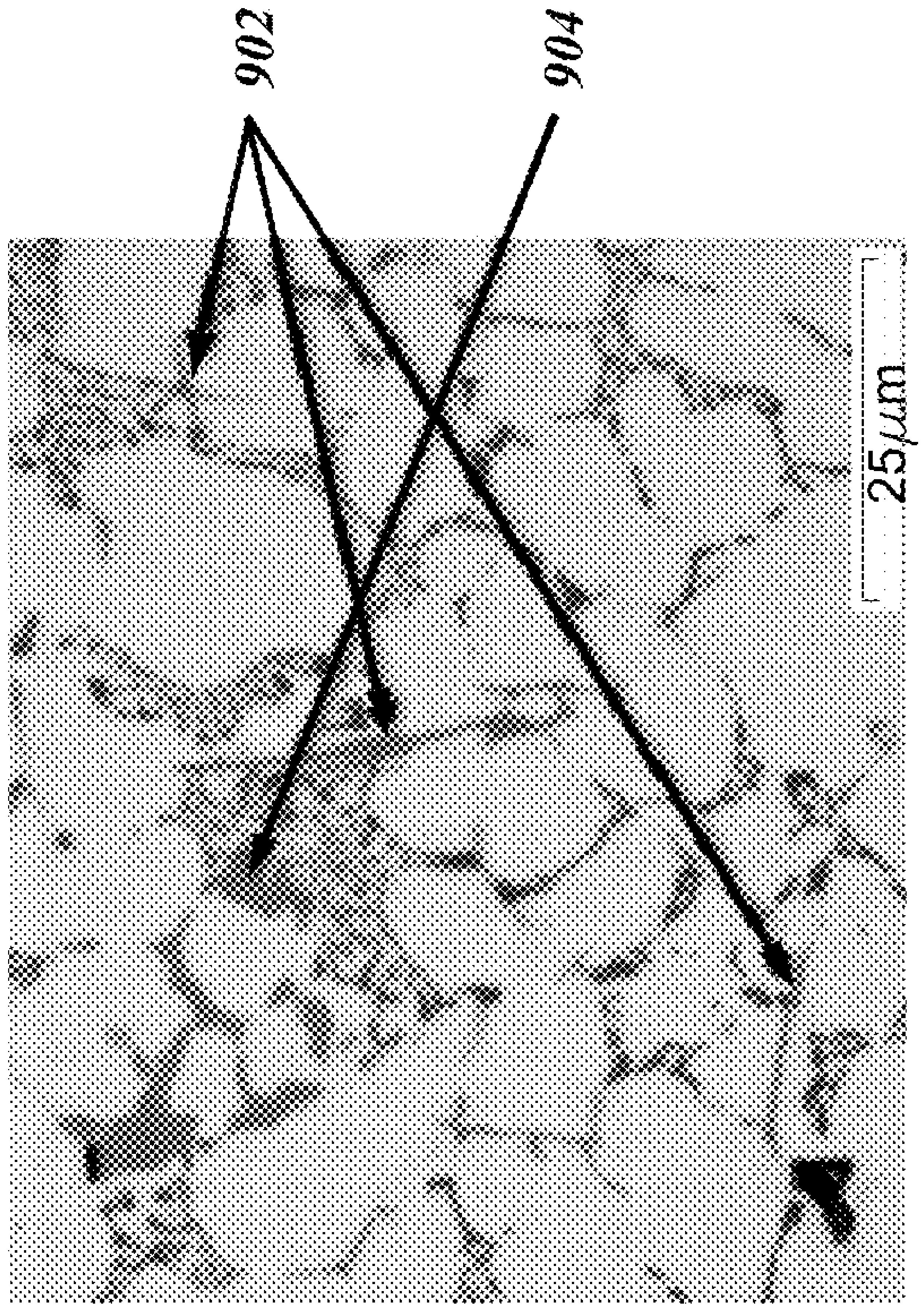

FIG. 9A

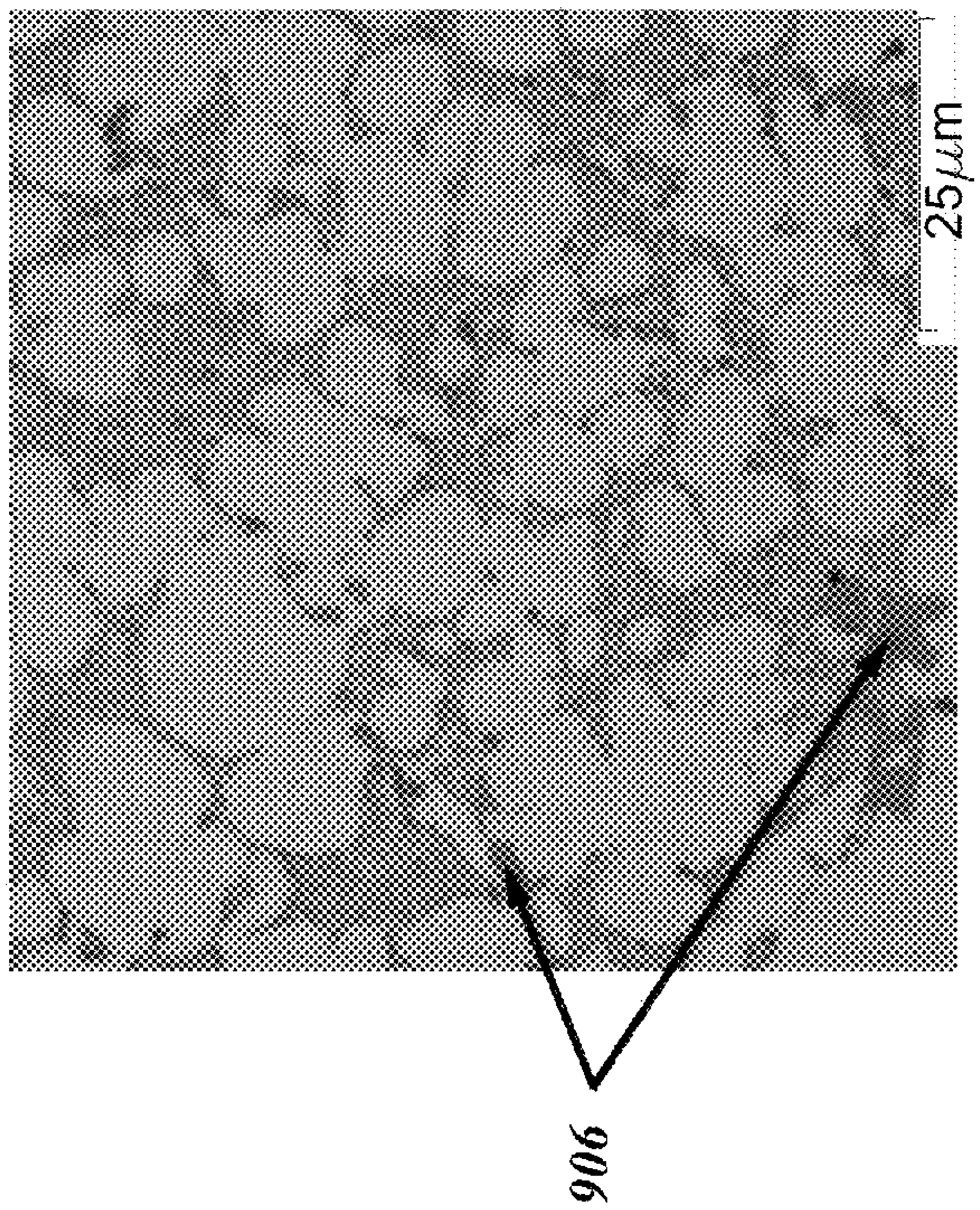

FIG. 9B

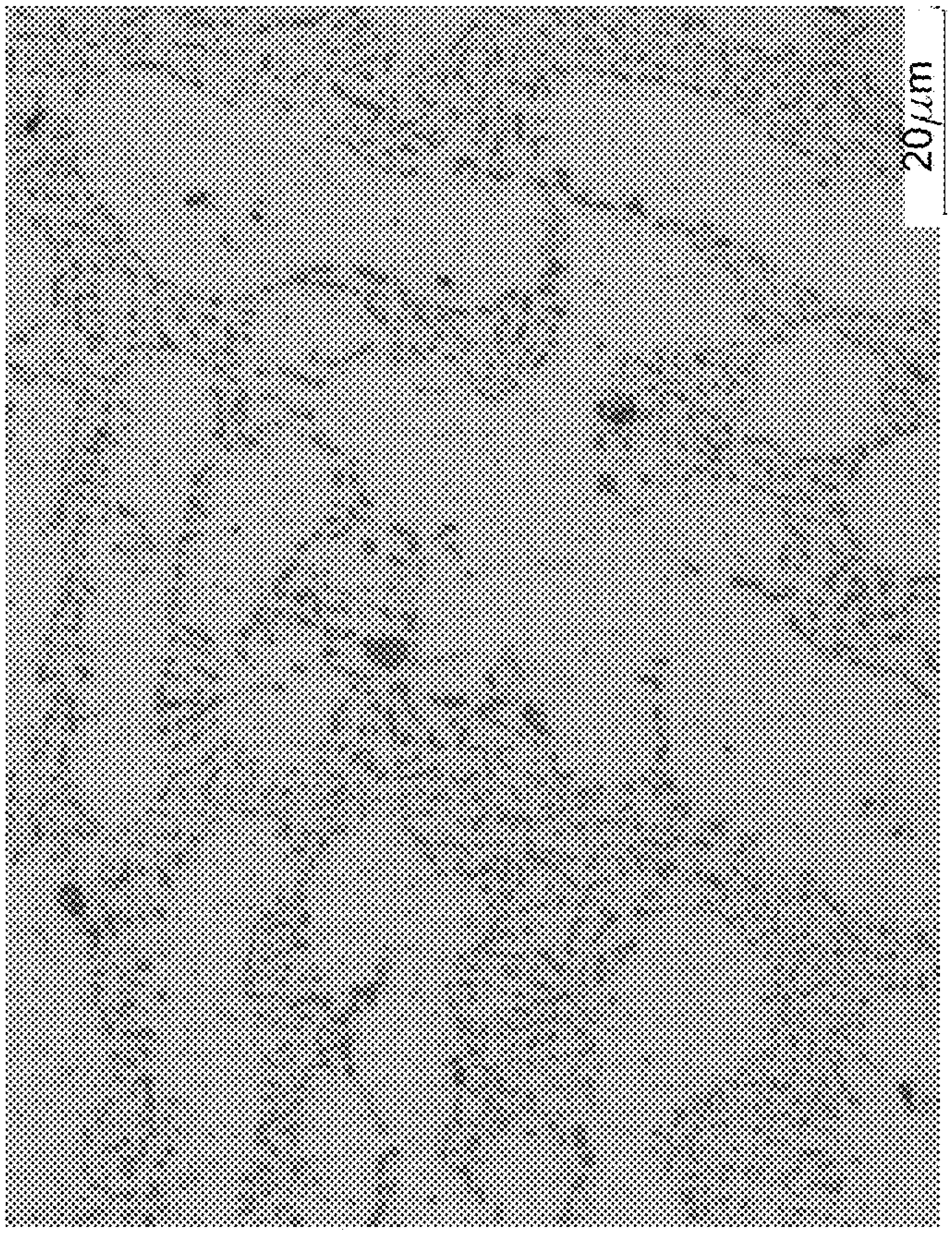

FIG. 10B

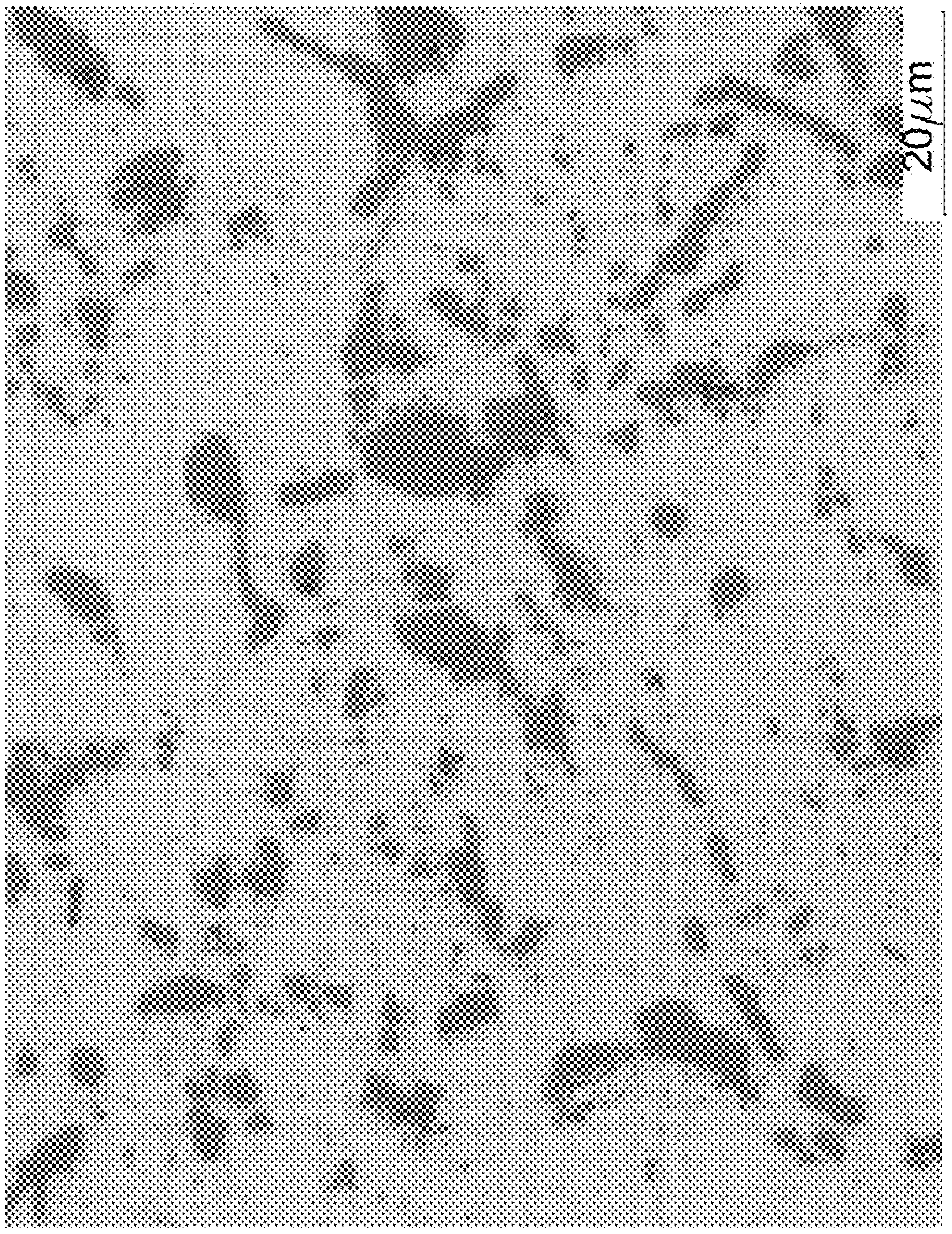

FIG. 10A

DIE CAST ALUMINUM ALLOYS FOR STRUCTURAL COMPONENTS

INCORPORATION BY REFERENCE TO ANY PRIORITY APPLICATIONS

[0001] Any and all applications for which a foreign or domestic priority claim is identified, for example, in the Application Data Sheet or Request as filed with the present application, are hereby incorporated by reference under 37 CFR 1.57, and Rules 4.18 and 20.6, such as U.S. Provisional Application No. 62/964,554, filed Jan. 22, 2020, and U.S. Provisional Application No. 63/093,608, filed Oct. 19, 2020, are hereby incorporated by reference in their entirety.

BACKGROUND

Field

[0002] The present invention relates to aluminum alloys. More specifically, the present invention relates to aluminum alloys with improved strength, ductility, and castability for high-performance applications including automobile parts.

Description of the Related Art

[0003] Commercial cast aluminum alloys for certain applications, for example structural components within an electric vehicle chassis, generally require both high strength and ductility. It is desirable to form these parts through a casting process, such that the parts may be cast quickly and reliably, such as through a high pressure die casting process. After casting, suitable alloys should maintain their structural properties sufficiently for the necessary application. Poor castability of the alloy often results in observed hot tearing, and can cause fill issues which typically decreases the mechanical properties of the part that results from the casting process. Furthermore, many structural components that are die cast may require heat treating, quenching, solution treating or aging the component after being cast to improve strength or ductility. However, heat treatment may require a large capital expenditure, long process time, and can cause costly yield loss. These issues are compounded by large part sizes which may be complicated to put through a heat treatment process, such as a quenching process.

[0004] It may be desirable to produce cast aluminum alloys with high yield strengths such that the alloys do not fail easily, while also containing sufficient ductility. Furthermore, it may be desirable to produce cast aluminum alloys that do not require a heat treatment.

SUMMARY

