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(54) IMPROVED ALUMINUM CASTING ALLOYS CONTAINING VANADIUM

VERBESSERTE ALUMINIUMGUSSLEGIERUNGEN MIT VANADIUM

ALLIAGES DE MOULAGE D'ALUMINIUM AMÉLIORÉS CONTENANT DU VANADIUM

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Description**BACKGROUND**

- 5 [0001] Aluminum casting alloys are useful in a variety of applications. However, improving one property of an aluminum casting alloy without degrading another property is elusive. For example, it is difficult to increase the strength of an alloy without decreasing the ductility of an alloy.
- 10 [0002] EP 1 524 324 A2 discloses aluminum alloys having 4 - 12 mass % of Si, less than 0.2 mass % of Cu, 0.1 - 0.5 mass % of Mg, 0.2 - 3.0 mass % of Ni, 0.1 - 0.7 mass % of Fe, 0.15 - 0.3 mass % of Ti and the remainder of AC and inevitable impurities.

SUMMARY OF THE DISCLOSURE

- 15 [0003] Broadly, the present patent application relates to improved aluminum casting alloys (also known as foundry alloys), and methods for producing the same. Specifically, the present patent application relates to aluminum casting alloys having silicon vanadium and, optionally, iron. Generally, the new aluminum casting alloys including vanadium, and optionally iron, achieve an improved combination of properties.
- 20 [0004] The new aluminum casting alloys generally include from about 0.01 to 0.15 wt. % vanadium (V). In one embodiment, the new aluminum casting alloy may include from about 0.03 to 0.12 wt. % vanadium. In another embodiment, the new aluminum casting alloy may include from about 0.05 to 0.10 wt. % vanadium. By maintaining vanadium within the aluminum casting alloy in the above-described amounts, optionally with iron, an improved combination of properties may be realized. For example, the aluminum casting alloy may realize an improved combination of strength and elongation, among other properties.
- 25 [0005] In one embodiment, the aluminum casting alloy includes not greater than 0.08 wt. % iron. In another embodiment, the aluminum casting alloy includes not greater than 0.05 wt. % iron. In some embodiments, iron is included in the alloy. In one embodiment, the aluminum casting alloy includes 0.01 - 0.08 wt. % iron.
- 30 [0006] In one approach, the aluminum casting alloy is a silicon-based casting alloy including the above-described amounts of vanadium, optionally with iron. The silicon-based casting alloys may be any of the 3xx series of casting alloys known to those skilled in the art. In this approach, the silicon-based casting alloy includes from 4.0 to 10.0 wt. % silicon, and silicon is the predominate alloying element of the casting alloy, except for aluminum. The silicon-based casting alloys may optionally include secondary element, tertiary elements, and other elements, defined below. In one embodiment, the silicon-based casting alloy includes from about 6.0 to 9.0 wt. % silicon. In one embodiment, the silicon-based casting alloy includes from about 6.5 to 8.5 wt. % silicon.
- 35 [0007] The silicon-based aluminum alloy may include one or more secondary elements. These secondary elements are selected from the group consisting of magnesium, copper, zinc, nickel, and combinations thereof. The secondary elements may be included in the alloy for various purposes, such as for strengthening (e.g., solid solution, precipitate and constituent strengthening). In one approach, the silicon-based casting alloy includes magnesium. In one embodiment, the silicon-based casting alloy includes magnesium, and in the range of from about 0.05 to 1.5 wt. % magnesium. In other embodiments, the silicon-based casting alloy includes magnesium as an impurity, i.e., not greater than 0.04 wt. % magnesium.
- 40 [0008] In one approach, the silicon-based casting alloy includes copper. In one embodiment, the silicon-based casting alloy includes copper, and in the range of from about 0.40 to 5.0 wt. % copper. In other embodiments, the silicon-based casting alloy includes copper as an impurity, i.e., not greater than 0.39 wt. % copper.
- 45 [0009] In one approach, the silicon-based casting alloy includes zinc. In one embodiment, the silicon-based casting alloy includes zinc, and in the range of from about 0.25 to 5.0 wt. % zinc. In other embodiments, the silicon-based casting alloy includes zinc as an impurity, i.e., not greater than 0.24 wt. % zinc.
- 50 [0010] In one approach, the silicon-based casting alloy includes nickel. In one embodiment, the silicon-based casting alloy includes nickel, and in the range of from about 0.50 to 3.0 wt. % nickel. In other embodiments, the silicon-based casting alloy includes nickel as an impurity, i.e., not greater than 0.49 wt. % nickel.
- 55 [0011] The silicon-based aluminum alloy may include tertiary elements, such as manganese, chromium, titanium, strontium, sodium, antimony, and combinations thereof. One or more of these tertiary elements may be added to the alloy for various purposes. For example, manganese and/or chromium may be included in the silicon-based aluminum alloy to prevent die soldering for high pressure die casting. Titanium may be included in the silicon-based aluminum alloy for grain refining. Strontium, sodium and/or antimony may be added for silicon particle modification. In these embodiments, the silicon-based aluminum alloy generally includes not greater than about 1.0 wt. % each of the tertiary elements. When a tertiary element is included, the alloy generally includes at least about 0.01 wt. % of that tertiary element (e.g., 0.01 - 1.0 wt. % Mn). In one embodiment, the silicon-based aluminum alloy includes 0.01 to 0.8 wt. % manganese. In one embodiment, the silicon-based aluminum alloy includes 0.01 to 0.5 wt. % chromium. In one embod-

