HU000032076T2

(19) **HU** (11) Lajstromszám: **E 032 076** (13) **T2**

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EURÓPAI SZABADALOM
SZÖVEGÉNEK FORDÍTÁSA

(21) Magyar ügyszám: **E 13 798957**
(22) A bejelentés napja: **2013. 11. 14.**

(96) Az európai bejelentés bejelentési száma:
EP 20130798957
(97) Az európai bejelentés közzétételi adatai:
EP 2920334 A1 **2014. 05. 22.**
(97) Az európai szabadalom megadásának meghirdetési adatai:
EP 2920334 B1 **2016. 11. 02.**

(51) Int. Cl.:
C22C 21/02 *(2006.01)*
B22D 18/04 *(2006.01)*
C22C 21/04 *(2006.01)*
F16J 1/01 *(2006.01)*
B22D 21/00 *(2006.01)*

(86) A nemzetközi (PCT) bejelentési szám:
PCT/EP 13/073812
(87) A nemzetközi közzétételi szám:
WO 14076174

(30) Elsőbbségi adatok:
102012220765 **2012. 11. 14.** **DE**

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(54) **Eljárás motoralkatrész előállítására, motoralkatrész, valamint alumíniumötvözet alkalmazása**

715705/BO

EPA 13 798 957.0

SZTNH-100035476

Technical field

The present invention relates to a method for producing and using an engine component, in particular a piston for an internal combustion engine, in which an aluminium alloy is cast in a gravity die casting method, to an engine component, which consists at least partly of an aluminium alloy, and to the use of an aluminium alloy for producing such an engine component.

State of the art

In recent years increasingly demands for particularly economical and hence ecological transport means have become known which have to do justice to high consumption and emission requirements. In addition there is always the need to design engines to be as efficient and low-consumption as possible. A crucial factor in the development of efficient and low-emission internal combustion engines are pistons which may be used at ever higher combustion temperatures and combustion pressures, which is facilitated essentially by ever more efficient piston materials.

In principle a piston for an internal combustion engine must have a high heat resistance and thus at the same time must be as light and solid as possible. Hence, it is of particular importance how the microstructural distribution, morphology, composition and thermal stability of extremely heat-resistant phases are designed. Optimisation regarding this usually takes into account a minimum content of pores and oxidic inclusions.

The sought-after material must be optimised both with regard to isothermal vibrational strength (HCF) and with regard to thermomechanical fatigue resistance (TMF). In order to design the TMF as well as possible, as fine as possible a microstructure of the material is always to be strived for. A fine microstructure reduces the danger of producing microplasticity or of micro-cracks at relatively large primary phases (in particular at primary silicon deposits) and hence also the danger of crack initiation and crack spreading.

Microplasticities or micro-cracks, which may considerably reduce the service life of the piston material, occur under TMF stress at relatively large primary phases, in particular at primary silicon deposits, due to different coefficients of expansion of the individual constituents of the alloy, namely the matrix and the primary phases. To increase the service life it is known to keep the primary phases as small as possible.

In the gravity die casting used there is an upper concentration limit up to which alloying elements are to be introduced and if exceeded reduces the castability of the alloy or casting becomes impossible. Furthermore, at too high concentrations of strength-increasing elements there is formation of large plate-like intermetallic phases which drastically lower the fatigue resistance.

DE 44 04 420 A1 describes an alloy which may be used in particular for pistons and for components which are exposed to high temperatures and are considerably stressed mechanically. The aluminium alloy described comprises 8.0 to 10.0 wt.% of silicon, 0.8 to 2.0 wt.% of magnesium, 4.0 to 5.9 wt.% of copper, 1.0 to 3.0 wt.% of nickel, 0.2 to 0.4 wt.% of manganese, less than 0.5 wt.% of iron and at least one element selected from antimony, zirconium, titanium, strontium, cobalt, chromium, and vanadium, wherein at least one of these elements is present in a quantity of > 0.3 wt.%, wherein the sum of these elements is < 0.8 wt.%.

EP 0 924 310 B1 describes an aluminium-silicon alloy which is used in the production of pistons, in particular for pistons in internal combustion engines. The aluminium alloy has the following composition: 10.5 to 13.5 wt.% of silicon, 2.0 to less than 4.0 wt.% of copper, 0.8 to 1.5 wt.% of magnesium, 0.5 to 2.0 wt.% of nickel, 0.3 to 0.9 wt.% of cobalt, at least 20 ppm of phosphorus and either 0.05 to 0.2 wt.% of titanium or up to 0.2 wt.% of zirconium and/or up to 0.2 wt.% of vanadium and as the remainder, aluminium and unavoidable impurities.

