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(54) **HIGH TEMPERATURE ALUMINIUM ALLOY**

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(57) **ABSTRACT**

In an aluminium alloy of type AlMgSi with good creep strength at elevated temperatures for the production of castings subject to high thermal and mechanical stresses the contents of the alloying elements magnesium and silicon in % w/w in a Cartesian coordinate system are limited by a polygon A with the coordinates [Mg; Si] [8.5; 2.7] [8.5; 4.7] [6.3; 2.7] [6.3; 3.4] and that the alloy also contains
0.1 to 1% w/w manganese
max. 1% w/w iron
max. 3% w/w copper
max. 2% w/w nickel
max. 0.5% w/w chromium
max. 0.6% w/w cobalt
max. 0.2% w/w zinc
max. 0.2% w/w titanium
max. 0.5% w/w zirconium
max. 0.008% w/w beryllium
max. 0.5% w/w vanadium
as well as aluminium remainder rest with further elements and manufacturing-related impurities of individually max. 0.05% w/w and max. 0.2% w/w in total.
The alloy is suitable in particular for the production of cylinder crankcases by the pressure die casting method.

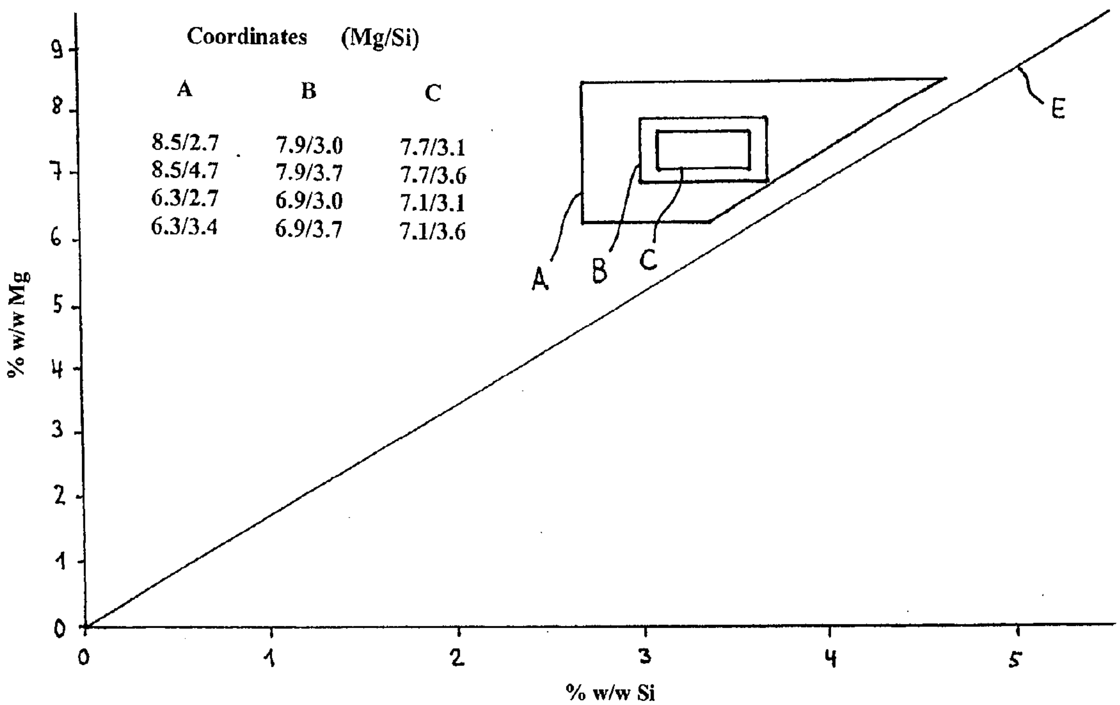
Coordinates (Mg/Si)
A
B
C
8.5/2.7
8.5/4.7
6.3/2.7
6.3/3.4
7.9/3.0
7.9/3.7
6.9/3.0
6.9/3.7
7.7/3.1
7.7/3.6
7.1/3.1
7.1/3.6
A
B
C
E
% w/w Mg
% w/w Si
0
1
2
3
4
5
6
7
8
9

**Fig. 1**

# HIGH TEMPERATURE ALUMINIUM ALLOY

## BACKGROUND OF THE INVENTION

**[0001]** 1. Field of the Invention

**[0002]** The invention relates to an aluminium alloy of type AlMgSi with good creep strength at elevated temperatures for the production of castings subject to high thermal and mechanical stresses.