[0005] For purposes of summarizing the disclosure and the advantages achieved over the prior art, certain objects and advantages of the disclosure are described herein. Not all such objects or advantages may be achieved in any particular embodiment. Thus, for example, those skilled in the art will recognize that the invention may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other objects or advantages as may be taught or suggested herein.

[0006] All of these embodiments are intended to be within the scope of the invention herein disclosed. These and other embodiments will become readily apparent to those skilled in the art from the following detailed description of the preferred embodiments having reference to the attached figures, the invention not being limited to any particular preferred embodiment(s) disclosed.

[0007] In one aspect, an alloy composition is described. The alloy composition includes Al, wherein the alloy comprises a yield strength of at least about 130 MPa and a bend angle of at least about 20° at a 3 mm section thickness when as-cast and without further processing.

[0008] In some embodiments, the alloy comprises a yield strength of at least about 130 MPa when as-cast and without further processing. In some embodiments, the alloy comprises a bend angle of at least about 24° at a 3 mm section thickness when as-cast and without further processing. In some embodiments, the alloy comprises a flow length of at least about 1.8 in. In some embodiments, the alloy comprises an α-Al volume fraction of at least about 90%.

[0009] In some embodiments, the alloy comprises about 0.03 wt. % to about 0.25 wt. % of Mg_2Si phases. In some embodiments, the alloy comprises about 0.01 wt. % to about 0.9 wt. % of Al_2Cu phases. In some embodiments, the alloy comprises about 0.03 wt. % to about 0.2 wt. % of AlCuMgSi phases. In some embodiments; the alloy comprises about 0.3 wt. % to about 3 wt. % of AlFeSi phases. In some embodiments, the alloy composition further comprises Cu and Mg, wherein a weight ratio of Cu:Mg is about 4:1 to about 1:1. In some embodiments; the alloy has an oxygen reduction factor (ORF) with respect to A380 kinetics of at most about 1.

[0010] In some embodiments, the alloy composition further comprises one or more of:

[0011] Si at about 6.5-7.5 wt. %;
[0012] Cu at about 0.4-0.8 wt. %;
[0013] Mn at about 0.3-0.7 wt. %:
[0014] Mg at about 0.1-0.4 wt. %;
[0015] Fe at most about 0.4 wt. %;
[0016] V at about 0.05-0.15 wt. %;
[0017] Sr at about 0.01-0.03 wt. %;
[0018] Ti at most about 0.15 wt. %;
[0019] Cr at most about 0.03 wt. %; and
[0020] remainder Al and incidental impurities.