WO 00/71767 A1 describes an aluminium alloy which is suitable for high-temperature applications, such as for example highly stressed pistons or other applications in internal combustion engines. The aluminium alloy is thus composed of the following elements: 6.0 to 14.0 wt.% of silicon, 3.0 to 8.0 wt.% of copper, 0.01 to 0.8 wt.% of iron, 0.5 to 1.5 wt.% of magnesium, 0.05 to 1.2 wt.% of nickel, 0.01 to 1.0 wt.% of manganese, 0.05 to 1.2 wt.% of titanium, 0.05 to 1.2 wt.% of zirconium, 0.05 to 1.2 wt.% of vanadium, 0.001 to 0.10 wt.% of strontium and as the remainder, aluminium.

DE 103 33 103 B4 describes a piston which is made from an aluminium casting alloy, wherein the aluminium casting alloy contains: 0.2 or less wt.% of magnesium, 0.05 to 0.3 mass% of titanium, 10 to 21 wt.% of silicon, 2 to 3.5 wt.% of copper, 0.1 to 0.7 wt.% of iron, 1 to 3 wt.% of nickel, 0.001 to 0.02 wt.% of phosphorus, 0.02 to 0.3 wt.% of zirconium and as the remainder, aluminium and impurities. It is further described that the size of a non-metallic inclusion, which is present within the piston, is less than 100 µm.

EP 1 975 262 B1 describes an aluminium casting alloy consisting of: 6 to 9 % of silicon, 1.2 to 2.5 % of copper, 0.2 to 0.6 % of magnesium, 0.2 to 3 % of nickel, 0.1 to 0.7 % of iron, 0.1 to 0.3 % of titanium, 0.03 to 0.5 % of zirconium, 0.1 to 0.7 % of manganese, 0.01 to 0.5 % of vanadium and one or more of the following elements: strontium 0.003 to 0.05 %, antimony 0.02 to 0.2 % and sodium 0.001 to 0.03 %, wherein the total quantity of titanium and zirconium is less than 0.5 % and aluminium and unavoidable impurities form the remainder if the total quantity is set as 100 mass per cent.

WO 2010/025919 A2 describes a method for producing a piston of an internal combustion engine, wherein a piston blank is cast from an aluminium-silicon alloy with addition of copper proportions and then finished. The invention thus makes provision that the copper proportion is 5.5 % at the most of the aluminium-silicon alloy and, that proportions of titanium (Ti), zirconium (Zr), chromium (Cr) or vanadium (V) are admixed to the aluminium-silicon alloy and the sum of all constituents is 100 %.

DE 102011083969 relates to a method for producing an engine component, in particular a piston for an internal combustion engine, in which an aluminium alloy is cast in a gravity die casting method, to an engine component, which consists at least partly of an aluminium alloy, and to the use of an aluminium alloy for producing an engine component. The aluminium alloy thus has the following alloying elements: 6 to 10 wt.% of silicon, 1.2 to 2 wt.% of nickel, 8 to 10 wt.% of copper, 0.5 to 1.5 wt.% of magnesium, 0.1 to 0.7 wt.% of iron, 0.1 to 0.4 wt.% of manganese, 0.2 to 0.4 wt.% of zirconium, 0.1 to 0.3 wt.% of vanadium, 0.1 to 0.5

wt.% of titanium and aluminium and unavoidable impurities as the remainder. This alloy preferably has a phosphorus content of less than 30 ppm.

JP 2004 256873 A discloses an alloy having in mass per cent 9.5 to 11.5 % of Si, 5.0 to 7.7 % of Cu, 3.5 to 5.5 % of Ni, 0.55 to 1.5 % of Mg, 0.003 to 0.1 % of P and 0.15 to 0.7 % of Fe, and, if necessary, at least one of the following metals, 0.005 to 0.3 % of Ti, 0.02 to 0.3 % of Zr, 0.02 to 0.3 % of V, 0.001 to 0.1 % of B and 0.1 to 0.7 % of Mn, and essentially Al as the remainder.

