



(11) **EP 3 589 766 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention
of the grant of the patent:
28.06.2023 Bulletin 2023/26

(21) Application number: **19773328.0**

(22) Date of filing: **06.05.2019**

(51) International Patent Classification (IPC):
C22C 21/08 ^(2006.01) **B22D 21/00** ^(2006.01)

(52) Cooperative Patent Classification (CPC):
C22C 21/08; B22D 21/007

(86) International application number:
PCT/US2019/030924

(87) International publication number:
WO 2019/217319 (14.11.2019 Gazette 2019/46)

(54) **AL-MG-SI-MN-FE CASTING ALLOYS**

AL-MG-SI-MN-FE-GUSSLEGIERUNGEN

ALLIAGES DE MOULAGE D'AL-MG-SI-MN-FE

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**

(30) Priority: **07.05.2018 US 201862667930 P**

(43) Date of publication of application:
08.01.2020 Bulletin 2020/02

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Description

BACKGROUND

- 5 [0001] Aluminum alloys are useful in a variety of applications. Aluminum casting (foundry) alloys, for instance, are used in dozen of industries, including, for instance, the automotive and consumer electronics industries.
- [0002] GB 1384264 discloses Al-Mg-Si alloys for use as structural parts.
- [0003] JP 2002 146463 A discloses an aluminum alloy for die casting containing magnesium, manganese and silicon with a controlled ratio between magnesium and silicon.
- 10 [0004] "Long term corrosion behavior of clad aluminum materials under different atmospheric conditions" by M. Poltavtseva et al. in Materials and Corrosion 2013, 64, no. 8, discloses a study of the long term behaviour of roof profiles of Alclad 3004 after long term environmental exposure.
- [0005] JP 2011 137200 A discloses aluminum alloy sheet for a heat insulator including Si, Fe, Cu, Mn, Mg and Zn with a recrystallised structure.
- 15 [0006] US 2016/222493 A1 discloses an Al-Mg-Si alloy containing Sr, for a cast metal structure in which Mg₂Si is crystallised.

SUMMARY OF THE INVENTION

- 20 [0007] Broadly, the present disclosure relates to new aluminum casting (foundry) alloys and associated products. The new aluminum casting alloy is defined in appended claim 1. The new aluminum casting alloys may realize an improved combination of properties, such as an improved combination of two or more of strength, ductility, castability, die soldering resistance and quality index, among others.

25 i. Composition

- [0008] As noted above, the new aluminum casting alloys include from 2.75 to 4.6 wt. % Mg. In one embodiment, a new aluminum casting alloy includes at least 3.0 wt. % Mg.
- 30 [0009] As noted above, the new aluminum casting alloys include from 1.00 to 2.0 wt. % Si. In one embodiment, a new aluminum casting alloy includes at least 1.05 wt. % Si. In another embodiment, a new aluminum casting alloy includes at least 1.10 wt. % Si. In yet another embodiment, a new aluminum casting alloy includes at least 1.15 wt. % Si. In another embodiment, a new aluminum casting alloy includes at least 1.20 wt. % Si.
- 35 [0010] As noted above, the weight ratio of magnesium to silicon in the new aluminum casting alloys is 1.7:1 to 3.6:1 (wt. % Mg / wt. % Si). In one embodiment, the weight ratio of magnesium to silicon in the new aluminum casting alloy is at least 1.8:1. In another embodiment, the weight ratio of magnesium to silicon in the new aluminum casting alloy is at least 1.85:1. In one embodiment, the weight ratio of magnesium to silicon in the new aluminum casting alloy is not greater than 3.6:1. In another embodiment, the weight ratio of magnesium to silicon in the new aluminum casting alloy is not greater than 3.5:1.
- 40 [0011] In one embodiment, a new aluminum casting alloy includes an amount of magnesium and silicon sufficient to facilitate production of a crack-free cast product (e.g., a crack-free high pressure die cast product). A crack-free product is a product sufficiently free of cracks so that it can be used for its intended purpose. In one embodiment, a new aluminum casting alloy includes an amount of magnesium and silicon sufficient to realize a hot cracking tendency index (HCTI) of not greater than 0.30, such as any of the low HCTI values disclosed herein.
- 45 [0012] As noted above, the new aluminum casting alloys include from 0.55 to 1.5 wt. % Mn. In one embodiment, a new aluminum casting alloy includes at least 0.60 wt. % Mn. In one embodiment, a new aluminum casting alloy includes not greater than 1.45 wt. % Mn. In another embodiment, a new aluminum casting alloy includes not greater than 1.40 wt. % Mn. In yet another embodiment, a new aluminum casting alloy includes not greater than 1.35 wt. % Mn. In another embodiment, a new aluminum casting alloy includes not greater than 1.30 wt. % Mn. In yet another embodiment, a new aluminum casting alloy includes not greater than 1.25 wt. % Mn. In another embodiment, a new aluminum casting alloy includes not greater than 1.20 wt. % Mn.
- 50 [0013] As noted above, the new aluminum casting alloys include from 0.20 to 0.60 wt. % Fe. In one embodiment, a new aluminum casting alloy includes at least 0.25 wt. % Fe. In yet another embodiment, a new aluminum casting alloy includes at least 0.30 wt. % Fe. In another embodiment, a new aluminum casting alloy includes at least 0.35 wt. % Fe. In one embodiment, a new aluminum casting alloy includes not greater than 0.55 wt. % Fe. In another embodiment, a new aluminum casting alloy includes not greater than 0.50 wt. % Fe. In yet another embodiment, a new aluminum casting alloy includes not greater than 0.45 wt. % Fe.
- 55 [0014] In one embodiment, a new aluminum casting alloy includes an amount of iron and manganese sufficient to facilitate formation of alpha phase particles while restricting formation of beta phase particles. In one embodiment, at

least due to the iron content, a new aluminum casting alloy includes not greater than 0.012 wt. % of β -Al₅FeSi compounds. In another embodiment, a new aluminum casting alloy includes not greater than 0.010 wt. % of β -Al₅FeSi compounds. In yet another embodiment, a new aluminum casting alloy includes not greater than 0.008 wt. % of β -Al₅FeSi compounds. In another embodiment, a new aluminum casting alloy includes not greater than 0.006 wt. % of β -Al₅FeSi compounds. In yet another embodiment, a new aluminum casting alloy includes not greater than 0.004 wt. % of β -Al₅FeSi compounds. In another embodiment, a new aluminum casting alloy includes not greater than 0.002 wt. % of β -Al₅FeSi compounds. In yet another embodiment, a new aluminum casting alloy includes not greater than 0.001 wt. % of β -Al₅FeSi compounds. In another embodiment, a new aluminum casting alloy includes not greater than 0.0005 wt. % of β -Al₅FeSi compounds.

[0015] The new aluminum casting alloy includes an amount of magnesium, silicon, manganese and iron sufficient to satisfy the following requirements:

$$(1) \text{ wt. \% Si} \leq (0.4567 * (\text{wt. \% Mg}) + 0.2 * (\text{wt. \% Mg}) + 0.25 * (\text{wt. \% Fe}));$$

and

$$(2) \text{ wt. \% Si} \geq (0.4567 * (\text{wt. \% Mg}) + 0.2 * (\text{wt. \% Mg}) + 0.25 * (\text{wt. \% Fe}) - 0.6).$$

[0016] As noted above, the new aluminum casting alloys include from 0.01 to 0.13 wt. % Ti. In one embodiment, a new aluminum casting alloy includes at least 0.03 wt. % Ti. In yet another embodiment, a new aluminum casting alloy includes at least 0.05 wt. % Ti. In another embodiment, a new aluminum casting alloy includes at least 0.07 wt. % Ti. In one embodiment, a new aluminum casting alloy includes not greater than 0.115 wt. % Ti. In another embodiment, a new aluminum casting alloy includes not greater than 0.10 wt. % Ti. In one embodiment, a new aluminum casting alloy include an amount of titanium sufficient to facilitate grain refining while restricting / avoiding formation of primary titanium-containing particles. In some embodiments, titanium is included in a new aluminum casting alloy as an impurity.

[0017] As noted above, the new aluminum casting alloys may optionally include up to 0.10 wt. % Sr. In one embodiment, a new aluminum casting alloy includes an amount of strontium sufficient to facilitate modification of the Mg₂Si eutectic while restricting / avoiding formation of primary strontium-containing particles. In one embodiment, a new aluminum casting alloy includes at least 0.005 wt. % Sr. In one embodiment, a new aluminum casting alloy includes not greater than 0.08 wt. % Sr. In another embodiment, a new aluminum casting alloy includes not greater than 0.05 wt. % Sr. In some embodiments, strontium is included in a new aluminum casting alloy as an impurity.

[0018] As noted above, the new aluminum casting alloys may optionally include up to 0.15 wt. % of any of Zr, Hf, V, and Cr. In one embodiment, a new aluminum casting alloy includes an amount of zirconium, hafnium, vanadium, and/or chromium sufficient to facilitate solid solution strengthening while restricting / avoiding formation of primary particles containing zirconium, hafnium, vanadium, and chromium. In one embodiment, a new aluminum casting alloy includes at least 0.01 wt. % of any of Zr, Hf, V, and Cr. In another embodiment, a new aluminum casting alloy includes at least 0.03 wt. % of any of Zr, Hf, V, and Cr. In yet another embodiment, a new aluminum casting alloy includes at least 0.05 wt. % of any of Zr, Hf, V, and Cr. In one embodiment, a new aluminum casting alloy includes not greater than 0.10 wt. % of any of Zr, Hf, V, and Cr. In some embodiments, zirconium is included in a new aluminum casting alloy as an impurity. Scandium is included in a new aluminum casting alloy as an impurity. In some embodiments, hafnium is included in a new aluminum casting alloy as an impurity. In some embodiments, vanadium is included in a new aluminum casting alloy as an impurity. In some embodiments, chromium is included in a new aluminum casting alloy as an impurity.

[0019] The balance of the new aluminum casting alloys is generally aluminum and unavoidable impurities. The new aluminum casting alloy comprises not greater than 0.15 wt. % of the unavoidable impurities, wherein the new aluminum casting alloy comprises not greater than 0.05 wt. % of any one element of the unavoidable impurities. In one embodiment, a new aluminum casting alloy comprises not greater than 0.10 wt. % of the unavoidable impurities, and wherein the new aluminum casting alloy comprises not greater than 0.03 wt. % of any one element of the unavoidable impurities.

ii. Processing

[0020] The new aluminum casting alloys may be cast using any suitable casting method. The new aluminum casting alloy is shape cast into a complex shape cast product, such as a complex automotive component. In one embodiment, the shape cast product is an automotive structural component. In another embodiment, the shape cast product is a door frame. In another embodiment, the shape cast product is a shock tower. In another embodiment, the shape cast product is a tunnel structure for an automobile.