iment, the silicon-based aluminum alloy includes 0.01 to 0.25 wt. % titanium. In one embodiment, the silicon-based aluminum alloy includes 0.001 to 0.1 wt. % strontium. In one embodiment, the silicon-based aluminum alloy includes 0.001 to 0.1 wt. % sodium. In one embodiment, the silicon-based aluminum alloy includes 0.001 to 0.1 wt. % antimony.

[0012] In addition or as an alternative to titanium grain refining, the silicon-based aluminum alloy may include TiB_2 and/or TiC as a grain refiner. In one embodiment, the silicon-based aluminum alloy includes 0.001 to 0.03 wt. % boron. In one embodiment, the silicon-based aluminum alloy includes 0.001 to 0.03 wt. % carbon.

[0013] The silicon-based aluminum alloy may be substantially free of other elements (e.g., deoxidizers, impurities). Other elements means any other element of the periodic table that may be included in the silicon-based aluminum alloy, except for aluminum, the silicon, the vanadium, the iron, the secondary elements, and the tertiary elements, described above. In the context of this paragraph the phrase "substantially free" means that the aluminum alloy body contains not more than 0.25 wt. % each of any element of the other elements, with the total combined amount of these other elements not exceeding 0.50 wt. %. In one embodiment, each one of these other elements, individually, does not exceed about 0.10 wt. % in the silicon-based aluminum alloy, and the total combined amount of these other elements does not exceed about 0.35 wt. %, in the silicon-based aluminum alloy. In another embodiment, each one of these other elements, individually, does not exceed about 0.05 wt. % in the silicon-based aluminum alloy, and the total combined amount of these other elements does not exceed about 0.15 wt. % in the silicon-based aluminum alloy. In another embodiment, each one of these other elements, individually, does not exceed about 0.03 wt. % in the silicon-based aluminum alloy, and the total combined amount of these other elements does not exceed about 0.10 wt. % in the silicon-based aluminum alloy.

[0014] The silicon-based aluminum alloy may be used in various types of foundry casting processes, such as sand mold casting, investment casting (ceramic shell mold), lost foam casting, permanent mold casting, high pressure die casting, squeeze casting, and semi-solid casting, to name a few. The Secondary Dendrite Arm Spacing (SDAS) of the silicon-based aluminum alloy produced by various casting methods may range from 1 micrometer (e.g., with a fast solidification rate) to 100 micrometers (e.g., with a slow solidification rate). SDAS may be determined, for instance, using standard metallographic techniques and the "intercept method". The intercept method involves (1) drawing a straight line parallel to the primary dendrite,(2) counting the number of dendrite arm intercepted, (3) using the following equation to calculate a specific SDAS: $SDAS = \text{line length} / \text{number of arms} / \text{magnification}$; and (4) repeating several times (at least 5) and averaging the results to obtain an overall SDAS.