[0021] In some embodiments, the alloy composition further comprises one or more of:

[0022] Si at about 6.5-7.5 wt. %;
[0023] Cu at about 0,4-0.8 wt. %;
[0024] Mn at about 0.3-0.7 wt. %;
[0025] Mg at about 0.1-0.4 wt. %;
[0026] Fe at most about 0.4 wt. %;
[0027] V at about 0.05-0.15 wt. %;
[0028] Sr at about 0.01-0.03 wt %;
[0029] Ti at most about 0.15 wt. %;
[0030] Cr at most about 0.03 wt. %; and
[0031] remainder Al and incidental impurities.

[0032] In some embodiments, the alloy composition further comprises one or more of:

[0033] Si at about 6-11 wt. %;
[0034] Cu at about 0.3-0.8 wt %;
[0035] Mn at about 0.3-0.8 wt. %;
[0036] Mg at about 0.1-0.4 wt. %;
[0037] Fe at most about 0.5 wt. %;
[0038] V at about 0.05-0.15 wt. %;
[0039] Sr at about 0.01-0.05 wt. %;
[0040] Ti at most about 0.15 wt. %;
[0041] Cr at most about 0.03 wt. %: and
[0042] remainder Al and incidental impurities.

[0043] In some embodiments, the incidental impurities are at most about 0.1 wt. %.

[0044] In another aspect, an automobile article including the alloy composition is described. In some embodiments, the automobile article is an automobile chassis.

[0045] In one aspect, a process for preparing an alloy is described. The process includes providing alloy components, wherein at least one of the alloy components comprises Al, melting the alloy components to form a melted alloy, and cooling the melted alloy to form an as-cast alloy, wherein the as-cast alloy comprises a yield strength of at least about 130 MPa and a bend angle of at least about 200 at a 3 mm section thickness.

[0046] In some embodiments, further processing is not performed on the as-cast alloy. In some embodiments, the process further comprises die-casting the melted alloy. In some embodiments, die-casting is high-pressure die-casting (HPDC), In some embodiments, the process further comprises further processing the as-cast alloy to form a processed alloy. In some embodiments, the further processing step is selected from the group consisting of heat treating, aging, solution treating, surface finishing and combinations thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[0047] FIG. **1** is a chart showing bend angles and yield strengths numerous commercial alloys and the target alloys of some embodiments.

[0048] FIG. **2** is a bar chart showing the predicted and tested yield strengths of alloys of some embodiments.

[0049] FIG. **3**A is a plot of bend angles and ot-aluminum volume fractions for alloys of some embodiments.

[0050] FIG. **3**B is a plot of bend angles and magnesium/nickel content for alloys of some embodiments.