[0021] In one embodiment, the shape casting comprises high pressure die casting. In another embodiment, the shape casting comprises permanent mold casting.

[0022] The new aluminum casting alloys do not require a solution heat treatment step. The new aluminum casting alloys may be provided, therefore, in the appropriate temper, such as in the F temper or the T5 temper.

iii. Properties

[0023] As noted above, the new aluminum casting alloys may realize an improved combination of properties, such as an improved combination of at least two of strength, ductility, castability, die soldering resistance and quality index. Mechanical properties may be measured in accordance with ASTM E8 and B557 (e.g., when directionally solidified). Castability may be measured using the HCTI method described herein. Die soldering resistance may be determined by casting the alloy.

[0024] In one embodiment, a new aluminum casting alloy realizes an ultimate tensile strength of at least 200 MPa. In another embodiment, a new aluminum casting alloy realizes an ultimate tensile strength of at least 210 MPa. In yet another embodiment, a new aluminum casting alloy realizes an ultimate tensile strength of at least 220 MPa. In another embodiment, a new aluminum casting alloy realizes an ultimate tensile strength of at least 230 MPa.

[0025] In one embodiment, a new aluminum casting alloy realizes a tensile yield strength of at least 100 MPa. In another embodiment, a new aluminum casting alloy realizes a tensile yield strength of at least 105 MPa. In yet another embodiment, a new aluminum casting alloy realizes a tensile yield strength of at least 110 MPa. In another embodiment, a new aluminum casting alloy realizes a tensile yield strength of at least 115 MPa. In another embodiment, a new aluminum casting alloy realizes a tensile yield strength of at least 120 MPa. In another embodiment, a new aluminum casting alloy realizes a tensile yield strength of at least 125 MPa. Any of the above tensile yield strength values may be realized with any of the above ultimate tensile strength values.

[0026] In one embodiment, a new aluminum casting alloy realizes an elongation of at least 7%. In another embodiment, a new aluminum casting alloy realizes an elongation of at least 8%. In yet another embodiment, a new aluminum casting alloy realizes an elongation of at least 9%. In another embodiment, a new aluminum casting alloy realizes an elongation of at least 10%. In yet another embodiment, a new aluminum casting alloy realizes an elongation of at least 11%. In another embodiment, a new aluminum casting alloy realizes an elongation of at least 12%. In yet another embodiment, a new aluminum casting alloy realizes an elongation of at least 13%. In another embodiment, a new aluminum casting alloy realizes an elongation of at least 14%. In yet another embodiment, a new aluminum casting alloy realizes an elongation of at least 15%. In another embodiment, a new aluminum casting alloy realizes an elongation of at least 16%, or higher. Any of the above elongation values may be realized with any of the above ultimate tensile strength or tensile yield strength values.

[0027] In one embodiment, a new aluminum casting alloy realizes a HCTI of not greater than 0.30. In another embodiment, a new aluminum casting alloy realizes a HCTI of not greater than 0.25. In yet another embodiment, a new aluminum casting alloy realizes a HCTI of not greater than 0.20. In another embodiment, a new aluminum casting alloy realizes a HCTI of not greater than 0.15, or lower.

[0028] In one embodiment, a new aluminum casting alloy is die soldering resistant wherein the as-cast aluminum alloy product is removed from the die without damage to the cast product and/or without sticking to the die. Die soldering can occur during high pressure die casting wherein molten aluminum solders to the die surface. In some embodiments, the new aluminum casting alloys described herein may be cast without being soldered to the die.

[0029] These and other combination of features are disclosed in the below Detailed Description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030]

FIG. 1 is a graph showing silicon content versus hot cracking tendency index for Example 1 alloys.

FIG. 2 is a graph showing silicon content versus hot cracking tendency index for Example 2 alloys.

FIG. 3 is a graph showing silicon content versus hot cracking tendency index for Example 3 alloys.

FIG. 4 is a graph showing manganese content versus hot cracking tendency index for Example 4 alloys.

FIG. 5a is a graph showing beta phase content (shown in wt. %) as a function of Mn and Fe content based on ICME modeling; the amounts of 3.6 wt. % Mg and 1.5 wt. % Si were kept constant.

FIG. 5b is a graph showing alpha phase content (shown in wt. %) as a function of Mn and Fe content based on ICME modeling; the amounts of 3.6 wt. % Mg and 1.5 wt. % Si were kept constant.

FIG. 6 is a graph showing beta phase content (shown in wt. %) as a function of Fe content based on ICME modeling; the amounts of 3.6 wt. % Mg, 1.5 wt. % Si and 0.5 wt. % Mn were kept constant.

FIG. 7a is a graph showing ultimate tensile strength (MPa) versus iron content (wt. %) for Example 6 alloys.

FIG. 7b is a graph showing elongation (%) versus iron content (wt. %) for Example 6 alloys.

FIG. 7c is a graph showing tensile yield strength (MPa) versus iron content (wt. %) for Example 6 alloys.

FIG. 7d is a graph showing quality index (Q in MPa) versus iron content (wt. %) for Example 6 alloys.

FIG. 8a is a graph showing HCl (computed hot cracking index) as a function of Si and Mg content based on ICME modeling; the amounts of 0.70 wt. % Mn and 0.25 wt. % Fe were kept constant.

FIG. 8b is a graph showing non-equilibrium solidification temperature range (in °C) as a function of Si and Mg content based on ICME modeling; the amounts of 0.70 wt. % Mn and 0.25 wt. % Fe were kept constant.

FIG. 8c is a graph showing HCl (computed hot cracking index) as a function of Si and Mn content based on ICME modeling; the amounts of 4.0 wt. % Mg and 0.25 wt. % Fe were kept constant.

FIG. 8d is a graph showing HCl (computed hot cracking index) as a function of Si and Fe content based on ICME modeling; the amounts of 4.0 wt. % Mg and 0.70 wt. % Mn were kept constant.

DETAILED DESCRIPTION

Example 1

[0031] Six aluminum alloys were cast as pencil probe castings. The compositions of the aluminum alloys is given in Table 1, below. The Example 1 aluminum alloys of Table 1 do not fall within the scope of claim 1.

Table 1 - Composition of Example 1 Alloys (all values in weight percent)

Alloy *	Si	Fe	Mn	Mg	Ti
A1	0.06	0.07	1.24	3.51	0.10
A2	0.75	0.07	1.27	3.59	0.09
A3	1.20	0.10	1.20	3.59	0.09
A4	1.56	0.10	1.20	3.52	0.09
A5	1.88	0.11	1.17	3.69	0.09
A6	2.37	0.08	1.26	3.61	0.09

*The balance of the aluminum alloys was aluminum and unavoidable impurities. The aluminum alloy contained not greater than 0.03 wt. % of any one impurity, and contained not greater than 0.10 wt. %, it total, of all impurities.

[0032] Five tests per alloy were conducted and at various connection sizes. Table 2, below, provides the hot cracking results. In the below table, "C" means cracked during casting, "OK" means casting was successful without cracking, and "NF" means the pencil probe mold was not completely filled. The hot cracking tendency index ("HCTI") of each alloy was calculated in accordance with the results. Table 2 also lists the calculated HCTI for each alloy.

[0033] The hot cracking tendency index (HCTI) of an alloy is defined as

$$HCTI = \frac{\sum \text{diameter of the cracked rod}}{(4 + 6 + 8 + 10 + 12 + 14 + 16)}$$

[0034] If no cracking is found on any connection rods, the HCTI value will be 0. If cracking is found in all 7 connection rods (from 4 mm to 16 mm), the HCTI value will be 1. Therefore, a smaller HCTI indicates a higher hot cracking resistance for a specific alloy.

Table 2 - Hot Cracking Results of the Example 1 Alloys

Alloy	Connection size							HCTI
	16mm	14mm	12mm	10mm	8mm	6mm	4mm	
Alloy A-1	C	C	C	C	C	C	C	1
	C	C	C	C	C	C	C	
	C	C	C	C	C	C	C	
	C	C	C	C	C	C	C	
	C	C	C	C	C	C	C	

(continued)

Alloy	Connection size							HCTI
	16mm	14mm	12mm	10mm	8mm	6mm	4mm	
Alloy A-2	OK	C	OK	OK	C	C	OK	0.6
	OK	C	OK	OK	C	C	C	
	OK	C	C	OK	OK	C	C	
	C	C	OK	C	C	C	C	
	C	C	OK	C	C	OK	C	
Alloy A-3	OK	OK	OK	OK	OK	C	OK	0.1
	OK	OK	OK	OK	OK	C	OK	
	OK	OK	OK	OK	OK	OK	C	
	OK	OK	OK	C	OK	OK	OK	
	OK	OK	OK	OK	OK	OK	OK	
Alloy A-4	OK	OK	OK	OK	OK	OK	OK	0.06
	OK	OK	OK	OK	OK	C	OK	
	OK	OK	OK	OK	OK	OK	OK	
	OK	OK	OK	OK	OK	OK	OK	
	OK	OK	OK	OK	OK	OK	C	
Alloy A-5	OK	OK	OK	OK	C	OK	C	0.16
	OK	OK	OK	OK	OK	OK	OK	
	OK	OK	OK	OK	C	OK	C	
	OK	OK	OK	OK	C	C	C	
	OK	OK	OK	OK	OK	C	OK	
Alloy A-6	OK	OK	OK	C	C	C	C	0.39
	OK	OK	OK	OK	C	C	C	
	OK	OK	OK	C	C	C	C	
	OK	OK	C	C	C	C	C	
	OK	OK	OK	OK	C	C	C	

FIG. 1 shows a plot of the silicon content versus the determined HCTI value. As shown, alloys having from about 1 to about 2 wt. % Si at similar amounts of Fe, Mn, Mg and Ti realized improved hot cracking resistance. The Mg/Si ratio for these alloys is from about 2.0 to 3.0. Alloy A4 with 1.56 wt. % Si had a Mg to Si ratio of 2.26.