[0015] These and other aspects, advantages, and novel features of this new technology are set forth in part in the description that follows and will become apparent to those skilled in the art upon examination of the following description and figures, or may be learned by practicing one or more embodiments of the technology provided for by the patent application.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016]

FIG. 1 is a graph illustrating the performance of various silicon-based aluminum casting alloys.

FIG. 2 is a graph illustrating the performance of various silicon-based aluminum casting alloys.

FIGS. 3a-3b are pictures illustrating the microstructure of various silicon-based aluminum casting alloys.

DETAILED DESCRIPTION

Example 1

[0017] Several silicon-based aluminum casting alloys having the compositions listed in Table 1, below, are cast via sand mold casting.

Table 1 - Composition of Silicon-based casting alloy (all values in weight percent)

Alloy (Variante)	Si	Mg	Fe	V	Ti	Na	Other, Each	Others, Total	Bal.
1	6.92	0.318	0.074	0.083	0.113	0.0078	≤ 0.05	≤ 0.15	Al
2	7.06	0.332	0.077	<0.001	0.108	0.0046	≤ 0.05	≤ 0.15	Al
3	7.08	0.319	0.141	0.079	0.113	0.0039	≤ 0.05	≤ 0.15	Al

[0018] After casting, the properties of the alloys have been measured (i.e., in the F temper) for each alloy in the same

way. The results are illustrated in FIG. 1. The given average of the measured data include tensile yield strength data ($\text{ØR}_{\text{p}0.2}$) and ultimate tensile strength data (ØR_m) given in MPa and Brinell scale hardness data HBW5/250 (ØHärte). Moreover, average elongation data are given, where ØA (lower graph) refers to average elongation based on machine measured data, and where ØAI (upper graph) refers to average elongation based on manually measured data. Alloy 1 with 0.08 wt. % V and 0.08 wt. % Fe has both better strength and elongation than Alloys 2-3 achieving an ultimate tensile strength of about 143 MPa, and an elongation of about 4.2-4.4%. By comparison, Alloys 2-3 achieve only about 123-130 MPa in ultimate tensile strength, and with much lower elongation (2.6-2.8%).

[0019] These alloys (Variante 1 - 3) are also aged to a T6 temper. The same mechanical characteristics ($\text{ØR}_{\text{p}0.2}$, ØR_m , ØHärte , ØA , ØAI) as that depicted in Fig. 1 have been determined. The results of the measurements are illustrated in FIG. 2 (one with water quench after a 5h solution heat treatment at 540 °C, followed by a two step artificial ageing for 3h at 140° and 6h at 160°C, and one with air cooling after a 3.5h solution heat treatment at 540 °C, followed by a one step artificial ageing for 5h at 185°C).

[0020] Again, Alloy 1 with 0.08 wt. % vanadium and 0.08 wt. % iron outperforms Alloys 2-3 in terms of strength and elongation, achieving both higher strength and elongation than Alloys 2-3.

[0021] The microstructures of Alloys 1-3 are illustrated in FIGS. 3a-3b, below.

[0022] Alloy 1 contains smaller β -AlFeSi particles and less/smaller π -AlFeMgSi particles. The porosity of Alloys 1-3 is also measured (by image analysis), the results of which are provided in Table 2, below. Alloys 1 and 3 with 0.08 wt. % V have reduced porosity. It is believed that both factors, i.e., less/smaller particles and less porosity, may contribute to the higher strength and elongation properties.

Table 2 - Porosity of Silicon-based casting alloy (all porosity values in percent)

Measurement	Alloy 1	Alloy 2	Alloy 3
1	0.88	5.03	1.57
2	2.04	3.96	1.63
3	1.91	6.32	1.31
4	1.36	5.9	1.44
5	1.87	4.84	1.17
6	1.13	7.19	1.19
7	0.84	2.92	1.37
8	1.28	3.48	1.07
9	1.26	4.05	2.18
10	0.96	4.83	1.59
11	0.67	3.71	0.57
12		5.93	1.37
13		3.08	1.91
14		1.94	1.31
15		1.86	0.93
16		1.49	0.92
17		1.09	
18		2.11	
Average	1.291	3.874	1.346
STDEV	0.467	1.792	0.392