[0051] FIG. **4** is a bar chart showing the predicted and tested normalized flow lengths of alloys of some embodiments.

[0052] FIG. **5** is a plot showing bend angles and yield strengths for alloys of some embodiments.

[0053] FIG. **6**A is a bar chart showing experimental results of flow lengths and silicon content for alloys of some embodiments.

[0054] FIG. **6**B is a line graph showing calculated results demonstrating the relationship between bend angle and FCC mole fraction as a function of silicon content for alloys of some embodiments.

[0055] FIG. **7** is a predictive model chart showing yield strengths at Cu:Mg ratios of 3:1 at various magnesium and silicon weight percentages for alloys of some embodiments.

[0056] FIG. **8**A is a plot showing experimental results of bend angle for alloys of some embodiments including various magnesium and strontium amounts.

[0057] FIG. **8**B is a plot showing experimental results of tensile yield strength and bend angles for alloys of some embodiments with varying copper and magnesium weight percentages.

[0058] FIG. **9**A is an optical micrograph cross-sectional image of a comparative alloy.

[0059] FIG. **9**B is an optical micrograph cross-sectional image of an alloy according to some embodiments.

[0060] FIG. **10**A is an optical micrograph cross-sectional image of an aluminum and silicon alloy.

[0061] FIG. **10**B is an optical micrograph cross-sectional image of an aluminum, silicon and strontium alloy.

DETAILED DESCRIPTION

[0062] The present disclosure may be understood by reference to the following detailed description. It is noted that, for purposes of illustrative clarity, certain elements in various drawings may not be drawn to scale, may be represented schematically or conceptually, or otherwise may not correspond exactly to certain physical configurations of embodiments.

[0063] Embodiments relate to aluminum alloys useful for creating products such as vehicle chassis or chassis components. In one embodiment, the vehicle is an electric vehicle powered by a battery pack. In one embodiment, the alloys were created to provide sufficient castability, and also provide relatively high yield strength and ductility, as well as eliminating the need for subsequent heat treatment of the cast alloy. In one embodiment, the alloy comprises a yield strength of at least about 130 MPa and a bend angle of at least about 20° at a 3 mm section thickness when as-cast and without further processing. In one embodiment, the aluminum alloys comprise vanadium to provide many of these enhancements. In another embodiment, the aluminum alloy has a specific weight ratio of copper to magnesium to provide many of these enhancements of an alloy with the desired features. In one embodiment, the aluminum alloy has a weight ratio of Cu:Mg of about 4:1 to about 1:1. In one embodiment, the aluminum alloy has a weight ratio of Cu:Mg of about 4:1 to about 2:1. As mentioned below, aluminum alloys with these compositions were found to have high yield strength and high ductility compared to available aluminum alloys. As mentioned below, the aluminum alloys are described herein by the weight percent (wt %) of the total elements and particles within the alloy, as well as specific properties of the alloys. It will be understood that the remaining composition of any alloy described herein is aluminum and incidental impurities.

Aluminum Alloy Coinpositions

[0064] FIG. **1** is a chart showing bend angles and yield strengths numerous commercial high pressure die cast (HPDC) alloys. The target alloy mechanical requirements in FIG. **1** are shown to be greater than 135 MPa yield strength and greater than 24 degree bend angle. However, FIG. **1** demonstrates that the commercial alloys either require heat treatment to meet the necessary mechanical requirements, or do not meet the necessary requirements.

[0065] In contrast, embodiments of the disclosure relate to casting aluminum alloys with both high yield strength and high ductility, without the need for post-casting heat treatment. The aluminum alloys were found to have high yield strength and high ductility compared to conventional, commercially available aluminum alloys. The aluminum alloys are described herein by the weight percent (wt %) of the total elements and particles within the alloy, as well as specific properties of the alloys. It will be understood that the remaining composition of any alloy described herein is aluminum and incidental impurities.

[0066] impurities may be present in the starting materials or introduced in one of the processing and/or manufacturing steps to create the aluminum alloy. Incidental impurities are compounds and/or elements that do not or do not substantially affect the material properties of the composition, such as yield strength, ductility and eliminating the need for heat treatment. In some embodiments, the total incidental impurities are, are about, are at most, or are at most about, 1 wt. %, 0.5 wt %, 0.2 wt. % 0.1 wt. %, 0.05 wt. % or 0.01 wt. %, or any range of values therebetween. in embodiments, the total incidental impurities are, are about, are at most, or are at most about, 1 wt. %, 0.5 wt. %, 0.2 wt. % 0.1 wt. %, 0.05 wt. % or 0.01 wt. %, or any range of values therebetween. In some embodiments, each elemental incidental impurity is, is about, is at most, or is at most about, 0.5 wt. %, 0.2 wt. % 0.1 wt. %, 0.05 wt. %, 0.01 wt. %, 0.005 wt. % or 0.001 wt. %, or any range of values therebetween.

[0067] In some embodiments, the aluminum alloy composition comprises Si in the range of, or of about, 6.5-7.5 wt %, Cu in the range of, or of about, 0.4-0.8 wt %, Mn in the range of, or of about, 0.3-0.7 wt %, Mg in the range of, or of about, 0.2-0.4 wt %, Fe of at most, or of at most about, 0.4 wt %, V in the range of, or of about, 0.05-0.15 wt %, Sr in the range of, or of about, 0.01-0.03 wt %, Ti of at most, or of at most about, 0.15 wt %, Cr of at most, or of at most about, 0.03 wt %, with the remaining composition (by wt %) being Al and incidental impurities, wherein the maximum incidental impurities total 0.15 or 0.1 wt %. In some embodiments, each elemental incidental impurity is, is about, is at most, or is at most about 0.05 wt %.

[0068] In some embodiments, the aluminum alloy composition comprises Si in the range of, or of about, 6.5-11 wt %, Cu in the range of, or of about, 0.3-0.8 wt %, Mn in the range of, or of about, 0.3-0.8 wt %, Mg in the range of, or of about, 0.1-0.4 wt %, Fe of at most, or of at most about, 0.5 wt %, V in the range of, or of about, 0.05-0.15 wt %, Sr in the range of, or of about, 0.01-0.05 wt %, Ti of at most, or of at most about, 0.15 wt %, Cr of at most, or of at most about, 0.03 wt %, with the remaining composition (by wt %) being Al and incidental impurities, wherein the maximum incidental impurities total 0.15 or 0.1 wt %. In some embodiments, each elemental incidental impurity is, is about, is at most, or is at most about 0.05 wt %.