Example 2

[0035] Four additional alloys were cast and their hot cracking susceptibility was determined, as per Example 1. Like Example 1, the silicon content was again varied, but using a lower nominal amount of magnesium and manganese. The compositions of the Example 2 alloys are shown in Table 3, below. The Example 2 alloys of Table 3 do not fall within the scope of claim 1. The HCTI results for the Example 2 alloys are shown in the below figure. Alloy B2 showed the best hot cracking resistance. The Mg/Si ratio for this alloy is about 2.65.

Table 3 - Composition of Example 2 Alloys (all values in weight percent)

Alloy *	Si	Fe	Mn	Mg	Ti
B1	0.54	0.12	1.12	2.56	0.08

(continued)

Alloy *	Si	Fe	Mn	Mg	Ti
B2	0.96	0.15	1.14	2.54	0.08
B3	1.35	0.15	1.12	2.48	0.08
B4	1.68	0.15	1.11	2.46	0.08
*The balance of the aluminum alloys was aluminum and unavoidable impurities. The aluminum alloy contained not greater than 0.03 wt. % of any one impurity, and contained not greater than 0.10 wt. %, it total, of all impurities.					

[0036] FIG. 2 shows the experimental measured hot cracking tendency indexes of the Al-2.5Mg-1.1Mn-x%Si alloys. Alloy B2, with 0.96 wt. % Si and 2.54 wt. % Mg, showed the best hot cracking resistance. The Mg/Si ratio for this alloy is about 2.65.

Example 3

[0037] Four additional alloys were cast and their hot cracking susceptibility was determined, as per Example 1. Like Example 1, the silicon content was again varied, but using a higher nominal amount of magnesium and a lower nominal amount of manganese. The compositions of the Example 3 alloys are shown in Table 4, below. The Example 3 alloys of Table 4 do not fall within the scope of claim 1. The HCTI results for the Example 3 alloys are shown in FIG. 3. As shown, the HCTI for all alloys is generally good. The lowest HCTI was realized by alloy C3 with a Mg/Si ratio of 2.22.

Table 4 - Composition of Example 3 Alloys (all values in weight percent)

Alloy *	Si	Fe	Mn	Mg	Ti	Mg/Si
C1	1.31	0.14	0.95	4.55	0.08	3.48
C2	1.57	0.15	0.92	4.51	0.08	2.87
C3	2.00	0.15	0.91	4.43	0.08	2.22
C4	2.40	0.15	0.91	4.35	0.08	1.81
*The balance of the aluminum alloys was aluminum and unavoidable impurities. The aluminum alloy contained not greater than 0.03 wt. % of any one impurity, and contained not greater than 0.10 wt. %, it total, of all impurities.						

[0038] The results of Examples 1-3 indicate that the Mg/Si (weight ratio) should be from about 1.7 to about 3.6, preferably from about 2.0 to about 3.0 to facilitate hot cracking resistance.

Example 4

[0039] Four additional alloys were cast and their hot cracking susceptibility was determined, as per Example 1. This time, the manganese content was varied, targeting a nominal magnesium amount of 3.6 wt. % and a nominal silicon amount of 1.5 wt. %. The compositions of the Example 4 alloys are shown in Table 5, below. The Example 4 alloys of Table 5 do not fall within the scope of claim 1. The HCTI results for the Example 4 alloys are shown in FIG. 4. As shown, the HCTI for all alloys is generally good. Alloy D4 with 1.20 wt. % Mn realized the best HCTI results.

Table 5 - Composition of Example 4 Alloys (all values in weight percent)

Alloy *	Si	Fe	Mn	Mg	Ti	Mg/Si
D1	1.52	0.11	0.47	3.64	0.08	2.39
D2	1.53	0.14	0.81	3.66	0.08	2.39
D3	1.53	0.13	1.09	3.58	0.08	2.34
D4	1.53	0.13	1.20	3.57	0.08	2.33
*The balance of the aluminum alloys was aluminum and unavoidable impurities. The aluminum alloy contained not greater than 0.03 wt. % of any one impurity, and contained not greater than 0.10 wt. %, it total, of all impurities.						

Example 5

[0040] Four additional alloys were cast and their hot cracking susceptibility was determined, as per Example 1. This time, the iron content was varied, targeting a nominal magnesium amount of 3.45 wt. %, a nominal silicon amount of 1.55 wt. %, and a nominal manganese amount of 0.90 wt. %. The compositions of the Example 5 alloys are shown in Table 6, below. Example alloys E1 and E2 are outside the scope of claim 1. The HCTI results for the Example 5 alloys are shown in the below figure. As shown, the HCTI for all alloys is generally good. Alloy E4 with 0.29 wt. % Fe realized the best HCTI results.

Table 6 - Composition of Example 5 Alloys (all values in weight percent)

Alloy*	Si	Fe	Mn	Mg	Ti	Mg/Si
E1	1.54	0.11	0.83	3.46	0.07	2.25
E2	1.55	0.17	0.85	3.46	0.07	2.23
E3	1.55	0.23	0.90	3.44	0.07	2.22
E4	1.55	0.29	0.94	3.45	0.07	2.23
*The balance of the aluminum alloys was aluminum and unavoidable impurities. The aluminum alloy contained not greater than 0.03 wt. % of any one impurity, and contained not greater than 0.10 wt. %, it total, of all impurities.						

[0041] These results are unexpected. The mechanical properties of Al-Si foundry alloys are adversely affected by iron because the iron is present as large primary or pseudo-primary compounds which increase the hardness but decrease the ductility. Given these improved HCTI results, modeling was conducted (ICME - Integrated Computational Materials Engineering). These results show that, by controlling Fe and Mn contents, formation of unwanted needle-shaped β -Al₅FeSi can be potentially avoided. FIGS. 5a, 5b and 6 show the correlation between manganese and iron content and the volume fraction on β -Al₅FeSi and α -Al₁₅FeMn₃Si₂ phase particles (for a Al-3.6Mg-1.5Si alloys). Adding Mn to the Al-Mg-Si alloys can promote formation of α -Al₁₅FeMn₃Si₂ phase and restrict or prevent formation of β -Al₅FeSi phase. For instance, a Al-3.6Mg-1.5Si alloy with from 0.4 to 0.6 wt. % Mn, using increased iron amounts decreases the amount of β -Al₅FeSi phase. As shown in FIG. 6, the amount of β -Al₅FeSi phase decreases from about 0.018 wt. % to essentially 0 wt. % by increasing iron from 0.15 wt. % to 0.4 wt. %. Thus, alloys having improved properties (e.g., elongation) may be realized due to the increase in iron and the corresponding decrease in β -Al₅FeSi phase within the alloy.

Example 6

[0042] Eight additional alloys were cast via directional solidification. All alloys varied iron content. The first group (F) targeted a nominal magnesium amount of 3.6 wt. %, a nominal silicon amount of 1.5 wt. %, and a nominal manganese amount of 0.90 wt. %. The second group (G) targeted a nominal magnesium amount of 4.0 wt. %, a nominal silicon amount of 1.7 wt. %, and a nominal manganese amount of 0.65 wt. %. The compositions of the Example 6 alloys are shown in Table 7, below. Example alloys F1, F2, G1 and G2 are outside the scope of claim 1.

Table 6 - Composition of Example 5 Alloys (all values in weight percent)

Alloy*	Si	Fe	Mn	Mg	Ti	Mg/Si
F1	1.53	0.12	0.93	3.61	0.08	2.36
F2	1.55	0.19	0.93	3.63	0.08	2.34
F3	1.56	0.27	0.93	3.63	0.08	2.33
F4	1.53	0.38	0.93	3.60	0.08	2.35
G1	1.72	0.12	0.65	4.01	0.08	2.33
G2	1.73	0.19	0.64	4.03	0.08	2.33
G3	1.73	0.29	0.64	4.02	0.08	2.33
G4	1.73	0.40	0.64	4.00	0.08	2.32
*The balance of the aluminum alloys was aluminum and unavoidable impurities. The aluminum alloy contained not greater than 0.03 wt. % of any one impurity, and contained not greater than 0.10 wt. %, it total, of all impurities.						

[0043] The mechanical properties of the directionally solidified alloys were tested in accordance with ASTM E8 and B557, the results of which are provided in Table 7, below. The mechanical properties of the Example 5 alloys were also tested, so those results are also included in Table 7. The quality index (Q) is also provided. ($Q = UTS + 150 \cdot \log(\text{Elong.})$). Various graphs relating to these properties and the alloy compositions are provided in FIGS. 7a-7d.

Table 7 - Properties of Alloys E1-E4, F1-F4 and G1-G4

Alloy	Mechanical Property							
	Average				STDEV			
	UTS, MPa	TYS, MPa	Elong., %	Q, MPa	UTS	TYS	Elong.	Q
E1	226	104	9.0	369	12.1	6.0	0.7	15.2
E2	224	109	7.3	353	10.3	4.1	1.2	14.6
E3	233	105	9.2	377	6.4	6.2	0.5	9.0
E4	232	106	10.6	385	8.1	2.3	2.3	20.0
F1	212	112	13.8	382	6.7	4.0	1.7	13.5
F2	212	112	13.8	382	5.6	3.0	2.1	11.8
F3	214	113	16.0	394	7.1	3.5	1.4	11.1
F4	209	116	11.5	365	0.5	5.0	4.0	23.7
G1	211	114	12.5	375	7.5	4.1	1.0	11.2
G2	211	113	12.8	376	8.0	2.6	2.4	19.3
G3	215	126	11.3	372	4.9	4.2	1.5	9.7
G4	212	113	14.0	384	5.0	8.2	1.6	6.6

Example 7 - Experimental Modeling

[0044] Based on the prior experiments, various aluminum alloy compositions were modeled. The results are shown in FIGS. 8a-8b. These modeling results indicate that for an Al-Mg-Si alloy targeting 0.7 wt. % Mn and 0.25 wt. % Fe, it may be useful to control the magnesium and silicon such that (all values in weight percent): $(0.4567 \cdot \text{Mg} - 0.5) \leq \text{Si} \leq$

(0.4567*Mg +0.2)

[0045] Similar modeling was done on additional aluminum alloys, as shown in FIGS. 8c-8d. These modeling results indicate that, as the manganese or iron content increases, the silicon content needs to be increased. These results further indicate that it may be useful to control magnesium, silicon, manganese, and iron as per the following:

$$(0.4567*Mg+0.2*Mn+0.25*Fe - 0.6) \leq Si \leq (0.4567*Mg +0.2*Mn+0.25*Fe)$$

[0046] While various embodiments of the present disclosure have been described in detail, it is apparent that modifications and adaptations of those embodiments will occur to those skilled in the art.