Furthermore, JP 2000 204428 A relates to a piston made from an aluminium alloy with 11 to 16 % of Si, 0.5 to 2.0 % of Mg, 3 to 7 % of Cu, 3 to 7 % of Ni, 0.2 to 1.5 % of Fe, 0.2 to 1.0 % of Mn, 0.003 to 0.015 % of P and <=0.002 % of Ca, wherein impurities <=0.2 % may be present. Furthermore, 0.01 to 0.3 % of Ti, 0.0001 to 0.03 % of B, 0.01 to 0.3 % of Cr, 0.01 to 0.3 % of Zr or similar elements may be present.

Finally, JP H8-134577 A describes an aluminium alloy which contains 1-7 % of Cu, 10-16 % of Si, 0.3-2 % of Mg, 0.5-2 % of Fe, 0.1-4 % of Mn, 0.01-0.3 % of Ti, 0.001-0.02 % of P, 0.0001-0.02 % of Ca and furthermore, if necessary, 0.2-6 % of Ni.

Presentation of the invention

An object of the present invention lies in providing a method for producing an engine component, in particular a piston for an internal combustion engine, in which an aluminium alloy is cast in a gravity die casting method, so that an extremely heat-resistant engine component may be produced in a gravity die casting method.

The solution to this object is given by the method according to claim 1. Further preferred embodiments of the invention can be seen from the sub-claims regarding this.

A further object of the invention lies in providing an engine component, in particular a piston for an internal combustion engine, which is extremely heat-resistant and thus consists at least partly of an aluminium alloy.

This object is achieved by the object of claim 8 and further preferred embodiments can be seen from the sub-claims regarding this.

In a method of the invention, the aluminium alloy has the following alloying elements:

silicon:	9 wt.%	to ≤ 10.5 wt.%,
nickel:	> 2.0 wt.%	to < 3.5 wt.%,
copper:	> 3.7 wt.%	to 5.2 wt.%,
cobalt:		to < 1 wt.%
magnesium:	0.5 wt.%	to 1.5 wt.%,
iron:	0.1 wt.%	to 0.7 wt.%,
manganese:	0.1 wt.%	to 0.4 wt.%,
zirconium:	> 0.1 wt.%	to < 0.2 wt.%,
vanadium:	> 0.1 wt.%	to < 0.2 wt.%,
titanium:	0.05 wt.%	to < 0.2 wt.%,
phosphorus:	0.004 wt.%	to 0.008 wt.%,

and as the remainder, aluminium and unavoidable impurities.

The aluminium alloy preferably has:

from > 9 to ≤ 10.5, further preferably < 10, particularly preferably < 9.5 or further preferably from 9.5 to 10.5 wt.% of silicon;

from > 2.3, further preferably > 3 to < 3.5 or further preferably from 2.5, particularly preferably 2.9 to 3 wt.% of nickel;

from > 3.8, further preferably > 4 and particularly preferably > 4.8 to 5.2, or further preferably from > 3.7 to < 5, particularly preferably < 4 or further preferably from 4, particularly preferably 4.1 to 4.6 wt.% of copper;

from > 0.5, and further preferably > 0.9 to < 1 wt.% of cobalt;

from 0.5, and further preferably > 0.6 and particularly 0.7 to < 1.5, further preferably < 0.8 or further preferably from > 1, further preferably > 1.3 to 1.5 wt.% of magnesium;

from > 0.5, further preferably > 0.6 to 0.7 or further preferably 0.45 to 0.5 wt.% of iron;

from 0.1 to < 0.2 or further preferably from > 0.25 to 0.4 wt.% of manganese;
from 0.12, further preferably 0.13 to 0.19 wt.% of zirconium;

from 0.12 to 0.14 wt.% of vanadium;

from 0.05 to < 0.15 or further preferably from 0.11, particularly preferably 0.12 to 0.13 wt.% of titanium; and

from 0.005 to 0.006 wt.% of phosphorus.

Due to the aluminium alloy selected, it is possible to produce in a gravity die casting method an engine component which has a high proportion of finely distributed, highly heat-resistant, thermally stable phases and a fine microstructure. The susceptibility with respect to crack initiation and crack spreading, for example at oxides or primary phases, and the TMF-HCF service life is reduced by the choice of alloy of the invention with respect to the hitherto known production methods of pistons and similar engine components.