[0069] In some embodiments, the aluminum alloy composition comprises silicon (Si) in an amount of, of about, of at most, or of at most about, 15 wt. %, 13 wt. %, 12 wt. %, 11 wt. %, 10 wt. %, 9 wt. %. 8 wt. %, 7 wt. %, 6 wt. %, 5 wt. % or 3 wt. %, or any range of values therebetween. In some embodiments, the aluminum alloy composition comprises copper (Cu) in an amount of, of about, of at most, or of at most about, 1 wt. %, 0.9 wt. %, 0.8 wt. %, 0.7 wt. %, 0.6 wt. %, 0.5 wt. %, 0.4 wt. %, 0.3 wt. %, 0.2 wt. % or 0.1 wt. %, or any range of values therebetween. In some embodiments, the aluminum alloy composition comprises manganese (Mn) in an amount of, of about, of at most, or of at most about, 0.6 wt. %, 0.5 wt. %, 0.45 wt. %, 0.4 wt. %, 035 wt. %, 0.3 wt. %, 0.75 wt. %, 0.2 wt. %, 0.15 wt. %, 0.1 wt. % or 0.05 wt. %, or any range of values therebetween. In some embodiments, the aluminum alloy composition comprises iron (Fe) in an amount of, of about, of at most, or of at most about, 0.8 wt. %, 0.7 wt. %, 0.6 wt. %, 0.5 wt. %, 0.4 wt. %, 0.3 wt. %, 0.2 wt. %, 0.1 wt. %, 0.05 wt. %, or 0.01 wt. %, or any range of values therebetween. In some embodiments, the aluminum alloy composition comprises vanadium (V) in an amount of, of about, of at most, or of at most about, 4 wt %, 3 wt. %, 2.5 wt. %, 2 wt. %, 1.5 wt. %, 1 wt. %, 0.5 wt. %, 0.4 wt. %, 0.3 wt. %, 0.2 wt. %, 0.1 wt. % or 0.05 wt. %, or any range of values therebetween. In some embodiments, the aluminum alloy composition comprises strontium (Sr) in an amount of, of about, of at most, or of at most about, 0.1 wt. %, 0.08 wt. %, 0.07 wt. %, 0.06 wt. %, 0.05 wt. %, 0.045 wt. %, 0.04 wt. %, 0.035 wt. %, 0.03 wt. %, 0.025 wt. %, 0.02 wt %, 0.015 wt. %, 0.01 wt. % or 0.005 wt. %, or any range of values therebetween. In some embodiments, the aluminum alloy composition comprises titanium (Ti) in an amount of, of about, of at most, or of at most about, 0.3 wt. %, 0.2 wt. %, 0.15 wt. %, 0.14 wt. %, 0.13 wt. %, 0.12 wt. %, 0.1 wt. %, 0.08 wt. %, 0.07 wt. %, 0.06 wt. %, 0.05 wt. %, 0.04 wt. %, 0.03 wt. %, 0.02 wt. %, 0.01 wt. % or 0.005 wt. %, or any range of values therebetween. In some embodiments, the aluminum alloy composition comprises chromium (Cr) in an amount of, of about, of at most, or of at most about, 0.1 wt. %, 0.07 wt. %, 0.05 wt. %, 0.04 wt. %, 0.03 wt. %, 0.02 wt. %, 0.01 wt. % or 0.005 wt. %, or any range of values therebetween. In some embodiments, the aluminum alloy composition comprises each elemental incidental impurity in an amount of, of about, of at most, or of at most about, 0.1 wt. %, 0.07 wt. %, 0.05 wt. %, 0.04 wt. %, 0.03 wt. %, 0.02 wt. %, 0.01 wt. % or 0.005 wt. %, or any range of values therebetween. In some embodiments, the aluminum alloy composition comprises a maximum incidental impurities total in an amount of, of about, of at most, or of at most about, 0.3 wt. %, 0.2 wt. %, 0.15 wt. %, 0.1 wt. %, 0.07 wt. %, 0.05 wt. %, 0.04 wt. %, 0.03 wt. %, 0.02 wt. %, 0.01 wt. % or 0.005 wt. %, or any range of values therebetween.

[0070] In some embodiments, the aluminum alloy composition comprises a weight ratio of Cu:Mg in an amount of, or of about, 4:1, 3.5:1, 3:1, 2.5:1, 2:1, 1.5:1 or 1:1, or any range of values therebetween.

[0071] In some embodiments, the α-Al volume fraction of an alloy is, is about, is at least, or is at least about, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98% or 99%, or any range of values therebetween.

[0072] In some embodiments, the aluminum alloy composition comprises Mg_2Si phases in, in about in less than, or less than about, 2 wt. %, 1.5 wt. %, 1 wt. %, 0.9 wt. %, 0.8 wt. %, 0.7 wt. %, 0.6 wt. %, 0.5 wt. %, 0.45 wt. %, 0.4 wt. %, 0.35 wt. %, 0.3 wt. %, 025 wt. %, 0.2 wt. %, 0.15 wt. %), 0.1 wt. %, 0.05 wt. %, 0.04 wt. %, 0.03 wt. %, 0.02 wt. %, 0.01 wt. % or 0.005 wt. %, or any range of values therebetween. In some embodiments, the aluminum alloy composition comprises Al_2Cu phases in, in about, in less than, or less than about, 2 wt. %, 1.7 wt. %, 1.5 wt. %, 1.4 wt. %, 1.3 wt. %, 1.2 wt. %, 1.1 wt. %, 1 wt. %, 0.9 wt. %, 0.8 wt. %, 0.7 wt. %, 0.6 wt. %, 0.5 wt. %, 0.45 wt. %, 0.4 wt. %, 0.35 wt. %, 0.3 wt. %, 0.25 wt. %, 0.2 wt. %, 0.15 wt. %, 0.1 wt. %, 0.05 wt. %, 0.04 wt. %, 0.03 wt. %, 0.02 wt. %, 0.01 wt. %, 0.008 wt. %, 0.005 wt. % or 0.001 wt. %, or any range of values therebetween. In some embodiments, the aluminum alloy composition comprises AlCuMgSi phases in, in about, in at least, or in at least about, 2 wt. %, 1.7 wt. %, 1.5 wt. %, 1.4 wt. %, 1.3 wt. %, 1.2 wt. %, 1.1 wt. %, 1 wt. %, 0.9 wt. %, 0.8 wt. %, 0.7 wt. %, 0.6 wt. %, 0.5 wt. %, 0.45 wt. %, 0.4 wt. %, 0.35 wt. %, 0.3 wt. %, 0.25 wt. %, 0.2 wt. %, 0.15 wt. %, 0.1 wt %, 0.05 wt. %, 0.04 wt. %, 0.03 wt. %, 0.02 wt. %, 0.01 wt. %, 0.008 wt. %, 0.005 wt. % or 0.001 wt. %, or any range of values therebetween. In some embodiments, the aluminum alloy composition comprises AlFeSi phases in, in about, in less than, less than about, in at least, or in at least about, 6 wt. %, 5 wt. %, 4.5 wt. %, 4 wt. %, 3.7 wt. %, 3.5 wt. %, 3.4 wt. %, 3.2 wt. %, 3.1 wt. %, 3 wt. %, 2.9 wt. %, 2.8 wt. %, 2.7 wt. %, 2.6 wt. %, 2.5 wt. %, 2.4 wt. %, 2.2 wt. %, 2 wt. %, 1.8 wt. %, 1.5 wt. %, 1.2 wt. %, 1 wt. %, 0.9 wt. %, 0.8 wt. %, 0.7 wt. %, 0.6 wt.

%, 0.5 wt. %, 0.45 wt. %, 0.4 wt. %, 0.35 wt. %, 0.3 wt. %, 0.25 wt. %, 0.2 wt. %, 0.15 wt. %, 0.1 wt. % or 0.05 wt. %, or any range of values therebetween.

Alloy Yield Strength

[0073] Industrial applications in which thousands and hundreds-of-thousands of aluminum alloy parts may be cast can require high yield strength. As seen in, FIG. **2** the predicted and tested yield strengths of alloys of embodiments 1B3, 2F5, 3D2, 3C1, 3I1, 365-3, 365-2, 1B4, 3C3a, 3C3b, 3I3a, 3I3b and 3D3 were evaluated.