Claims

1. An aluminum casting alloy consisting of:

from 2.75 to 4.6 wt.% Mg;

from 1.00 to 2.0 wt.% Si;

wherein a weight ratio of magnesium to silicon (wt.% Mg / wt.% Si) is from 1.7:1 to 3.6:1;

from 0.55 to 1.5 wt.% Mn;

from 0.20 to 0.60 wt.% Fe;

wherein:

$$(1) \text{ wt. \% Si} \leq (0.4567 * (\text{wt. \% Mg}) + 0.2 * (\text{wt. \% Mn}) + 0.25 * (\text{wt. \% Fe}));$$

$$(2) \text{ wt. \% Si} \geq (0.4567 * (\text{wt. \% Mg}) + 0.2 * (\text{wt. \% Mn}) + 0.25 * (\text{wt. \% Fe}) - 0.6);$$

from 0.01 to 0.13 wt.% Ti;

optionally up to 0.10 wt.% Sr;

optionally up to 0.15 wt.% of any of Zr, Hf, V, and Cr;

the balance being aluminum and unavoidable impurities, wherein the aluminum casting alloy comprises not greater than 0.15 wt.% of the unavoidable impurities, and wherein the aluminum casting alloy comprises not greater than 0.05 wt.% of any one element of the unavoidable impurities, wherein scandium is included in a new aluminum casting alloy as an impurity; and

wherein the aluminum casting alloy is in the form of a complex shape casting.

2. The aluminum casting alloy of any of the preceding claims, wherein the aluminum casting alloy includes at least 3.0 wt.% Mg.

3. The aluminum casting alloy of any of the preceding claims, wherein the aluminum casting alloy includes at least 1.05 wt.% Si, or at least 1.10 wt.% Si, or at least 1.15 wt.% Si, or at least 1.20 wt.% Si.

4. The aluminum casting alloy of any of the preceding claims, wherein the weight ratio of magnesium to silicon is at least 1.8:1, or wherein the weight ratio of magnesium to silicon is at least 1.85:1.

5. The aluminum casting alloy of any of the preceding claims, wherein the weight ratio of magnesium to silicon is not greater than 3.5:1.

6. The aluminum casting alloy of any of the preceding claims, wherein the aluminum casting alloy includes at least 0.60 wt.% Mn.

7. The aluminum casting alloy of any of the preceding claims, wherein the aluminum casting alloy includes not greater than 1.45 wt.% Mn, or not greater than 1.40 wt.% Mn, or not greater than 1.35 wt.% Mn, or not greater than 1.30 wt.% Mn, or not greater than 1.25 wt.% Mn, or not greater than 1.20 wt.% Mn.

8. The aluminum casting alloy of any of the preceding claims, wherein the aluminum casting alloy includes at least

0.25 wt.% Fe, or at least 0.30 wt.% Fe, or at least 0.35 wt.% Fe.

9. The aluminum casting alloy of any of the preceding claims, wherein the aluminum casting alloy includes not greater than 0.55 wt.% Fe, or not greater than 0.50 wt.% Fe, or not greater than 0.45 wt.% Fe.
10. The aluminum casting alloy of any of the preceding claims, wherein the aluminum casting alloy includes at least 0.03 wt.% Ti, or at least 0.05 wt.% Ti, or at least 0.07 wt.% Ti.
11. The aluminum casting alloy of any of the preceding claims, wherein the aluminum casting alloy includes not greater than 0.115 wt.% Ti, or not greater than 0.10 wt.% Ti.
12. The aluminum casting alloy of any of the preceding claims, wherein the alloy includes not greater than 0.08 wt.% Sr, or not greater than 0.05 wt.% Sr.

Patentansprüche

1. Aluminiumgusslegierung, bestehend aus:

2,75 bis 4,6 Gew.-% Mg;
 1,00 bis 2,0 Gew.-% Si;
 wobei ein Gewichtsverhältnis von Magnesium zu Silicium (Gew.-% Mg/Gew.-% Si) 1,7:1 bis 3,6:1 beträgt;
 0,55 bis 1,5 Gew.-% Mn;
 0,20 bis 0,60 Gew.-% Fe;
 wobei:

$$(1) \text{ Gew.}\% \text{ Si} \leq (0,4567 * (\text{Gew.}\% \text{ Mg}) + 0,2 * (\text{Gew.}\% \text{ Mn}) + 0,25 * (\text{Gew.}\% \text{ Fe})) ;$$

$$(2) \text{ Gew.}\% \text{ Si} \geq (0,4567 * (\text{Gew.}\% \text{ Mg}) + 0,2 * (\text{Gew.}\% \text{ Mn}) + 0,25 * (\text{Gew.}\% \text{ Fe}) - 0,6) ;$$

0,01 bis 0,13 Gew.-% Ti;
 optional bis zu 0,10 Gew.-% Sr;
 optional bis zu 0,15 Gew.-% von einem aus Zr, Hf, V und Cr;
 wobei der Rest aus Aluminium und unvermeidbaren Verunreinigungen besteht, wobei die Aluminiumgusslegierung nicht mehr als 0,15 Gew.-% der unvermeidbaren Verunreinigungen umfasst und wobei die Aluminiumgusslegierung nicht mehr als 0,05 Gew.-% eines Elements der unvermeidbaren Verunreinigungen umfasst, wobei Scandium in einer neuen Aluminiumgusslegierung als Verunreinigung enthalten ist; und
 wobei die Aluminiumgusslegierung in Form eines Gussteils mit komplexer Form vorliegt.

2. Aluminiumgusslegierung nach einem der vorhergehenden Ansprüche, wobei die Aluminiumgusslegierung mindestens 3,0 Gew.-% Mg enthält.
3. Aluminiumgusslegierung nach einem der vorhergehenden Ansprüche, wobei die Aluminiumgusslegierung zumindest 1,05 Gew.-% Si enthält, oder zumindest 1,10 Gew.-% Si oder zumindest 1,15 Gew.-% Si oder zumindest 1,20 Gew.-% Si.
4. Aluminiumgusslegierung nach einem der vorhergehenden Ansprüche, wobei das Gewichtsverhältnis von Magnesium zu Silicium zumindest 1,8:1 beträgt, oder wobei das Gewichtsverhältnis von Magnesium zu Silicium zumindest 1,85:1 beträgt.
5. Aluminiumgusslegierung nach einem der vorhergehenden Ansprüche, wobei das Gewichtsverhältnis von Magnesium zu Silicium nicht größer als 3,5:1 ist.
6. Aluminiumgusslegierung nach einem der vorhergehenden Ansprüche, wobei die Aluminiumgusslegierung zumin-

dest 0,60 Gew.-% Mg enthält.

7. Aluminiumgusslegierung nach einem der vorhergehenden Ansprüche, wobei die Aluminiumgusslegierung nicht mehr als 1,45 Gew.-% Mn enthält, oder nicht mehr als 1,40 Gew.-% Mn oder nicht mehr als 1,35 Gew.-% Mn oder nicht mehr als 1,30 Gew.-% Mn oder nicht mehr als 1,25 Gew.-% Mn oder nicht mehr als 1,20 Gew.-% Mn.
8. Aluminiumgusslegierung nach einem der vorhergehenden Ansprüche, wobei die Aluminiumgusslegierung zumindest 0,25 Gew.-% Fe enthält, oder zumindest 0,30 Gew.-% Fe oder zumindest 0,35 Gew.-% Fe.
9. Aluminiumgusslegierung nach einem der vorhergehenden Ansprüche, wobei die Aluminiumgusslegierung nicht mehr als 0,55 Gew.-% Fe enthält, oder nicht mehr als 0,50 Gew.-% Fe oder nicht mehr als 0,45 Gew.-% Fe.
10. Aluminiumgusslegierung nach einem der vorhergehenden Ansprüche, wobei die Aluminiumgusslegierung zumindest 0,03 Gew.-% Ti enthält, oder zumindest 0,05 Gew.-% Ti oder zumindest 0,07 Gew.-% Ti.
11. Aluminiumgusslegierung nach einem der vorhergehenden Ansprüche, wobei die Aluminiumgusslegierung nicht mehr als 0,115 Gew.-% Ti enthält oder nicht mehr als 0,10 Gew.-% Ti.
12. Aluminiumgusslegierung nach einem der vorhergehenden Ansprüche, wobei die Legierung nicht mehr als 0,08 Gew.-% Sr enthält, oder nicht mehr als 0,05 Gew.-% Sr.

Revendications

1. Alliage de fonderie d'aluminium constitué par :

2,75 à 4,6 % en poids de Mg ;
1,00 à 2,0 % en poids de Si ;
dans lequel un rapport en poids entre magnésium et silicium (% en poids de Mg / % en poids de Si) est de 1,7:1 à 3,6:1 ;
0,55 à 1,5 % en poids de Mn ;
0,20 à 0,60 % en poids de Fe ;
dans lequel :

(1) % en poids de Si $\leq$ (0,4567*(% en poids de Mg) + 0,2*(% en poids de Mn) + 0,25*(% en poids de Fe)) ; et

(2) % en poids de Si $\geq$ (0,4567*(% en poids de Mg) + 0,2*(% en poids de Mn) + 0,25*(% en poids de Fe) - 0,6) ;

0,01 à 0,13 % en poids de Ti ;
éventuellement jusqu'à 0,10 % en poids de Sr ;
éventuellement jusqu'à 0,15 % en poids de l'un quelconque parmi Zr, Hf, V, et Cr ;
le reste étant constitué d'aluminium et d'impuretés inévitables, dans lequel l'alliage de fonderie d'aluminium ne comprend pas plus de 0,15 % en poids des impuretés inévitables, et dans lequel l'alliage de fonderie d'aluminium ne comprend pas plus de 0,05 % en poids d'un quelconque élément des impuretés inévitables, dans lequel le scandium est inclus dans un nouvel alliage de fonderie d'aluminium en tant qu'impureté ; et
dans lequel l'alliage de fonderie d'aluminium est sous la forme d'un moulage de forme complexe.

2. Alliage de fonderie d'aluminium selon l'une quelconque des revendications précédentes, dans lequel l'alliage de fonderie d'aluminium comporte au moins 3,0 % en poids de Mg.
3. Alliage de fonderie d'aluminium selon l'une quelconque des revendications précédentes, dans lequel l'alliage de fonderie d'aluminium comporte au moins 1,05 % en poids de Si, ou au moins 1,10 % en poids de Si, ou au moins 1,15 % en poids de Si, ou au moins 1,20 % en poids de Si.