Claims

1. An aluminum casting alloy comprising:

from 4.0 to 10.0 wt. % silicon (Si);
 from 0.01 to 0.15 wt. % vanadium (V);
 up to 0.08 wt. % iron (Fe);
 optionally one or more of the following secondary elements:

5 from 0.05 to 1.5 wt. % magnesium (Mg);
 from 0.40 to 5.0 wt. % copper (Cu);
 from 0.25 to 5.0 wt. % zinc (Zn); and
 from 0.50 to 3.0 wt. % nickel (Ni);

10 optionally 0.01 - 1.0 wt. % each of one or more of the following tertiary elements: manganese (Mn), chromium (Cr), titanium (Ti), strontium (Sr), sodium (Na), and antimony (Sb);
 optionally from 0.001 to 0.03 wt. % boron (B);
 optionally from 0.001 to 0.03 wt. % carbon (C);
 15 not more than 0.25 wt. % each of any other element, with the total combined amount of these other elements not exceeding 0.50 wt.%;
 the balance being aluminum and impurities.

- 2. The aluminum casting alloy of claim 1, comprising from 0.03 to 0.12 wt. % V.
- 3. The aluminum casting alloy of claim 1, comprising from 0.05 to 0.10 wt. % V.
- 4. The aluminum casting alloy of any of claims 1-3, comprising not greater than 0.05 wt. % iron.
- 5. The aluminum casting alloy of any of claims 1-4, comprising at least 0.01 wt. % iron.
- 6. The aluminum casting alloy of any of claims 1-5, comprising from 6.0 to 9.0 wt. % silicon.
- 7. The aluminum casting alloy of any of claims 1-5, comprising from 6.5 to 8.5 wt. % silicon.
- 8. The aluminum casting alloy of any of claims 1-7, comprising from 0.01 to 0.8 wt. % manganese.
- 9. The aluminum casting alloy of any of claims 1-8, comprising from 0.01 to 0.5 wt. % chromium.
- 35 10. The aluminum casting alloy of any of claims 1-9, comprising from 0.01 to 0.25 wt. % titanium.
- 11. The aluminum casting alloy of any of claims 1-10, comprising from 0.001 to 0.1 wt. % strontium.
- 12. The aluminum casting alloy of any of claims 1-11, comprising from 0.001 to 0.1 wt. % sodium.
- 40 13. The aluminum casting alloy of any of claims 1-12, comprising from 0.001 to 0.1 wt. % antimony.
- 14. The aluminum casting alloy of any of claims 1-13, wherein the alloy comprises not more than 0.10 wt. % each of the other elements, with the total combined amount of these other elements not exceeding 0.35 wt. %.
- 45 15. The aluminum casting alloy of any of claims 1-14, wherein the alloy realizes a Secondary Dendrite Arm Spacing (SDAS) of from 1 micrometer to 100 micrometers.

50 Patentansprüche

- 1. Eine Aluminiumgusslegierung aufweisend:
 - von 4,0 bis 10,0 Gew.% Silizium (Si);
 - von 0,01 bis 0,15 Gew.% Vanadium (V);
 - bis zu 0,08 Gew.% Eisen (Fe);
 - optional ein oder mehrere der folgenden Sekundärelemente:

von 0,05 bis 1,5 Gew.% Magnesium (Mg);
von 0,40 bis 5,0 Gew.% Kupfer (Cu);
von 0,25 bis 5,0 Gew.% Zink (Zn);
von 0,50 bis 3,0 Gew.% Nickel (Ni);

5 optional jeweils 0,01 bis 1,0 Gew.% von einem oder mehreren der folgenden Tertiärelemente: Mangan (Mn), Chrom (Cr), Titan (Ti), Strontium (Sr), Natrium (Na), und Antimon (Sb);
optional von 0,001 bis 0,03 Gew.% Bor (B);
optional von 0,001 bis 0,03 Gew.% Kohlenstoff (C);
10 nicht mehr als 0,25 Gew.% jeweils von einem anderen Element, die gesamte Menge dieser anderen Elemente 0,50 Gew.% nicht übersteigend;
der Rest Aluminium und Verunreinigungen.