The alloy of the invention, in particular the comparatively low silicon content, also leads to comparatively less and finer primary silicon being present in its thermally highly stressed recess edge region at least for a piston produced according to the invention so that the alloy leads to particularly good properties of a piston produced according to the invention. Hence, an extremely heat-resistant engine component may be produced in a gravity die casting method. The proportions of the invention of copper, zirconium, vanadium and titanium, in particular the comparatively high content of zirconium, vanadium and titanium, bring about an advantageous proportion of strength-increasing deposits but without thus causing large plate-like intermetallic phases. Furthermore, the proportions of the invention of cobalt and nickel are advantageous for increasing the thermal strength of the alloy. Nickel thus contributes to the formation of thermally stable intermetallic phases. In addition, cobalt increases the hardness and generally the strength of the alloy. Phosphorus as a nucleating agent contributes to primary silicon deposits being deposited as finely and homogeneously distributed as possible.

The aluminium alloy advantageously has preferably 0.6 wt.% to 0.8 wt.% of magnesium which, in the preferred concentration range, contributes in particular to the effective formation of secondary, strength-increasing phases without excessive oxide formation occurring. Furthermore, the alloy has alternatively or additionally preferably 0.4 wt.% to 0.6 wt.% of iron which advantageously reduces the alloy's tendency to adhere in the casting die, wherein the formation of plate-like phases remains restricted in the said concentration range.

In the aluminium alloy, the weight ratio of iron to manganese is advantageously not more than about 5:1, preferably about 2.5:1. In this embodiment, the aluminium alloy thus contains not more than five parts of iron with respect to one part of manganese, preferably about 2.5 parts of iron with respect to one part of manganese. Particularly advantageous strength properties of the engine component are achieved due to this ratio.

Furthermore, it is preferred if the sum of nickel and cobalt is > 2.0 wt.% and < 3.8 wt.%. The lower limit thus ensures an advantageous strength of the alloy and the upper limit advantageously guarantees a fine microstructure and avoids the formation of coarse, plate-like phases which would reduce the strength.

The aluminium alloy advantageously has a fine microstructure with a low content of pores and inclusions and/or little and small primary silicon, in particular in the highly stressed recess edge region. A low content of pores is thus understood to mean preferably a porosity of < 0.01 % and little primary silicon is understood to mean < 1 %. Furthermore, the fine microstructure is advantageously described in that the average length of the primary silicon is about < 5 µm and its maximum length about < 10 µm and the intermetallic phases and/or primary deposits have lengths of on average about < 30 µm and at the most < 50 µm.

Furthermore, it is preferred if the aluminium alloy, in particular in the recess edge region, has an average value of a surface of silicon deposits < about 100 μm^2 and/or an average value of a surface of the intermetallic phases < about 200 μm^2.

The characterisation of the microstructure of the aluminium alloy is preferably effected by means of quantitative structural analysis. Initially a metallographic section is prepared for this and section images appropriate for a light microscope recorded, in particular for the technologically particularly important recess edge region. By way of example an inverse reflected-light microscope may be used for this. Hence, for a defined magnification, individual images are then recorded, put together by computer to form a surface (for example 5.5 mm x 4.1 mm) and the surfaces and surface proportions of certain phases are ascertained by means of image-processing software.

The fine microstructure contributes in particular to the improvement of thermomechanical fatigue strength. A limitation of the size of the primary phases may reduce the susceptibility to crack initiation and crack spreading and thus significantly increase the TMF-HCF service life. Furthermore, due to the notch effect of pores and inclusions, it is particularly advantageous to keep their content low.

An engine component of the invention consists at least partly of one of the above-mentioned aluminium alloys. A further independent aspect of the invention lies in the use of the above-explained aluminium alloy for producing an engine component, in particular a piston of an internal combustion engine. In particular the aluminium alloy discovered is thus processed in a gravity die casting method.