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4. Alliage de fonderie d'aluminium selon l'une quelconque des revendications précédentes, dans lequel le rapport en poids entre magnésium et silicium est d'au moins 1,8:1, ou dans lequel le rapport en poids entre magnésium et silicium est d'au moins 1,85:1.
- 5 5. Alliage de fonderie d'aluminium selon l'une quelconque des revendications précédentes, dans lequel le rapport en poids entre magnésium et silicium n'est pas supérieur à 3,5:1.
6. Alliage de fonderie d'aluminium selon l'une quelconque des revendications précédentes, dans lequel l'alliage de fonderie d'aluminium comporte au moins 0,60 % en poids de Mn.
- 10 7. Alliage de fonderie d'aluminium selon l'une quelconque des revendications précédentes, dans lequel l'alliage de fonderie d'aluminium ne comporte pas plus de 1,45 % en poids de Mn, ou pas plus de 1,40 % en poids de Mn, ou pas plus de 1,35 % en poids de Mn, ou pas plus de 1,30 % en poids de Mn, ou pas plus de 1,25 % en poids de Mn, ou pas plus de 1,20 % en poids de Mn.
- 15 8. Alliage de fonderie d'aluminium selon l'une quelconque des revendications précédentes, dans lequel l'alliage de fonderie d'aluminium comporte au moins 0,25 % en poids de Fe, ou au moins 0,30 % en poids de Fe, ou au moins 0,35 % en poids de Fe.
- 20 9. Alliage de fonderie d'aluminium selon l'une quelconque des revendications précédentes, dans lequel l'alliage de fonderie d'aluminium ne comporte pas plus de 0,55 % en poids de Fe, ou pas plus de 0,50 % en poids de Fe, ou pas plus de 0,45 % en poids de Fe.
- 25 10. Alliage de fonderie d'aluminium selon l'une quelconque des revendications précédentes, dans lequel l'alliage de fonderie d'aluminium comporte au moins 0,03 % en poids de Ti, ou au moins 0,05 % en poids de Ti, ou au moins 0,07 % en poids de Ti.
- 30 11. Alliage de fonderie d'aluminium selon l'une quelconque des revendications précédentes, dans lequel l'alliage de fonderie d'aluminium ne comporte pas plus de 0,115 % en poids de Ti, ou pas plus de 0,10 % en poids de Ti.
- 35 12. Alliage de fonderie d'aluminium selon l'une quelconque des revendications précédentes, dans lequel l'alliage ne comporte pas plus de 0,08 % en poids de Sr, ou pas plus de 0,05 % en poids de Sr.
- 40
- 45
- 50
- 55

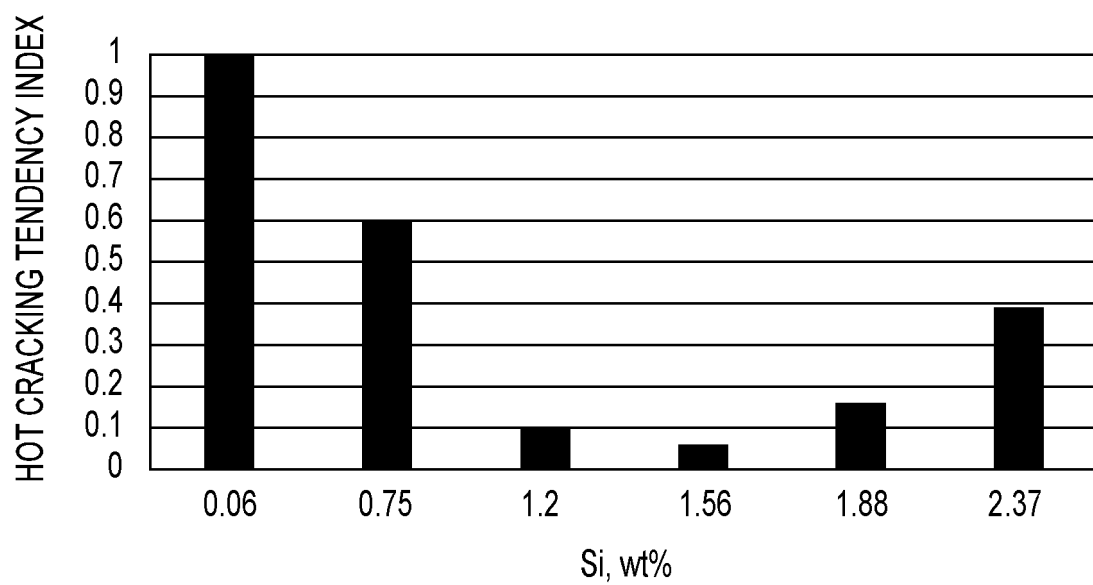


FIG.1

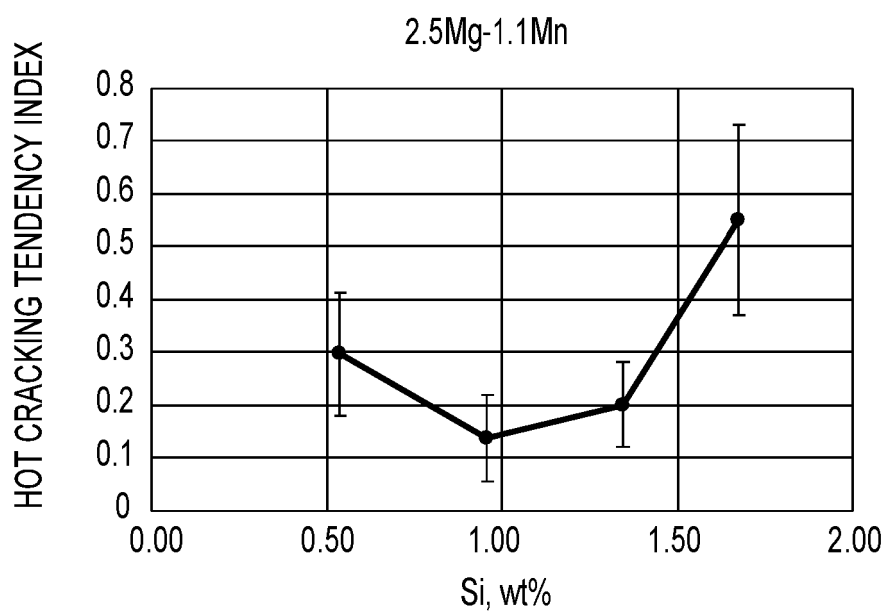


FIG.2

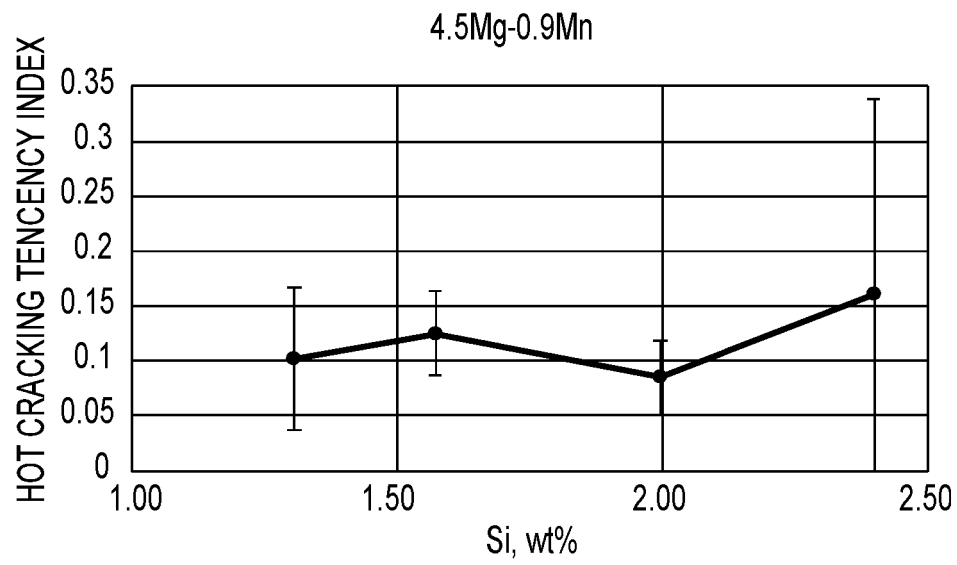


FIG.3

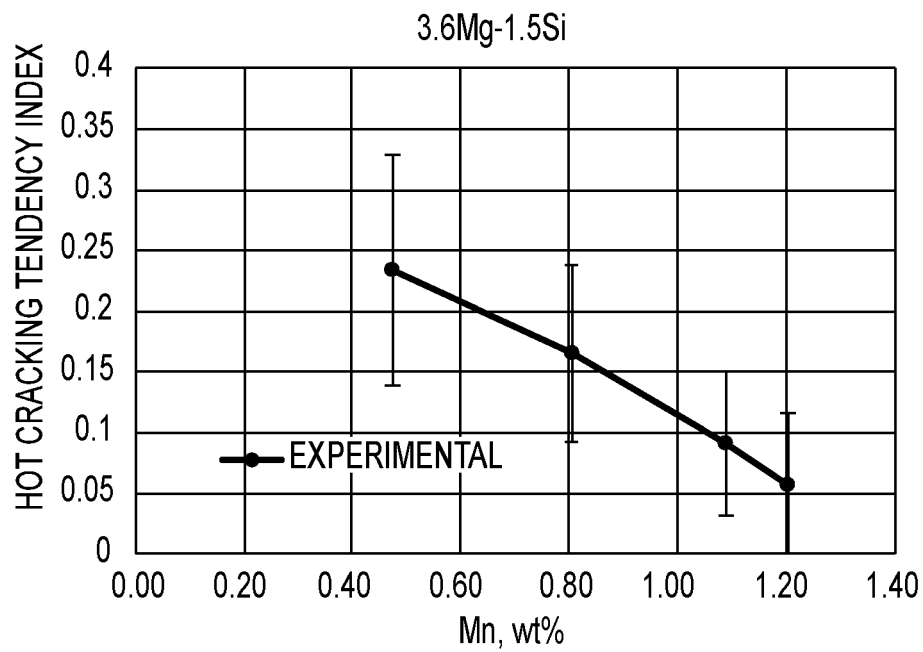


FIG.4

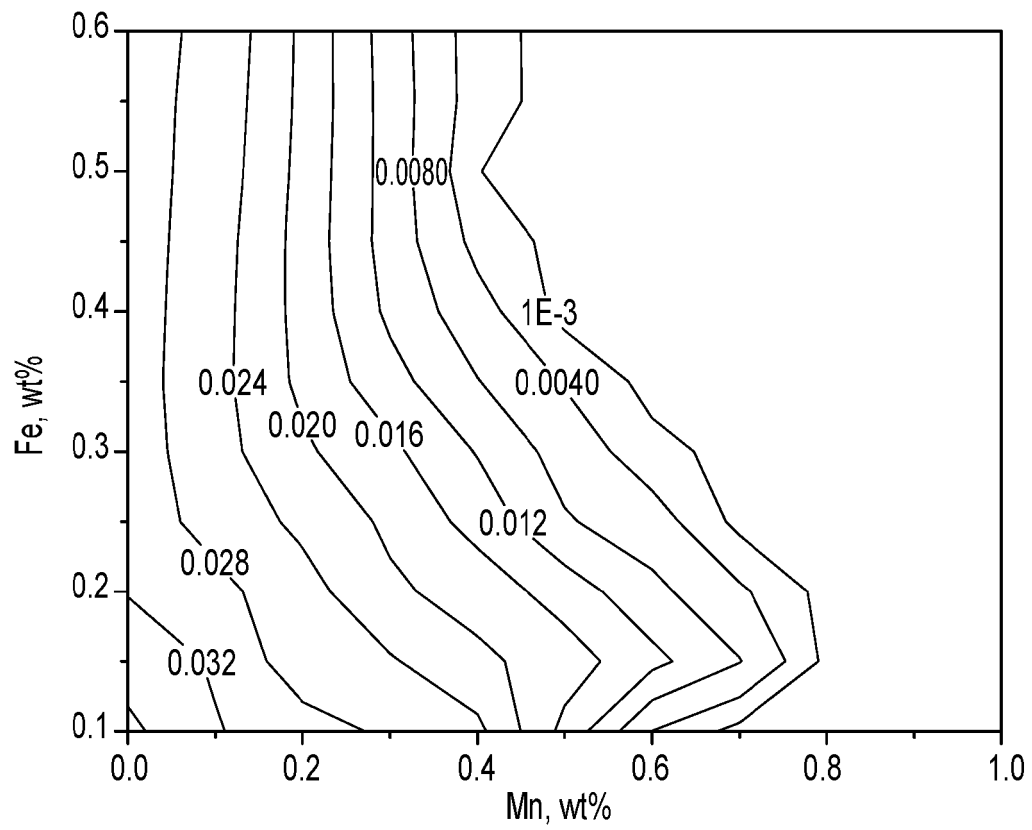


FIG.5a

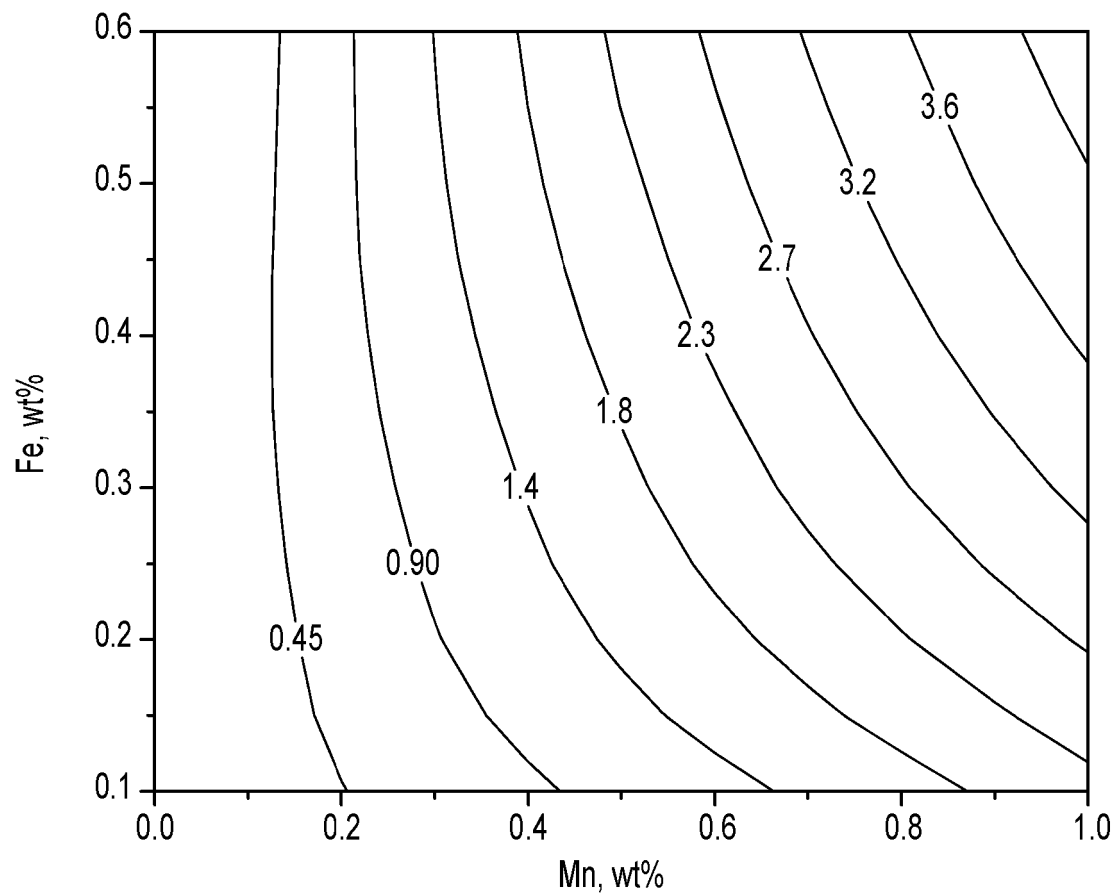