[0074] The yield strength of the aluminum alloys described herein are at least or at least about 120 MPa. In some embodiments, the yield strength is, is about, is at least, or is at least about, 120 MPa, 125 NIPa, 130 MPa, 135 MPa, 140 MPa, 145 MPa, 150 MPa, 155 MPa, 160 MPa, 165 MPa, 170 MPa, 180 MPa or 200 MPa, or any range of values therebetween. In some embodiments, the yield strength is, or is about, 120 MPa, 125 MPa, 130 MPa, 135 MPa, 140 MPa, 115 MPa, 150 MPa, 155 MPa, 160 MPa, 165 MPa, 170 MPa, 180 MPa or 200 MPa, or any range of values therebetween.

Alloy Ductility

[0075] The ductility of metal alloy should also be considered such that the parts are reproducibly manufacturable by using a casting process. Ductility of an alloy may be measured by the bend angle and/or the elongation of the alloy, although bend angle is preferred.

[0076] FIG. **3**A is a plot of bend angles and α-aluminum volume fractions for alloys, and FIG. **3B** is a plot of bend angles and magnesiumlnickel content for alloys of some embodiments.

[0077] In some embodiments, bend angle of an alloy is, is about, is at least, or is at least about, 15°, 20°, 23°, 25°, 30°, 35°, 40°, or 50°, or any range of values therebetween. In some embodiments, bend angle is, or is about, 15°, 20°, 23°, 25°, 30°, 35°, 40°, 50° or 60°, or any range of values therebetween. In some embodiments, the bend angle is measured at a 3 mm section thickness. In some embodiments, the bend angle is measured using the VDA238-1.00 evaluation standards. In some embodiments,

Die Cast Performance and Flowability

[0078] In addition to sufficient yield strength and ductility when cast, the as-cast aluminum alloy must provide sufficient flowability and resistance to hot tearing and shrinkage cracking when high pressure die cast (HPDC). Unless specified otherwise, flow lengths described herein are under HPLC conditions. In a metal casting process, the metal alloy must have sufficient flowability to flow into and fill all intricacies of the mold. In molds with narrow and/or long mold channels, a sufficiently high flowability of the alloy is required to fill the mold. FIG. **4** is a bar chart showing the predicted and tested normalized flow lengths under HPDC conditions of alloys of some embodiments.

[0079] A formula for predicting the flow length of alloys within a sand casting under HPDC conditions is shown below.

$$L_f = \frac{\rho^{0.2}}{(T_{0.65} - T_0)}(H_L + c_p \Delta T)$$

[0080] Hot tearing and shrinkage cracking are common and catastrophic defects observed when casting alloys, including aluminum alloys. Without being able to prevent hot tearing in alloy, reliable and reproducible parts cannot be created. Hot tearing is the formation of an irreversible crack while the cast part is still in the semisolid casting. Although hot tearing is often associated with the casting process itself—linked to the creation of thermal stresses during the shrinkage of the melt flow during solidification, the underlying thermodynamics and microstructure of the alloy plays a part.

[0081] In some embodiments, the alloy has a casting flow length under HPDC conditions of, of about, of at least, or of at least about, 1 m, 1.1 m, 1.2 m, 1.3 m, 1.4 m, 1.5 m, 1.6 m, 1.7 m, 1.8 m, 1.9 m, 2 m, 2.2 m, 2.5 m, 3 m or 5 m, or any range of values therebetween. In some embodiments, the alloy does not, or does not substantially, develop hot tears and/or shrinkage cracks throughout the casting flow length.

Corrosion/Oxidation Resistance

[0082] Structural castings are expected to last within punishing environments for automotive applications. In some embodiments, the as-cast alloys are resistant to corrosion and/or oxidation. In some embodiments, the alloy has an oxygen reduction factor (ORF) with respect to A380 kinetics of, of about, of at most, or of at most about, 2, 1.5, 1, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2 or 0.1, or any range of values therebetween. A formula for calculating ORF is shown below.

$$ORF = \frac{[a_1 V_1 + a_2 V_2 + a_3 V_3 + \cdots\ ]}{i_{A380}} = \frac{\sum_{i=1}^{n} a_i V_i}{i_{A380}}$$

where:

[0083] a_i=current density associated with noble phase i (refer to Table 3)

[0084] V_i=volume fraction of noble phase i

[0085] i_{A380}=oxygen reduction current density of cast A380 (baseline alloy) at −965 mV_{SCE}

Processing Methods

[0086] In some embodiments, a melt for an alloy can be prepared by heating the alloy above the melting temperature of the alloy components. As the melt is cast and cooled to room temperature, the alloys may go through cooling at various rates. The processing conditions can create larger or smaller grain sizes, increase or decrease the size and number of precipitates, and help minimize as-cast segregation.

[0087] In some embodiments, the alloy is die-cast. In some embodiments, the alloy is high pressure die-cast (HPDC). In certain embodiments, the aluminum alloy is cast without further processing. In some embodiments, the as-cast aluminum alloy is not further processed through heat treatment, and maintains the yield strength and ductility as mentioned above. In other embodiments, the as-cast aluminum alloy is further processed. In some embodiments, further processing methods include heat treating, aging, solution treating and surface finishing.

[0088] In certain embodiments, the after the aluminum-alloy melt has been formed, it may be cast into a die to form a high-performance product or part. In some embodiments, product can be part of an automobile, such as parts of chassis and/or other crash components.

EXAMPLES

Example 1

[0089] Predictive models were performed to calculate yield strengths and ductility (e.g. bend angle) of aluminum alloy cast without further heat treatment processing. A number of predictive aluminum alloy compositions were created and experimentally tested for their as-cast yield strengths and ductility without heat treatment, including compositions 3C1, 3C3a, 3C3b, 3C4, 3C5, 3C6, 3C7, 3C8, 3C9 and 3C10. The results of these experimental tests are shown in FIG. **5**, which is a plot showing bend angles and yield strengths of alloy compositions 3C1, 3C3a, 3C3b, 3C4, 3C5, 3C6, 3C7, 3C8, 3C9 and 3C10.

[0090] The elemental weight percent compositions of alloy compositions 3C1, 3C3a, 3C3b, 3C4, 3C5, 3C6, 3C7, 3C8, 3C9 and 3C10, with the remainder of the compositions being aluminum, are shown below in Table 1. The as-cast aluminum alloy composition of 3C10 was found to have a yield strength of about 143 MPa and a bend angle of about 25°, and the composition of aluminum alloy 3C10 that falls within Alloys 1, 2 and 3 shown below in Table 2.