- 15 2. Die Aluminiumgusslegierung nach Anspruch 1, enthaltend von 0,03 bis 0,12 Gew.% V.
3. Die Aluminiumgusslegierung nach Anspruch 1, enthaltend von 0,05 bis 0,10 Gew.% V.
4. Die Aluminiumgusslegierung gemäß einem der Ansprüche 1 - 3, enthaltend nicht mehr als 0,05 Gew.% Eisen.
20 5. Die Aluminiumgusslegierung gemäß einem der Ansprüche 1- 4, enthaltend mindestens 0,01 Gew.% Eisen.
6. Die Aluminiumgusslegierung gemäß einem der Ansprüche 1- 5, enthaltend von 6,0 bis 9,0 Gew.% Silizium.
7. Die Aluminiumgusslegierung gemäß einem der Ansprüche 1- 5, enthaltend von 6,5 bis 8,5 Gew.% Silizium.
25 8. Die Aluminiumgusslegierung gemäß einem der Ansprüche 1- 7, enthaltend von 0,01 bis 0,8 Gew.% Mangan.
9. Die Aluminiumgusslegierung gemäß einem der Ansprüche 1-8, enthaltend von 0,01 bis 0,5 Gew.% Chrom.
30 10. Die Aluminiumgusslegierung gemäß einem der Ansprüche 1- 9, enthaltend von 0,01 bis 0,25 Gew.% Titan.
11. Die Aluminiumgusslegierung gemäß einem der Ansprüche 1 - 10, enthaltend von 0,001 bis 0,1 Gew.% Strontium.
12. Die Aluminiumgusslegierung gemäß einem der Ansprüche 1-11, enthaltend von 0,001 bis 0,1 Gew.% Natrium.
35 13. Die Aluminiumgusslegierung gemäß einem der Ansprüche 1 - 12, enthaltend von 0,001 bis 0,1 Gew.% Antimon.
14. Die Aluminiumgusslegierung gemäß einem der Ansprüche 1 - 13, wobei die Legierung nicht mehr als 0,10 Gew.% eines der anderen Elemente enthält, wobei die Gesamtmenge der anderen Elemente 0,35 Gew.% nicht überschreitet.
40 15. Die Aluminiumgusslegierung gemäß einem der Ansprüche 1 - 14, wobei die Legierung einen sekundären Dendritenabstand (SDAS) von 1 Mikrometer bis 100 Mikrometer erreicht.

45 **Revendications**

1. Alliage de fonderie d'aluminium comprenant :

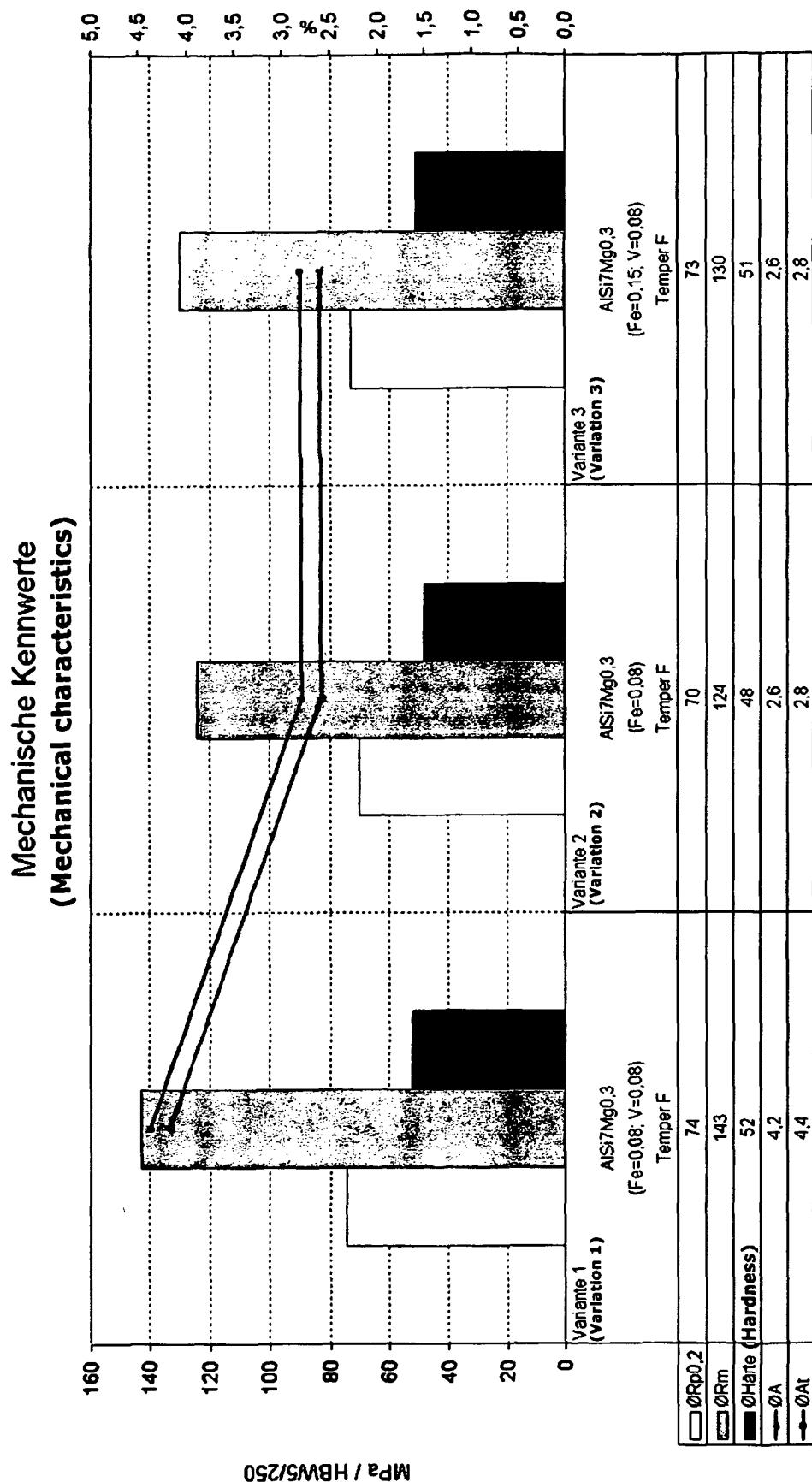
50 de 4,0 à 10,0 % en poids de silicium (Si) ;
de 0,01 à 0,15 % en poids de vanadium (V) ;
jusqu'à 0,08 % en poids de fer (Fe) ;
éventuellement un ou plusieurs des éléments secondaires suivants :
55 de 0,05 à 1,5 % en poids de magnésium (Mg) ;
de 0,40 à 5,0 % en poids de cuivre (Cu) ;
de 0,25 à 5,0 % en poids de zinc (Zn) ; et
de 0,50 à 3,0 % en poids de nickel (Ni) ;

éventuellement 0,01 - 1,0 % en poids de chacun d'un ou plusieurs des éléments tertiaires suivants : manganèse (Mn), chrome (Cr), titane (Ti), strontium (Sr), sodium (Na), et antimoine (Sb) ;
éventuellement de 0,001 à 0,03 % en poids de bore (B) ;
éventuellement de 0,001 à 0,03 % en poids de carbone (C) ;
au plus 0,25 % en poids de chacun d'un autre élément, avec la quantité combinée totale de ces autres éléments n'excédant pas 0,50 % en poids ;
le reste étant de l'aluminium et des impuretés.