FIG.5b

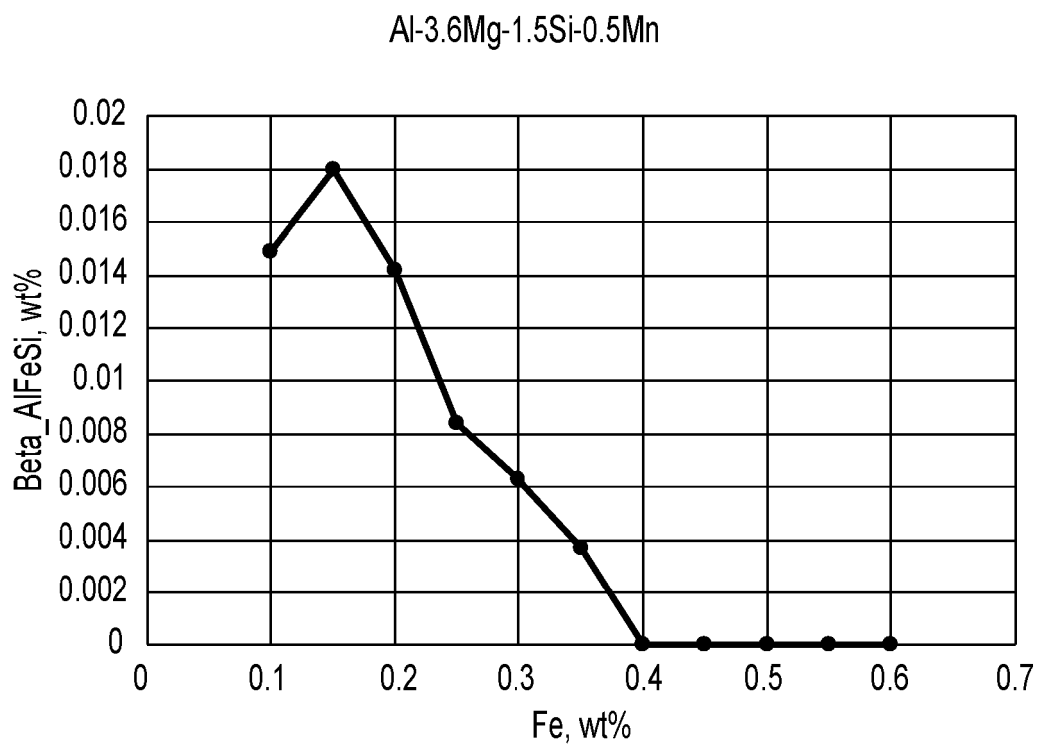


FIG.6

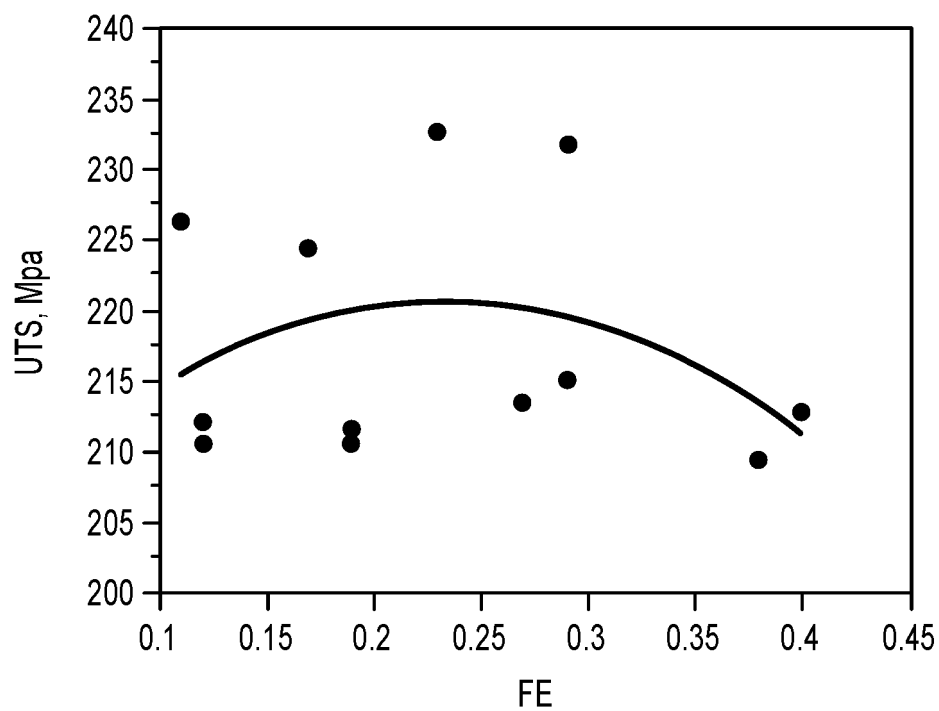


FIG.7a

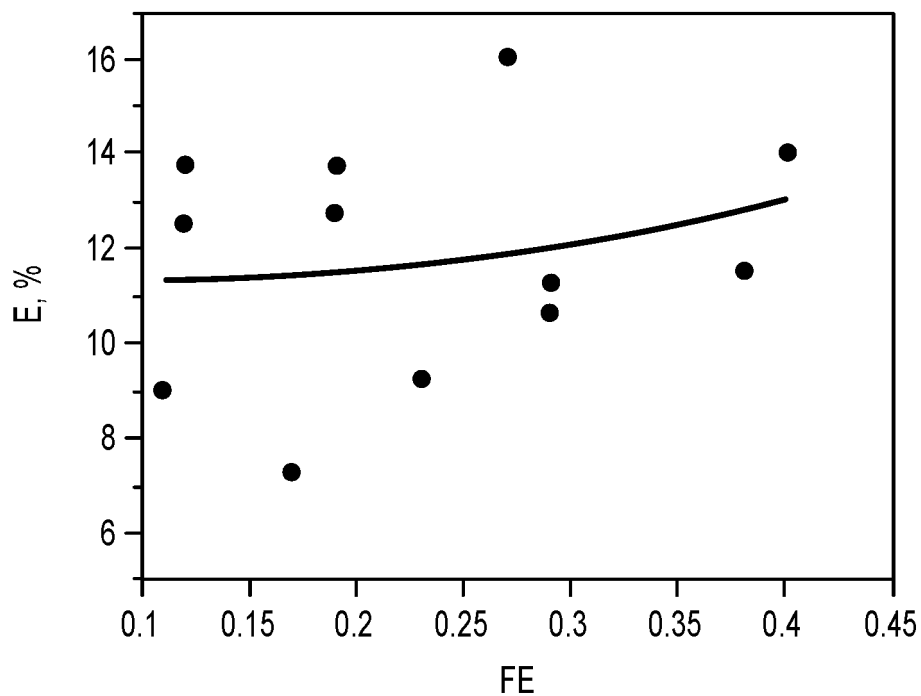


FIG.7b

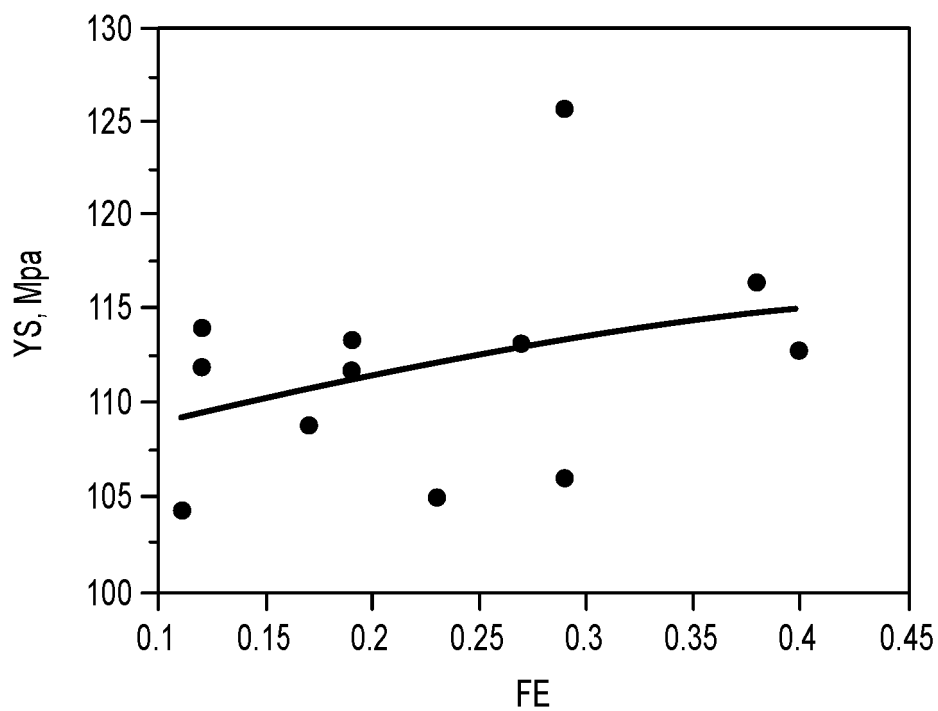


FIG.7c

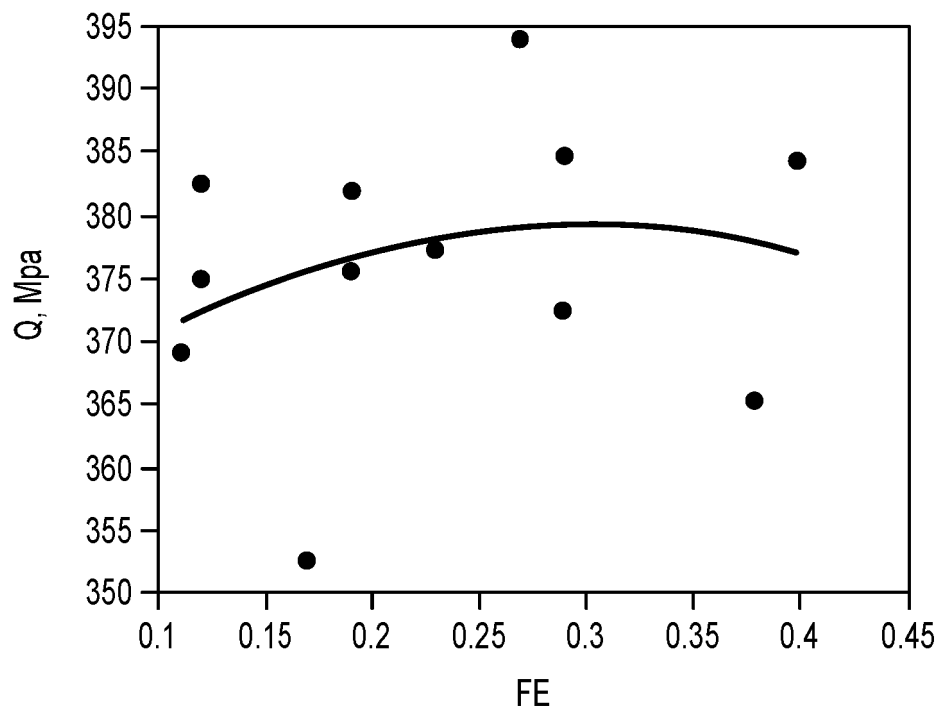


FIG.7d

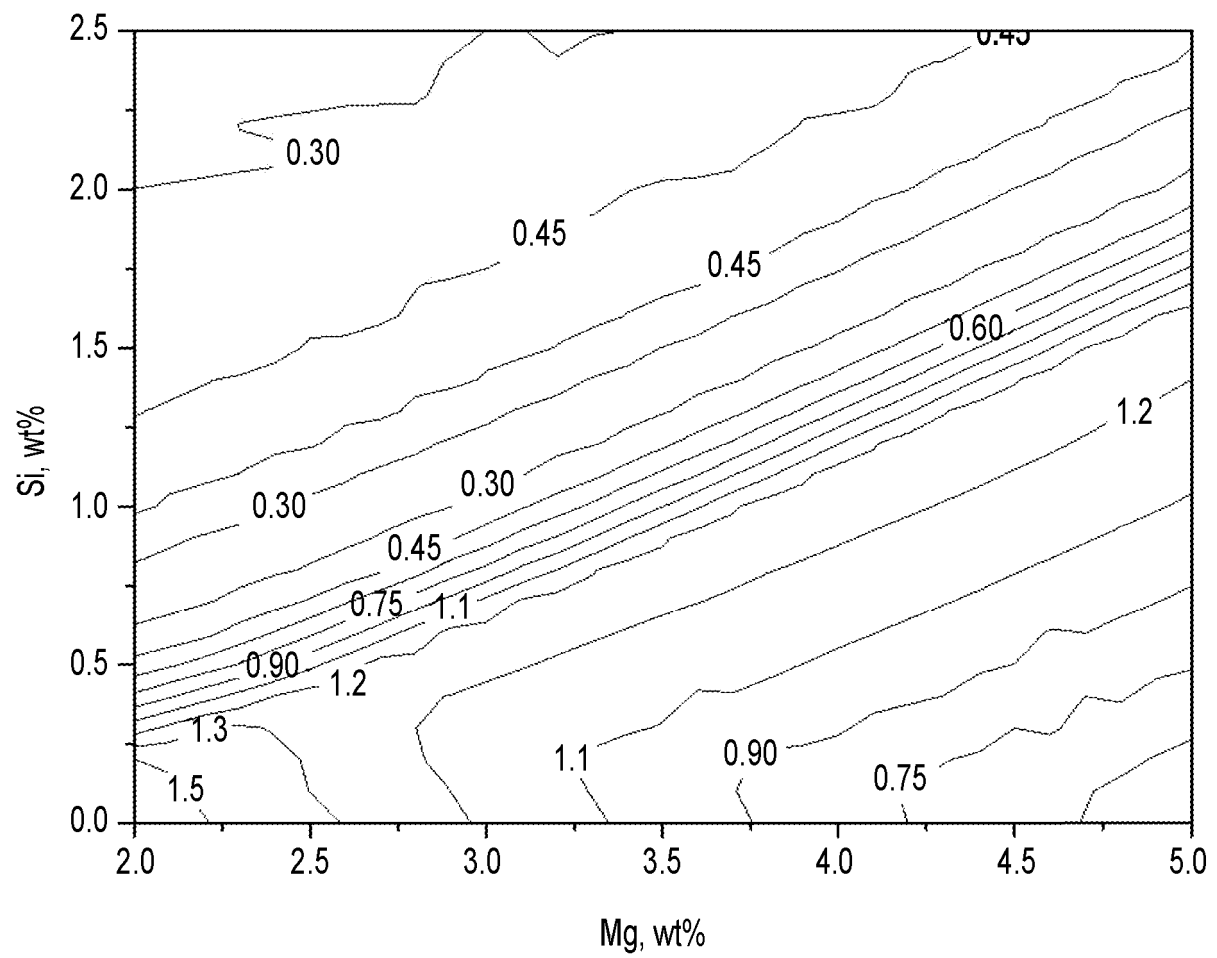


FIG.8a

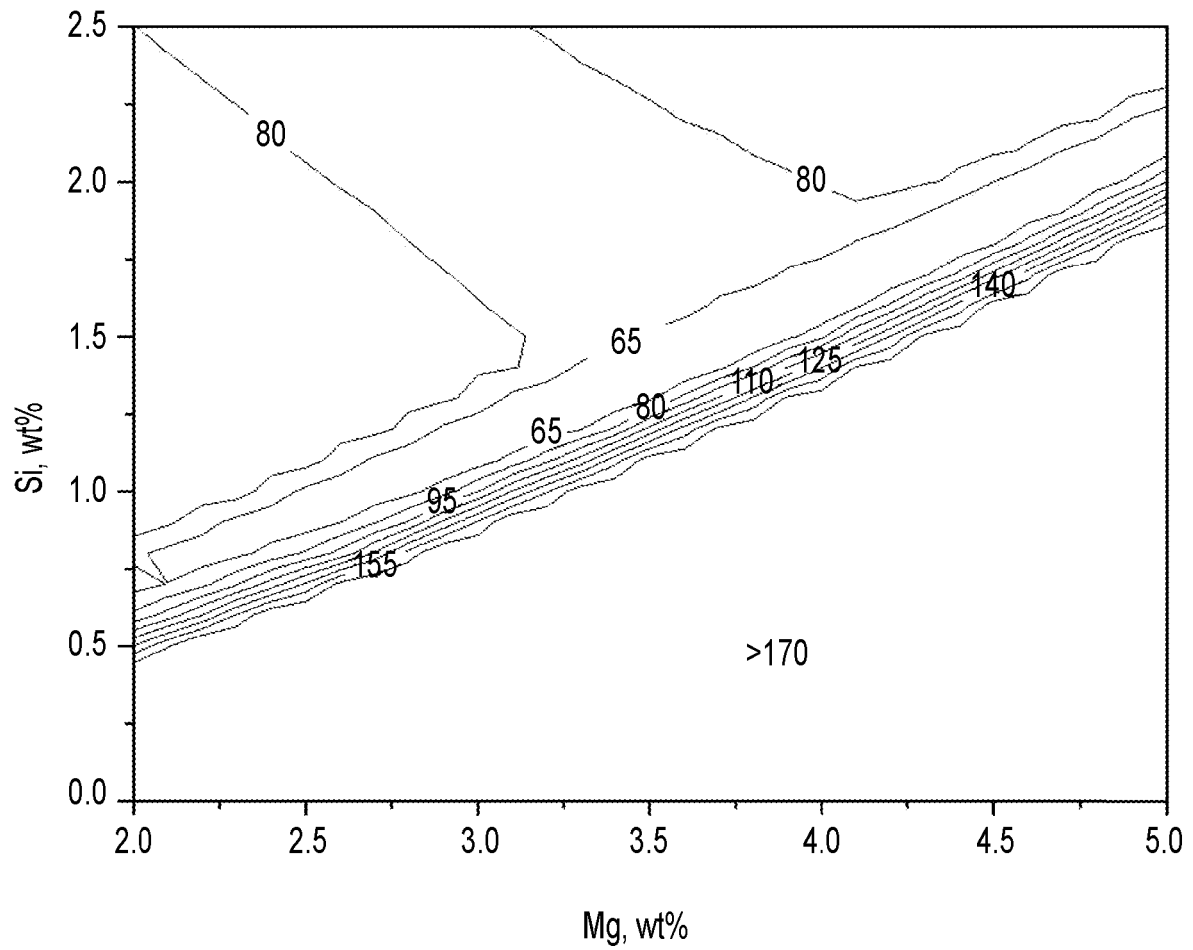


FIG.8b

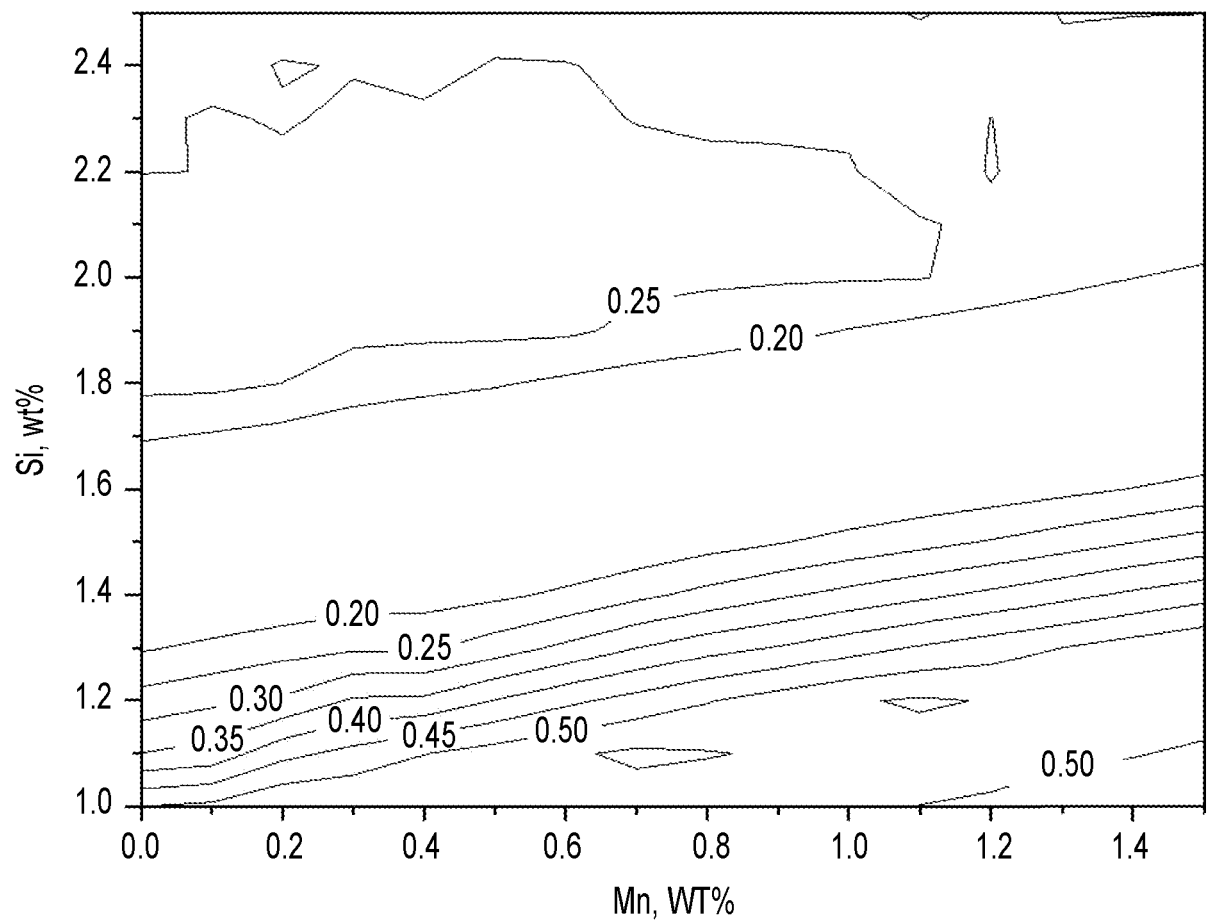


FIG.8c

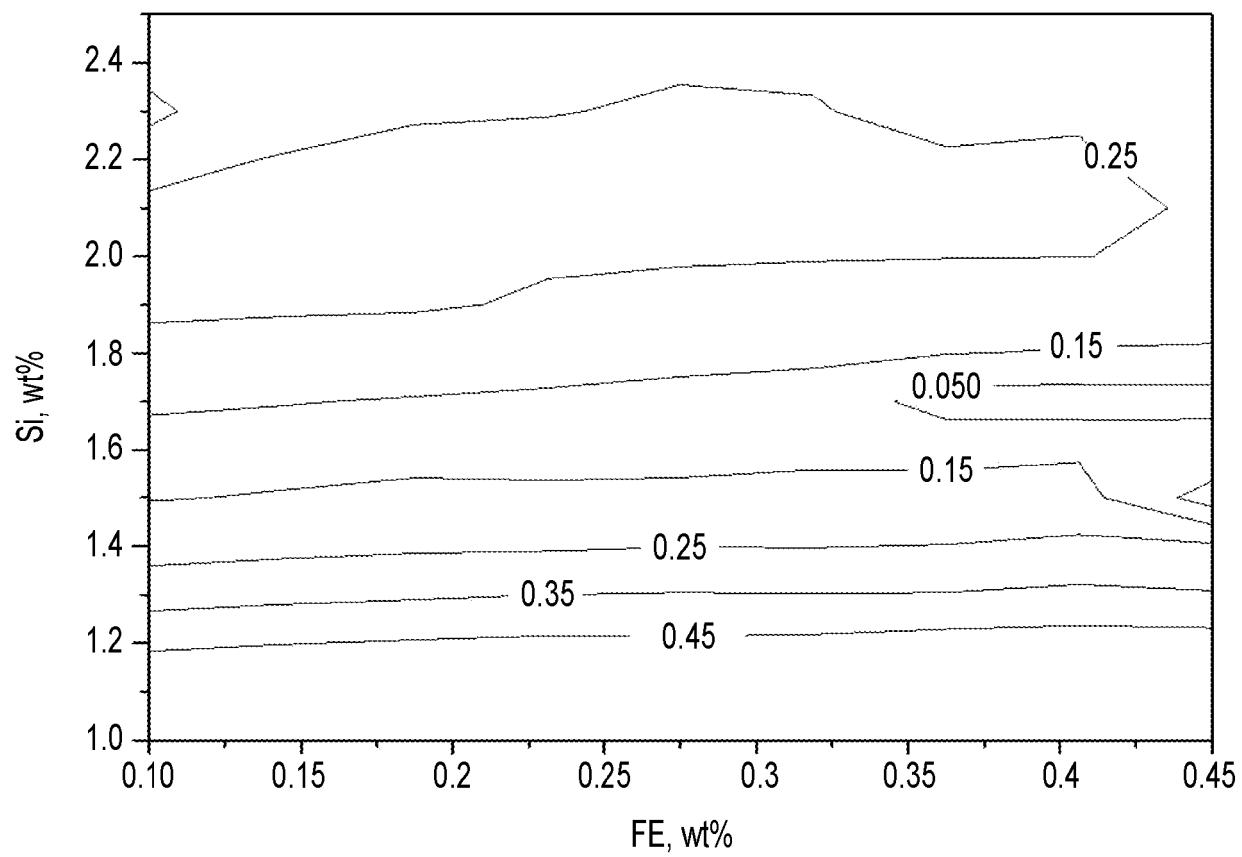


FIG.8d

REFERENCES CITED IN THE DESCRIPTION

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