Examples

For the above-described aluminium alloy, by way of example an alloy 1 having 10.5 wt.% of silicon; 3 wt.% of nickel; 4.1 wt.% of copper; 0.7 wt.% of magnesium; 0.5 wt.% of iron; 0.2 wt.% of manganese; 0.13 wt.% of zirconium; 0.12 wt.% of vanadium; 0.13 wt.% of titanium and 0.006 wt.% of phosphorus, an alloy 2 having 9.5 wt.% of silicon; 2.9 wt.% of nickel; 4.0 wt.% of copper; 0.7 wt.% of magnesium; 0.45 wt.% of iron; 0.2 wt.% of manganese; 0.12 wt.% of zirconium; 0.12 wt.% of vanadium; 0.12 wt.% of titanium and 0.006 wt.% of phosphorus and an alloy 3 having 9.5 wt.% of silicon; 2.5 wt.% of nickel; 4.6 wt.% of copper; 0.7 wt.% of magnesium; 0.45 wt.% of iron; 0.2 wt.% of manganese; 0.19 wt.% of zirconium; 0.14 wt.% of vanadium; 0.11 wt.% of titanium and 0.005 wt.% of phosphorus and in each case as the remainder, aluminium and unavoidable impurities, may be mentioned.

Eljárás motoralkatrész előállítására, motoralkatrész valamint alumíniumötvözet alkalmazása

SZABADALMI IGÉNYPONTOK

1. Eljárás motoralkatrész, különösen egy belsőégésű motor számára szolgáló dugattyú előállítására, amelyben egy alumíniumötvözetet egy kokillaöntési eljárásban öntünk, ahol az alumíniumötvözet a következő ötvöző elemekből áll:

szilícium:	9 tömeg%-tól	≤ 10.5 tömeg%-ig,
nikkel:	> 2.0 tömeg%-tól	< 3.5 tömeg%-ig,
réz:	> 3.7 tömeg%-tól	5.2 tömeg%-ig,
kobalt:		< 1 tömeg%-ig,
magnézium:	0.5 tömeg%-tól	1.5 tömeg%-ig,
vas:	0.1 tömeg%-tól	0.7 tömeg%-ig,
mangán:	0.1 tömeg%-tól	0.4 tömeg%-ig,
cirkónium:	> 0.1 tömeg%-tól	< 0.2 tömeg%-ig,
vanádium:	> 0.1 tömeg%-tól	< 0.2 tömeg%-ig,
titán:	0.05 tömeg%-tól	< 0.2 tömeg%-ig,
foszfor:	0.004 tömeg%-tól	0.008 tömeg%-ig,

valamint fennmaradó részben alumíniumból és elkerülhetetlen szennyeződésekből áll.

2. Az 1. igénypont szerinti eljárás, amelyben az alumíniumötvözet előnyösen 0,6 tömeg%-tól 0,8 tömeg%-ig terjedően tartalmaz magnéziumot.

3. Az előző 1-2. igénypontok egyike szerinti eljárás, amelyben az alumínium-ötvözet előnyösen 0,4 tömeg%-tól 0,6 tömeg%-ig terjedően tartalmaz vasat.

4. Az előző 1-3. igénypontok egyike szerinti eljárás, amelyben az alumínium-ötvözetben a vas/mangán tömegarány legfeljebb körülbelül 5:1, előnyösen a vas/mangán tömegarány körülbelül 2,5:1.

5. Az előző 1-4. igénypontok egyike szerinti eljárás, amelyben a nikkelből és kobaltból álló összeg előnyösen > 2,0 tömeg%, és < 3,8 tömeg%.

6. Az előző 1-5. igénypontok egyike szerinti eljárás, amelyben az alumínium-ötvözet egy csekély pórus- és zárvány-tartalommal és/vagy kevés vagy kicsi, különösen vályúél-tartományba eső primer szilícium-tartalommal jellemzett mikrostruktúrával rendelkezik, ahol a porozitás < 0,01 %, és/vagy a primer szilícium-tartalom < 1 %, ahol a primer szilícium < 5 μm közepes hosszúságot és/vagy < 10 μm maximális hosszúságot mutat, és a fémközi fázisok és/vagy primer lerakódások < 30 μm közepes hosszúságot és/vagy < 50 μm maximális hosszúságot mutatnak.

7. Az előző 1-6. igénypontok egyike szerinti eljárás, amelyben az alumíniumötvözet, különösen a vályúél-tartományban < körülbelül 100 μm^2 szilícium-lerakódás-felület átlagértékkel és/vagy < körülbelül 200 μm^2 fémközi-fázis-felület átlagértékkel rendelkezik.