2. Alliage de fonderie d'aluminium selon la revendication 1, comprenant de 0,03 à 0,12 % en poids de V.
3. Alliage de fonderie d'aluminium selon la revendication 1, comprenant de 0,05 à 0,10 % en poids de V.
4. Alliage de fonderie d'aluminium selon l'une quelconque des revendications 1-3, comprenant au plus 0,05 % en poids de fer.
5. Alliage de fonderie d'aluminium selon l'une quelconque des revendications 1-4, comprenant au moins 0,01 % en poids de fer.
6. Alliage de fonderie d'aluminium selon l'une quelconque des revendications 1-5, comprenant de 6,0 à 9,0 % en poids de silicium.
7. Alliage de fonderie d'aluminium selon l'une quelconque des revendications 1-5, comprenant de 6,5 à 8,5 % en poids de silicium.
8. Alliage de fonderie d'aluminium selon l'une quelconque des revendications 1-7, comprenant de 0,01 à 0,8 % en poids de manganèse.
9. Alliage de fonderie d'aluminium selon l'une quelconque des revendications 1-8, comprenant de 0,01 à 0,5 % en poids de chrome.
10. Alliage de fonderie d'aluminium selon l'une quelconque des revendications 1-9, comprenant de 0,01 à 0,25 % en poids de titane.
11. Alliage de fonderie d'aluminium selon l'une quelconque des revendications 1-10, comprenant de 0,001 à 0,1 % en poids de strontium.
12. Alliage de fonderie d'aluminium selon l'une quelconque des revendications 1-11, comprenant de 0,001 à 0,1 % en poids de sodium.
13. Alliage de fonderie d'aluminium selon l'une quelconque des revendications 1-12, comprenant de 0,001 à 0,1 % en poids d'antimoine.
14. Alliage de fonderie d'aluminium selon l'une quelconque des revendications 1-13, dans lequel l'alliage comprend au plus 0,10 % en poids de chacun des autres éléments, avec la quantité combinée totale de ces autres éléments n'excédant pas 0,35 % en poids.
15. Alliage de fonderie d'aluminium selon l'une quelconque des revendications 1-14, dans lequel l'alliage réalise un espacement de bras dendritique secondaire (SDAS) de 1 micromètre à 100 micromètres.

50

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**Fig. 1**

**Variation with
best results**

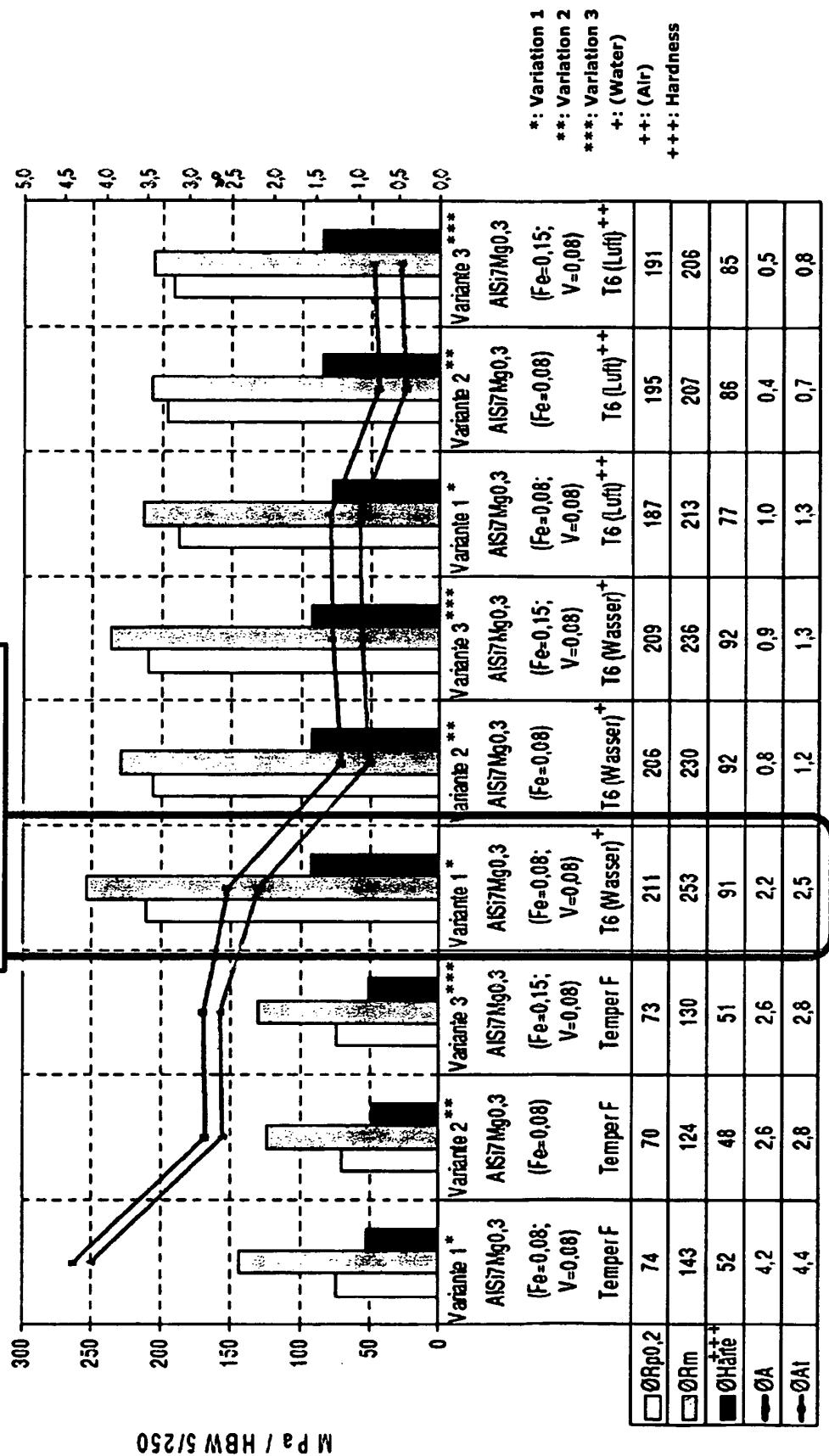


Fig. 2

Fig. 3a - Alloy 1

Fe=0.08 wt% and V=0.08 wt%

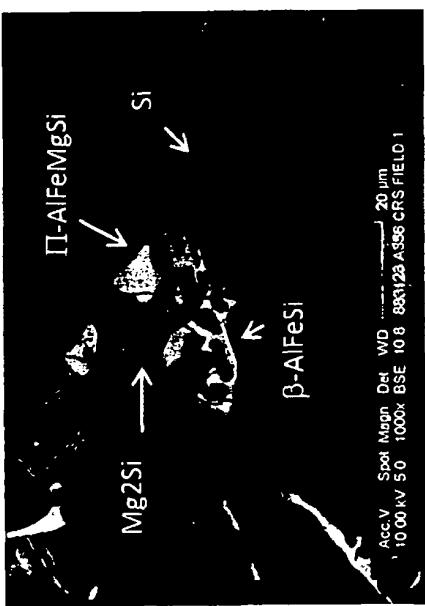
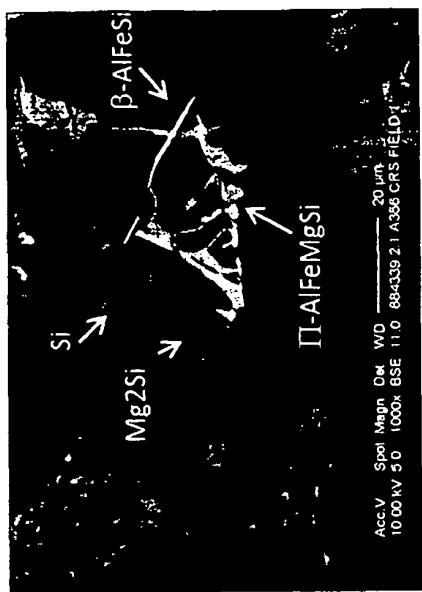


Fig. 3b - Alloy 2

Fe=0.08 wt% and V=0.00 wt%



Fe=0.15 wt% and V=0.08 wt%

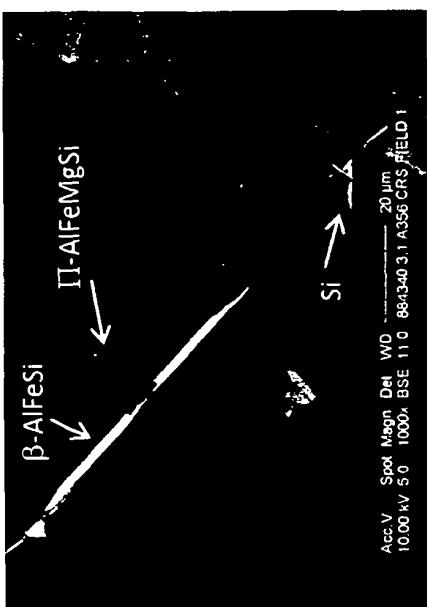


Fig. 3c - Alloy 3

REFERENCES CITED IN THE DESCRIPTION

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