TABLE 1

Alloy	Composition (wt %)									
ID	Al	Si	Mg	Mn	Ni	Cu	Fe	Ti	Sn	V	Sr
3C1	Remain	6	—	1	—	0.5	0.2	—	0.05	—	0.03
3C3a	Remain	7	—	0.45	—	0.8	0.2	—	—	—	0.03
3C3b	Remain	7	0.3	0.45	—	0.8	0.2	—	—	—	0.03
3C4	Remain	6.5	0.25	0.35	—	0.75	0.2	0.1	—	0.15	0.03
3C5	Remain	5	0.3	0.35	—	0.9	0.2	0.10	—	0.15	0.03
3C6	Remain	6.5	0.15	0.35	—	0.45	0.2	0.10	—	0.15	0.03
3C7	Remain	6.5	0.15	0.35	0.05	0.45	0.2	0.10	—	0.15	0.03
3C8	Remain	6.5	0.15	0.35	—	0.45	0.2	—	—	0.15	0.03
3C9	Remain	7	0.25	0.35	—	0.5	0.2	0.05	—	0.1	0.03
3C10	Remain	7	0.15	0.45	—	0.8	0.2	0.05	—	0.1	0.03

TABLE 2

Element	Alloy 1	Alloy 2	Alloy 3
Al	Remainder	Remainder	Remainder
Si	6.5-7.5 wt. %	6-11 wt. %	6-11 wt. %
Cu	0.4-0.8 wt. %	0.3-0.8 wt. %	0.3-0.8 wt. %
Mn	0.35-0.7 wt. %	0.35-0.8 wt. %	0.35-0.8 wt. %
Mg	0.1-0.4 wt. %	0.15-0.4 wt. %	0.1-0.4 wt. %
Fe	≤0.4 wt. %	≤0.5 wt. %	≤0.5 wt. %
V	0.05-0.15 wt. %	0.05-0.15 wt. %	0.05-0.15 wt. %
Sr	0.015-0.03 wt. %	0.015-0.05 wt. %	0.015-0.05 wt. %
Ti	≤0.15 wt. %	≤0.15 wt. %	≤0.15 wt. %
Cr	≤0.03 wt. %	≤0.03 wt. %	≤0.03 wt. %
Impurities	0-0.15 wt. %	0-0.15 wt. %	0-0.15 wt. %

Example 2

[0091] Although increased silicon content is known to decrease the ductility of an alloy, under traditional die casting conditions for aluminum alloys, silicon content is relatively high, at about 8-12 wt. % in order to have sufficient flowability when cast. This is because the relative increase of heat of fusion attributed to silicon content allows an increase in latent heat contribution such that heat may be retained within the alloy system When cast, and therefore the ahoy may retain its liquid phase for enough time to achieve sufficient casting lengths. However, it is not readily apparent if the same silicon concentrations are necessary for flowability when the alloy is cast in HPDC condition.

[0092] FIG. **6**A is a bar chart showing experimental results of flow lengths and silicon content for alloys of some embodiments under HPDC conditions through a 3 mm section thickness. Castings were made using an about 700 ton high pressure die casting machine and a die designed to maintain even flow front for a 3 mm thick casting up to 2 m in length. The various alloys were tested with the same casting conditions and the castings flow length was quantified.

[0093] FIG. **6**A shows that an alloy composition with 7.5 wt. % silicon had a flow length of about 1.4 meters, an alloy composition with 8.5 wt. % silicon had a flow length of about 1.45 meters, and an alloy composition with 9.5 wt. % silicon had a flow length of about 1.45 meters. As seen, there is a steep drop off in flowability gains of flow length for Si content over 7.5 wt %. Therefore, it was determined that silicon ranges for the alloy composition should be maintained over 6 wt. % to achieve advantageous flow lengths, but could be less than 11 wt. % (e.g. 8 wt. % or 7.5 wt. %) to minimize eutectic silicon phase's effect on reducing ductility. As such, under FIPDC conditions it was discovered that increasing silicon content, relative to silicon content under traditional die casting conditions, did not necessarily improve flow length grow to as great of a degree. This discovery allowed the alloy silicon content to be reduced in order to achieve a HPDC case alloy with relatively longer flow lengths and an improved ductility.

[0094] FIG. **6**B is a line graph showing calculated results demonstrating the relationship between bend angle and FCC (i.e. aluminum matrix) mole fraction as a function of silicon content for alloys of some embodiments. Whereas FCC of aluminum is the most ductile phase present in the alloy composition, the silicon eutectic phase is a relatively more brittle phase. FIG. **6**B demonstrates such a relationship between aluminum and silicon, where increasing silicon content of the alloy results in a reduction in the FCC mole fraction and bend angle.

Example 3

[0095] FIG. **7** is a predictive model chart showing yield strengths at Cu:Mg ratios of 3:1 at various magnesium and silicon weight percentages for alloys of some embodiments. Although increases in copper, magnesium and/or silicon are calculated to increase yield strengths of the alloy in part through the formation of strengthening precipitates (e.g. Mg_2Si, Al_2Cu and AlCuMgSi), decreased aluminum content typically leads to a decrease in alloy ductility. However, FIG. **7** demonstrates that alloys within the silicon compositional ranges of Alloys 1, 2 or 3 of Table 2 and a Cu:Mg ratio of about 3:1 (e.g. 2:1 to 4:1) carefully balances yield strength and ductility. Such a Cu:Mg ratio selection unexpectedly and advantageously promotes the formation of the AleuMgSi precipitate, which improves the alloys yield strength without substantially hindering ductility relative to other precipitates (e.g. M_2Si and/or Al_2Cu).

[0096] FIG. **8**A is a plot showing experimental results of bend angles for alloys of some embodiments including various magnesium and strontium amounts. As demonstrated, magnesium solute content and Mg_2Si are both contributors to yield strength, but have negative effects on ductility.

[0097] FIG. **8**B is a plot showing experimental results of tensile yield strength and bend angles for alloys of some embodiments with varying copper and magnesium weight percentages. As demonstrated, cast 3 mm coupon results matched predictions shown in FIG. **7** of improved yield strengths decreased ductility associated with increased magnesium content.

Example 4

[0098] FIGS. **9**A and **9**B are optical micrograph cross-sectional images of a comparative alloy and an alloy of the present disclosure, respectively, wherein indicated phases were located and analyzed using energy-dispersive X-ray spectroscopy (EDS). The comparative alloy of FIG. **9**A includes less than 0.05 wt % vanadium, which is outside of the range of Alloys 1, 2 and 3 of Table 2. In FIG. **9**A, feature **902** is a AiFeSi(Mn) phase shown with a plate morphology that was found to include less than 0.2 wt. % V, and feature **904** is a AlFeSi(Mn+V) phase with globular morphology more favorable for ductility that was found to include greater than 1.2 wt. % V. A person of ordinary skill in the art would appreciate that increased sharp morphological features (e.g. plate morphologies) in part caused by iron impurities increase alloy crack initiation and propagation.

[0099] In contrast, the alloy of FIG. **9**B shows a decrease in plate morphologies, and generally shows feature **906** of AlFeSi(Mn+V) phase with globular morphology more favorable for ductility, which was found to include greater than 1.2 wt. % V. As such, it is demonstrated that vanadium and manganese may be used to reduce iron impurity solubility and stabilize AlFeSi(Mn,V) phases that have a rounded morphology. This allows the alloy to maintain high ductility performance with higher tolerances of Fe.

Example 5

[0100] FIG. **10**A is an optical micrograph cross-sectional image of an aluminum and silicon alloy with 9.5 wt. % silicon and remainder of aluminum and incidental impurities, and FIG. **10**B is an optical micrograph cross-sectional image of an aluminum, silicon and strontium alloy with 9.5 wt. % silicon, added strontium and remainder of aluminum and incidental impurities. While FIG. **10**A shows silicon eutectic phases with sharp morphologies known to reduce ductility, the use of a strontium alloy the modifier in FIG. **10**B is shown to blunt the silicon phase growth and create an alloy with more rounded morphologies favorable for ductility.

[0101] While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the disclosure. Indeed, the novel methods and systems described herein may be embodied in a variety of other forms. Furthermore, various omissions, substitutions and changes in the systems and methods described herein may be made without departing from the spirit of the disclosure. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the disclosure.

[0102] Features, materials, characteristics, or groups described in conjunction with a particular aspect, embodiment, or example are to be understood to be applicable to any other aspect, embodiment or example described in this section or elsewhere in this specification unless incompatible therewith. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. The protection is not restricted to the details of any foregoing embodiments. The protection extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

[0103] Furthermore, certain features that are described in this disclosure in the context of separate implementations can also be implemented in combination in a single implementation. Conversely, various features that are described in the context of a single implementation can also be implemented in multiple implementations separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations, one or more features from a claimed combination can, in some cases, be excised from the combination, and the combination may be claimed as a subcotnbination or variation of a subcotnbination.

[0104] Moreover, while operations may be depicted in the drawings or described in the specification in a particular order, such operations need not be performed in the particular order shown or in sequential order, or that all operations be performed, to achieve desirable results. Other operations that are not depicted or described can be incorporated in the example methods and processes. For example, one or more additional operations can be performed before, after, simultaneously, or between any of the described operations. Further, the operations may be rearranged or reordered in other implementations. Those skilled in the art will appreciate that in some embodiments, the actual steps taken in the processes illustrated and/or disclosed may differ from those shown in the figures. Depending on the embodiment, certain of the steps described above may be removed, others may be added. Furthermore, the features and attributes of the specific embodiments disclosed above may be combined in different ways to form additional embodiments, all of which fall within the scope of the present disclosure. Also, the separation of various system components in the implementations described above should not be understood as requiring such separation in all implementations, and it should be understood that the described components and systems can generally be integrated together in a single product or packaged into multiple products. For example, any of the components for an energy storage system described herein can be provided separately, or integrated together (e.g., packaged together, or attached together) to form an energy storage system.

[0105] For purposes of this disclosure, certain aspects, advantages, and novel features are described herein. Not necessarily all such advantages may be achieved in accordance with any particular embodiment. Thus, for example, those skilled in the art will recognize that the disclosure may be embodied or carried out in a manner that achieves one advantage or a group of advantages as taught herein without necessarily achieving other advantages as may be taught or suggested herein.

[0106] Conditional language, such as "can," "could," "might," or "may," unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements, and/or steps. Thus, such conditional language is not generally intended to imply that features, elements, and/or steps are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without user input or prompting, whether these features, elements, and/or steps are included or are to be performed in any particular embodiment.

[0107] Conjunctive language such as the phrase "at least one of X, Y, and Z," unless specifically stated otherwise, is otherwise understood with the context as used in general to convey that an item, term, etc. may be either X, Y, or Z. Thus, such conjunctive language is not generally intended to imply that certain embodiments require the presence of at least one of X, at least one of Y, and at least one of Z.

[0108] Language of degree used herein, such as the terms "approximately," "about," "generally," and "substantially" as used herein represent a value, amount, or characteristic close to the stated value, amount, or characteristic that still performs a desired function or achieves a desired result. For example, the terms "approximately," "about," "generally," and "substantially" may refer to an amount that is within less than 10% of, within less than 5% of, within less than 1% of, within less than 0.1% of, and within less than 0.01% of the stated amount, depending on the desired function or desired result.

[0109] The scope of the present disclosure is not intended to be limited by the specific disclosures of preferred embodiments in this section or elsewhere in this specification, and may be defined by claims as presented in this section or elsewhere in this specification or as presented in the future. The language of the claims is to be interpreted broadly based on the language employed in the claims and not limited to the examples described in the present specification or during the prosecution of the application, which examples are to be construed as non-exclusive.

[0110] The headings provided herein, if any, are for convenience only and do not necessarily affect the scope or meaning of the devices and methods disclosed herein.

What is claimed is:

1. An alloy composition, comprising:
Al;
wherein the alloy comprises a yield strength of at least about 130 MPa and a bend angle of at least about 20° at a 3 mm section thickness when as-cast and without further processing.

2. The composition of claim **1**, wherein the alloy comprises a yield strength of at least about 130 MPa when as-cast and without further processing.

3. The composition of claim **1**, wherein the alloy comprises a bend angle of at least about 24° at a 3 mm section thickness when as-cast and without further processing.

4. position of claim **1**, wherein the alloy comprises a flow length of at least about 1.8 m.

5. The composition of claim **1**, wherein the alloy comprises an α-Al volume fraction of at least about 90%.

6. The composition of claim **1**, wherein the alloy comprises about 0.03 wt. % to about 0.25 wt. % of Mg_2Si phases.

7. The composition of claim **1**, wherein the alloy comprises about 0.01 wt. % to about 0.9 wt. % of Al_2Cu phases.

8. The composition of claim **1**, wherein the alloy comprises about 0.03 wt. % to about 0.2 wt. % of AlCuMgSi phases.

9. The composition of claim **1**, wherein the alloy comprises about 0.3 wt. % to about 3 wt. % of AlFeSi phases.

10. The composition of claim **1**, further comprising Cu and Mg, wherein a weight ratio of Cu:Mg is about 4:1 to about 2:1.

11. The composition of claim **1**, wherein the alloy has an oxygen reduction factor (ORF) with respect to A380 kinetics of at most about 1.

12. The composition of claim **1**, further comprising:
Si at about 6-11 wt. %;
Cu at about 0.3-0.8 wt. %;
Mn at about 0.3-0.8 wt. %;
Mg at about 0.1-0.4 wt. %;
Fe at most about 0.5 wt. %;
V at about 0.05-0.15 wt. %;
Sr at about 0.01-0.05 wt. %;
Ti at most about 0.15 wt. %;
Cr at most about 0.03 wt. %; and
remainder Al and incidental impurities.

13. The composition of claim **1**, further comprising:
Si at about 6.5-7.5 wt. %;
Cu at about 0.4-0.8 wt. %;
Mn at about 0.3-0.7 wt. %;
Mg at about 0.1-0.4 wt. %;
Fe at most about 0.4 wt. %;
V at about 0.05-0.15 wt. %;
Sr at about 0.01-0.03 wt. %;
Ti at most about 0.15 wt. %;
Cr at most about 0.03 wt. %; and
remainder Al and incidental impurities.

14. The composition of claim **1**, further comprising:
Si at about 6-11 wt. %;
Cu at about 0.3-0.8 wt. %;
Mn at about 0.348 wt. %;
Mg at about 0.15-0.4 wt. %;
Fe at most about 0.5 wt. %;
V at about 0.05-0.15 wt. %;
Sr at about 0.01.-0.05 wt. %;
Ti at most about 0,15 wt. %;
Cr at most about 0.03 wt. %; and
remainder Al and incidental impurities.

15. The composition of claim **12**, wherein the incidental impurities are at most about 0.1 wt. %.

16. An automobile article comprising the composition of claim **1**.

17. The article of claim **16**, wherein the automobile article is an automobile chassis.

18. A process for preparing an alloy, comprising:

providing alloy components, wherein at least one of the alloy components comprises Al;

melting the alloy components to form a melted alloy; and

cooling the melted alloy to form an as-cast alloy;

wherein the as-cast alloy comprises a yield strength of at least about 130 NIPa and a bend angle of at least about 20° at a 3 mm section thickness.

19. The process of claim **18**, wherein further processing is not performed on the as-cast alloy.

20. The process of claim **18**, further comprising die-casting the melted alloy.

21. The process of claim **20**, wherein die-casting is high-pressure die-casting (HPDC).

22. The process of claim **18**, further comprising further processing the as-cast alloy to form a processed alloy.

23. The process of claim **22**, wherein the further processing step is selected from the group consisting of heat treating, aging, solution treating, surface finishing and combinations thereof.

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