8. Motoralkatrész, különösen egy belsőégésű motor számára szolgáló dugattyú, amely legalább részben egy alumíniumötvözetből áll, ahol az alumíniumötvözet a következő ötvöző elemekből áll:

szilícium:	9 tömeg%-tól	≤ 10.5 tömeg%-ig,
nikkel:	> 2.0 tömeg%-tól	< 3.5 tömeg%-ig,
réz:	> 3.7 tömeg%-tól	5.2 tömeg%-ig,
kobalt:		< 1 tömeg%-ig,
magnézium:	0.5 tömeg%-tól	1.5 tömeg%-ig,
vas:	0.1 tömeg%-tól	0.7 tömeg%-ig,
mangán:	0.1 tömeg%-tól	0.4 tömeg%-ig,
cirkónium:	> 0.1 tömeg%-tól	< 0.2 tömeg%-ig,
vanádium:	> 0.1 tömeg%-tól	< 0.2 tömeg%-ig,
titán:	0.05 tömeg%-tól	< 0.2 tömeg%-ig,
foszfor:	0.004 tömeg%-tól	0.008 tömeg%-ig,

valamint fennmaradó részben alumíniumból és elkerülhetetlen szennyeződésekből áll.

9. A 8. igénypont szerinti motoralkatrész, amelyben az alumíniumötvözet előnyösen 0,6 tömeg%-tól 0,8 tömeg%-ig terjedően tartalmaz magnéziumot.

10. Az előző 8-9. igénypontok egyike szerinti motoralkatrész, amelyben az alumíniumötvözet előnyösen 0,4 tömeg%-tól 0,6 tömeg%-ig terjedően tartalmaz vasat.

11. Az előző 8-10. igénypontok egyike szerinti motoralkatrész, amelyben az alumíniumötvözetben a vas/mangán tömegarány legfeljebb körülbelül 5:1, előnyösen a vas/mangán tömegarány körülbelül 2,5:1.

12. Az előző 8-11. igénypontok egyike szerinti motoralkatrész, amelyben a nikkelből és kobaltból álló összeg előnyösen > 2,0 tömeg%, és < 3,8 tömeg%.

13. Az előző 8-12. igénypontok egyike szerinti motoralkatrész, amelyben az alumíniumötvözet egy csekély pórus- és zárvány-tartalommal és/vagy kevés vagy kicsi, különösen vályúél-tartományba eső primer szilícium-tartalommal jellemzett mikrostruktúrával rendelkezik, ahol a porozitás < 0,01 %, és/vagy a primer szilícium-tartalom < 1 %, ahol a primer szilícium < 5 µm közepes hosszúságot és/vagy < 10 µm maximális hosszúságot mutat, és a fémközi fázisok és/vagy primer lerakódások < 30 µm közepes hosszúságot és/vagy < 50 µm maximális hosszúságot mutatnak.

14. Az előző 8-13. igénypontok egyike szerinti motoralkatrész, amelyben az alumíniumötvözet, különösen a vályúél-tartományban < körülbelül 100 $µm^2$ szilícium-lerakódás-felület átlagértékkel és/vagy < körülbelül 200 $µm^2$ fémközi-fázis-felület átlagértékkel rendelkezik.

15. Egy alumíniumötvözet alkalmazása motoralkatrész, különösen egy belsőégésű motor számára szolgáló dugattyú előállítására, ahol az alumíniumötvözet a következő ötvöző elemekből áll:

szilícium:	9 tömeg%-tól	≤ 10.5 tömeg%-ig,
nikkel:	> 2.0 tömeg%-tól	< 3.5 tömeg%-ig,
réz:	> 3.7 tömeg%-tól	5.2 tömeg%-ig,
kobalt:		< 1 tömeg%-ig,
magnézium:	0.5 tömeg%-tól	1.5 tömeg%-ig,
vas:	0.1 tömeg%-tól	0.7 tömeg%-ig,
mangán:	0.1 tömeg%-tól	0.4 tömeg%-ig,
cirkónium:	> 0.1 tömeg%-tól	< 0.2 tömeg%-ig,
vanádium:	> 0.1 tömeg%-tól	< 0.2 tömeg%-ig,
titán:	0.05 tömeg%-tól	< 0.2 tömeg%-ig,
foszfor:	0.004 tömeg%-tól	0.008 tömeg%-ig,

valamint fennmaradó részben alumíniumból és elkerülhetetlen szennyeződésekből áll.

A meghatalmazott: