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(54) ALUMINIUM CASTING ALLOY

(57) The invention relates to the field of metallurgy and can be used to produce shaped castings by means of gravity die casting, pressure die casting and pressurised crystallisation, which shaped castings can be used in automobile construction, for housings of electronic device and also as heavy-duty components which are capable of operating at elevated temperatures. An aluminium based casting alloy comprises (in wt%): 0.01-1.1 iron, 0.5-2.5 manganese, 1.2-2.2 nickel, 0.02-0.20 chromium, 0.02-0.15 titanium, 0.02-0.35 zirconium, and the remainder being aluminium, wherein iron and nickel are preferably in the form of aluminides of eutectic origin in the amount of no less than 4 wt%. The invention is directed to the creation of a new, high-tech aluminium alloy that is capable of hardening without water quenching.

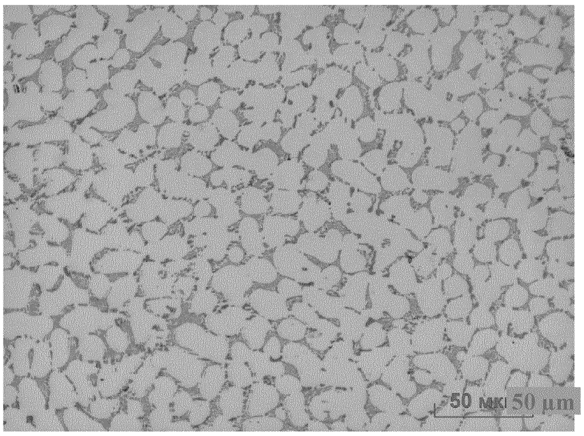

Fig. 1

EP 3 950 986 A1

Description

Field of the invention

[0001] The invention relates to the field of metallurgy, and specifically, to aluminum-based alloys, and can be used in the production of castings of complex shape by metal mold casting with the application of different casting techniques, in particular pressure casting, low-pressure casting, gravity casting, etc.

Summary of the prior art

[0002] Castings of complex shape, depending on their purpose, are produced from non-heat-treatable and heat-treatable Al-Si alloys. Castings, which are intended for the most critical parts, are usually used after a full T6 temper heat treatment that includes water quenching and ageing to maximum strength. The maximum strength of copper-free Al-Si alloys (for example, AlSi7Mg alloys) in the T6 temper is usually up to 250-300 MPa for ultimate tensile strength and 170-240 MPa for yield strength. Quenching makes the casting production process considerably more difficult, since quenching might cause geometrical distortions, changes in dimensions and cracks in castings.

[0003] Non-heat-treatable alloys are usually characterized by low mechanical strength properties. In particular, the AlSi1 1 alloy, when cast into a metal mold, has an ultimate tensile strength of no higher than 180-210 MPa; the yield strength of such an alloy is about 70-80 MPa, and its elongation is usually 6-15%. Low elongation values are due to the alloy's structure characterized by a coarse eutectic silicon morphology; Al-Si alloys are usually doped with various alloying components to increase elongation but it often causes an increase in porosity, which leads to deterioration of the tightness of thin-walled castings.

[0004] The related art discloses an Al-Ni-Mn based alloy for aerospace and automotive structural components, which is an alternative to Al-Si alloy grades. The alloy has been developed by Alcoa and is disclosed in US6783730B2 (publ. 31.08.2004). This alloy - which includes about 2-6 wt. % Ni, about 1-3 wt. % Mn, less than about 1 wt. % Fe, less than about 1 wt. % Si, with incidental elements and impurities - ensures production of castings with a good combination of casting and mechanical properties. One of the drawbacks of this disclosure is that a high level of casting and mechanical properties is ensured by the use of high-purity aluminum grades and by a high nickel content, which considerably increases the production cost of castings. Moreover, the proposed material is non-heat-treatable over the whole concentration range, which places limitations on its application. Furthermore, the corrosion resistance of castings significantly decreases in the region of high nickel concentrations.

[0005] The related art also discloses Al-Ni and Al-Ni-Mn alloys and a method for producing cast products out of these alloys, as disclosed in Alcoa's invention US8349462B2 (publ. 08.01.2013). The invention proposes compositions of alloys to be applied in the as-cast condition and a method of their production to obtain a target structure ensuring reaching a required level of mechanical properties and forming decorative anodized coatings. The chemical composition of the proposed disclosure comprises the following ranges of the alloy elements: about 6.6 to about 8.0 wt. % Ni; about 0.5 to about 3.5 wt. % Mn; up to about 0.25 wt. % of any of Fe and Si; up to about 0.5 wt. % of any of Cu, Zn, and Mg; up to about 0.2 wt. % of any of Ti, Zr, and Sc, wherein one of B and C may be included up to about 0.1 wt. %. As in US6783730B2, the high level of casting and mechanical properties is ensured by the use of high-purity aluminum grades and by a high nickel content, which considerably increases the production cost of castings. Moreover, the high nickel content considerably reduces the resistance of castings to corrosion. Furthermore, the corrosion resistance of castings significantly decreases in the region of high nickel concentrations. With a relatively low content of nickel and manganese, casting alloys have a low level of strength.

[0006] In US8950465B2 (publ. 10.02.2015) for aluminum alloys and a method of their production, Alcoa extended the concentration ranges of the alloy elements, which are disclosed in US8349462B2. In the proposed disclosure, castings in the as-cast condition may be produced from Al-Ni and Al-Ni-Mn alloys having the following concentration ranges of the alloy elements: an Al-Ni casting alloy comprising from about 0.5 wt. % to about 8.0 wt. % Ni; and an Al-Ni-Mn casting alloy comprising from about 0.5 wt. % to about 8.0 wt. % Ni and from about 0.5 wt. % to about 3.5 wt. % Mn. One of the drawbacks of this disclosure is that the high level of casting and mechanical properties is ensured by the use of high-purity aluminum grades and by a high nickel content, which considerably increases the production cost of castings

[0007] The closest prior art is an aluminum-based alloy developed by the National University of Science and Technology "MISiS" and disclosed in RF patent 2478131C2, publ. 27.03.2013. This alloy comprises (in wt.%): 1.5-2.5%Ni, 0.3-0.7%Fe, 1-2%Mn, 0.02-0.2%Zr, 0.02%-0.12%Sc and 0.002-0. 1%Ce. Castings produced from this alloy after annealing (without quenching) are characterized by an ultimate tensile strength of no less than 250 MPa and an elongation of no less than 4%. The first drawback of this alloy is that it is highly prone to forming localized porosity, which makes it difficult to produce high-quality, relatively large castings. The second drawback is related to the necessity of using high casting temperatures, which is not always possible at a casting facility.

Disclosure of the invention

[0008] The object of this invention is the development of a new aluminum alloy that is intended for the production of shaped castings and meets a number of target process and mechanical parameters - first of all, elongation.

[0009] The technical effect is to ensure a required combination of process and mechanical properties of the alloy during casting.

[0010] The technical effect is achieved by the fact that the aluminum-based casting alloy comprises iron, nickel, manganese, at least one element selected from a group consisting of titanium and zirconium, such alloy elements have the following concentrations, in weight %:

Iron	0.1-1.1,
Manganese	0.5-2.5,
Nickel	1.2-2.2,
Chromium	0.02-0.20,
Titanium	0.02-0.15,
Zirconium	0.02-0.35,

and Aluminum the remainder,
wherein the following conditions should be met: eutectic iron and nickel should be represented mainly in the form of eutectic aluminides in the amount of no less than 4% by weight.

[0011] An embodiment of this alloy allows producing castings, in which the following tensile strength properties are achieved:

- at a ratio of $0.02 \leq Zr+Ti \leq 0.45$: an ultimate tensile strength of no less than 200 MPa and an elongation of no less than 15% in the as-cast condition.

[0012] The amount of the eutectic component should be calculated with the use of the Thermo-Calc software (TTAL5 database).

[0013] Zirconium may be redistributed between the solid solution and secondary phases with a size of up to 20 nm and the $L1_2$ lattice type.

[0014] The alloy may comprise aluminum produced under an inert anode electrolysis technology.

[0015] The above embodiments are not the only ones possible. Different modifications and enhancements are allowed, if they are not beyond the scope of disclosure defined by claim 1.

Summary of the invention

[0016] The concentration of iron and nickel in the ranges claimed provides for the required amount of eutectic aluminides in the amount of no less than 4 wt. %, which, it its turn, ensures the required processability during casting (first of all, in terms of hot tearing tendency.) If the content of iron and nickel is lower than the amount claimed, the amount of eutectic phases will be lower than required, and the required level of properties will not be ensured. If the content of iron and nickel is higher than the amount claimed, primary crystals of the (Fe, Ni)-containing phases will be formed in the structure during crystallization, which will lead to a reduction in the total level of mechanical properties.

[0017] Manganese in the range claimed is required to ensure solid solution hardening in case of the as-cast condition and precipitation age hardening in case of the heat-treated condition. A lower manganese concentration will not be enough to ensure the required level of strength properties. A higher concentration will likely lead to the formation of primary crystals of the $Al_6(Fe, Mn)$ phase, which will lead to a reduction in the level of mechanical properties and casting processability.

[0018] Zirconium in the range claimed is required for solid solution hardening (when used in the as-cast condition) or the precipitation of the Al_3Zr secondary phase with the $L1_2$ lattice (in case heat treatment is used). If the concentration is lower, the amount of the latter will not be enough to achieve target strength properties; if the concentration is higher, it will be required to increase the casting temperature to make it higher than the target level.

[0019] Titanium in the range claimed is required to refine the aluminum solid solution. Moreover, titanium can dissolve in the Al_3Zr secondary phase with the $L1_2$ lattice, which increases the effect of precipitation age hardening in case heat treatment is used. If the concentration is higher, primary crystals may appear in the structure and reduce the total level of mechanical properties; if the concentration is lower, there will be no positive effect from this element.

[0020] Chromium in the range claimed is required to ensure solid solution hardening for the as-cast condition and/or for precipitation age hardening for the heat-treated condition. A lower chromium concentration will not be enough to ensure the required level of strength properties. A higher concentration will likely lead to the formation of primary crystals of the Al_7Cr phase, which will lead to a reduction in the level of mechanical properties.

[0021] The presence of silicon, as an impurity, in the amount of up to 0.15 wt.% will ensure an additional effect from solid solution hardening. If the content of silicon is higher, the crystallization interval will be considerably longer, which will reduce casting characteristics.

Embodiments of the invention

EXAMPLE 1

[0022] The alloy compositions as per Table 1 were prepared under laboratory conditions. The alloys were prepared in an induction furnace in graphite crucibles with the use of aluminum (grade AA1085), nickel (cathode nickel) and master alloys Al-10Cr, Al-10Mn, and Al-5Ti. The casting temperature was 750°C for the alloys. The prepared alloys were poured into a rod-type metal mold to assess the mechanical properties and analyze the microstructure. The casting properties were assessed based on the hot tearing tendency (HT) with the use of the "ring sample", where the best parameter is a ring with the minimum section of the wall solidified without a crack. Using a computational method, the phase composition and the content of the eutectic phase in the alloys were analyzed. The results are given in Table 2. For alloy 5 in Table 1, no calculation was made because of an incorrect calculation of the eutectic phase due to the presence of primary crystals.

[0023] The analysis of the results in Table 1 and 2 shows that alloys 2-5 in the claimed concentration ranges provide for a good level of casting characteristics. Alloy composition 1 is characterized with an unsatisfactory level of casting properties (based on the hot tearing tendency) - first of all, due to a low eutectic content. In the structure of alloy 5, primary crystals of the ferrous phase were found, which had a negative effect on the mechanical properties and, first of all, on elongation (Table 3). The mechanical properties were defined based on a casting produced by gravity casting with an average cooling rate of about 10 K/sec. The tensile strength test was run with the use of separately-cast test bars with a diameter of 10 mm and a calculated length of 50 mm. The traverse speed was 10 mm/min.

Table 1 - Chemical composition and Eutectic content

	Chemical composition, wt.%							Eutectic content, wt.%		
	Fe	Ni	Mn	Cr	Zr	Ti	Al	Al_3Ni	Al_9FeNi	Total
1	0.01	0.5	0.1	0.01	-	0.001	base	2.18	0.13	2.31
2	1.1	1.2	0.5	0.25	-	0.02	base	-	5.46	5.46
3	0.31	1.8	0.6	0.08	0.24	0.15	base	5.84	6.19	12.03
4	0.1	2.2	2.5	0.02	0.30	0.1	base	9.49	2.10	11.59
5*	0.8	3.1	2.0	0.3	-	0.1	base	-	-	-

Table 2 - Hot tearing tendency and Microstructure analysis

Alloy No.	HT, mm	Microstructure analysis
1	10	(Al)**, eutectic ((Al)+ Al_3Ni+Al_9FeNi)
2	3	(Al), eutectic ((Al+Al_9FeNi)
3	3	(Al), eutectic ((Al)+Al_3Ni+Al_9FeNi)
4	3	(Al), eutectic ((Al)+ Al_3Ni+Al_9FeNi)
5	3	(Al), eutectic ((Al)+Al_3Ni+Al_9FeNi), primary crystals of the Al_9FeNi phase
* - see Table 1; ** - (Al) - aluminum solid solution.		

[0024] The formation of eutectic aluminides with favorable morphology in the structure is an essential prerequisite for achieving a high level of elongation. A typical structure ensuring a good level of elongation is shown in Fig. 1.

[0025] The composition of alloys 2 and 3 (Table 1) is the most preferable composition for use in the as-cast condition.

Table 3 - Tensile strength testing (Gravity casting)

Alloy No.*	Condition**	YS, MPa	UTS, MPa	Elongation, %
2	F	85	161	18.0
3	F	104	164	24.3
4	F	121	189	16.2
5	F	124	197	4.5
* - see Table 1; ** - F - as-cast condition.				

EXAMPLE 2

[0026] For assessing the effect of the eutectic content, alloys with a variable eutectic content and a fixed iron and nickel content were prepared. The chemical composition is presented in Table 4. For alloy 5 in Table 1, no calculation was made because of an incorrect calculation of the eutectic phase due to the presence of primary crystals.

Table 4 - Chemical composition and Eutectic content in the alloys considered, and Hot tearing tendency

	Chemical composition, wt. %							Eutectic content, wt.%	HT, mm
	Fe	Ni	Mn	Cr	Ti	Al			
1	0.31	0.2	0.5	0.02	0.05	base		3.2	7
2	0.32	0.4	0.5	0.03	0.05	base		4.1	3
3	0.31	0.6	0.6	0.03	0.05	base		6.2	3
4	0.1	0.6	1.5	0.03	0.05	base		3.3	7
5	0.4	0.6	1.5	0.03	0.05	base		5.3	3
6	1.0	0.6	1.5	0.02	0.05	base		-	3

[0027] Table 4 shows that the claimed alloys, provided the eutectic content is higher than 4, ensure the required hot tearing tendency.

EXAMPLE 3

[0028] From the composition of alloys 2 and 3 in Table 1, castings were produced by High-Pressure Die Casting (HPDC). The results are given in Table 5.

Table 5 - Tensile strength testing (Gravity casting)

Alloy No.*	Condition**	YS, MPa	UTS, MPa	Elongation, %
2	F	96	175	17.0
3	F	126	201	15.5
* - see Table 1; ** - F - as-cast condition				

Claims

1. An aluminum-based casting alloy comprising iron, nickel, and manganese, wherein said alloy further comprises chromium and at least one element from a group consisting of titanium and zirconium, said alloy elements have the following concentrations, in weight %:

Iron	0.1-1.1,
Manganese	0.5-2.5,

(continued)

Nickel	1.2-2.2,
Chromium	0.02-0.20,
Titanium	0.02-0.15,
Zirconium	0.02-0.35, and
Aluminum	the remainder,

where iron and nickel are mainly represented in the form of eutectic aluminides in an amount of no less than 4% by weight.

2. The alloy according to claim 1, wherein said alloy comprises aluminum produced under an inert anode electrolysis technology.

3. The alloy according to claim 1 or 2, wherein said alloy is in the form of castings with a ratio of $0.02 \leq Zr+Ti \leq 0.35$, said castings having the following tensile properties: an ultimate tensile strength of no less than 160 MPa and an elongation of no less than 15%.

4. The alloy according to claim 1 or 2, wherein said alloy is in the form of castings with a ratio of $Ni/Fe \geq 1.1$, said castings having the following tensile properties in the as-cast condition: an ultimate tensile strength of no less than 160 MPa and an elongation of no less than 15%.

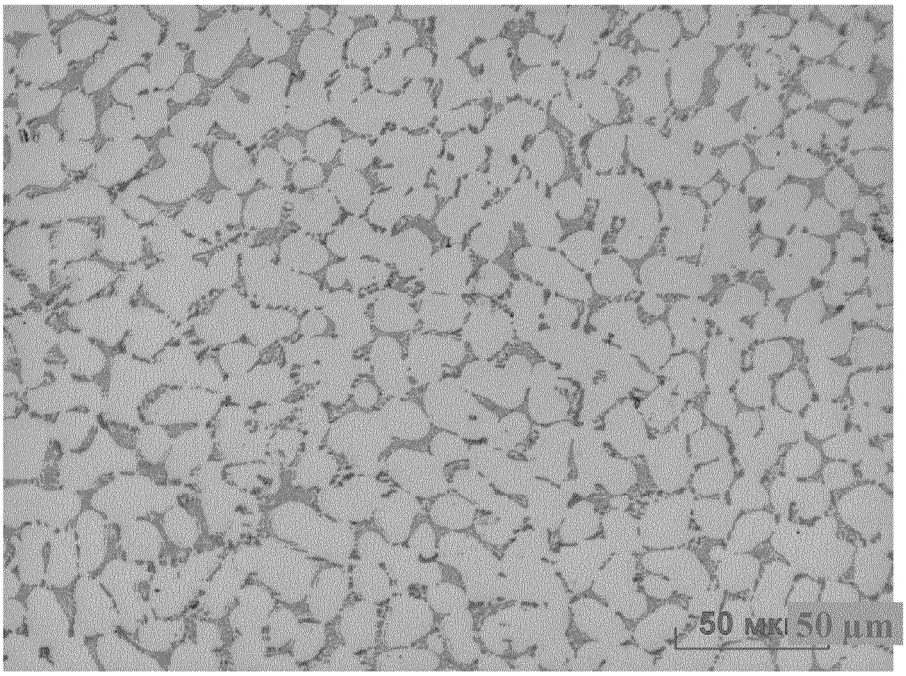

Fig. 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/RU 2019/050246

A. CLASSIFICATION OF SUBJECT MATTER

C22C21/00(2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Espacenet, PatSearch, PAJ, WIPO, USPTO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	RU 2478131 C2 (FGOU VPO «NATSIONALNYI ISSLEDOVATELSKII TEKHNOLOGICHESKII UNIVERSITET «MISIS») 27.03.2013	1-4
A	FR 1370542 A (LANCKER MARC VAN) 21.08.1964	1-4
A	US 8950465 B2 (ALCOA INC.) 10.02.2015	1-4
A	US 6783730 B2 (ALCOA INC.) 31.08.2004	1-4

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
25 May 2020 (25.05.2020)	28 May 2020 (28.05.2020)
Name and mailing address of the ISA/	Authorized officer
Facsimile No.	Telephone No.

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REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- US 6783730 B2 **[0004] [0005]**
- US 8349462 B2 **[0005] [0006]**
- US 8950465 B2 **[0006]**
- WO 2478131C2 A **[0007]**