**[0003]** 2. Description of the Prior Art

**[0004]** The further development of diesel engines with the aim of achieving an improved combustion of the diesel fuel and a higher specific output leads inter alia to a higher explosion pressure and in consequence to a pulsating mechanical load acting on the cylinder crankcase that makes very high demands on the material. Apart from a high fatigue strength, a good endurance strength at high temperatures of the material is a further precondition for its use in the production of cylinder crankcases.

**[0005]** AlSi alloys are generally used today for components subject to high thermal stresses, this high-temperature strength being achieved by the addition of Cu to the alloy. Copper does, however, also increase the hot shortness and has a negative effect on the castability. Applications in which in particular high-temperature strength is demanded are primarily found in the area of the cylinder heads of automotive engines, see e.g. F. J. Feikus, "Optimierung von Aluminium-Silicium-Gusslegierungen für Zylinderköpfe" [Optimization of Aluminium-Silicon Casting Alloys for Cylinder Heads], Giesserei-Praxis, 1999, Volume 2, pp. 50-57.

**[0006]** A high-temperature AlMgSi alloy for the production of cylinder heads is known from U.S. Pat. No. 3,868,250. The alloy contains, apart from the normal additives, 0.6 to 4.5% w/w Si, 2.5 to 11% w/w Mg, of which 1 to 4.5% w/w free Mg, and 0.6 to 1.8% w/w Mn.

**[0007]** WO-A-96 15281 describes an aluminium alloy with 3.0 to 6.0% w/w Mg, 1.4 to 3.5% w/w Si, 0.5 to 2.0% w/w Mn, max. 0.15% w/w Fe, max. 0.2% w/w Ti and aluminium as remainder with further impurities of individually max. 0.02% w/w, and max. 0.2% w/w in total. The alloy is suitable for the production of components where high demands are made on the mechanical properties. Processing of the alloy is preferably by pressure die casting, thixocasting or thixoforging.

**[0008]** A similar aluminium alloy for the production of safety components by pressure die casting, squeeze casting, thixoforming or thixoforging is known from WO-A-0043560. The alloy contains 2.5-7.0% w/w Mg, 1.0-3.0% w/w Si, 0.3-0.49% w/w Mn, 0.1-0.3% w/w Cr, max. 0.15% w/w Ti, max. 0.15% w/w Ti, max. 0.15% w/w Fe, max. 0.00005% w/w Ca, max. 0.00005% w/w Na, max. 0.0002% w/w P, further impurities of individually max. 0.02% w/w and aluminium as remainder.

**[0009]** A casting alloy of type AlMgSi known from EP-A-1 234 893 contains 3.0 to 7.0% w/w Mg, 1.7 to 3.0% w/w Si, 0.2 to 0.48% w/w Mn, 0.15 to 0.35% w/w Fe, max. 0.2% w/w Ti, optionally also 0.1 to 0.4% w/w Ni and Al as remainder and manufacturing-related impurities of individually max. 0.02% w/w and max. 0.2% w/w in total, with the further condition that magnesium and silicon in the alloy essentially exist in a ratio Mg:Si of 1.7:1 by weight, corresponding to the composition of the quasi-binary eutectic with the solid phases Al and $Mg_2Si$. The alloy is suitable for the production of safety components in motor vehicles by pressure die casting, rheocasting and thixocasting.

**[0010]** The object of the invention is to provide an aluminium alloy with good creep strength at elevated temperatures for the production of components subject to high thermal and mechanical stresses. The alloy should be suitable in particular for pressure die casting, but also for gravity die casting, low-pressure die casting and sand casting.

**[0011]** A specific object of the invention is the provision of an aluminium alloy for cylinder crankcases of internal combustion engines, in particular of diesel engines, produced by pressure die casting.

**[0012]** The components cast from the alloy should exhibit high strength together with high ductility. The intended mechanical properties in the component are defined as follows:

| | |
|---|---|
| Proof strength | Rp0.2 > 170 MPa |
| Tensile strength | Rm > 230 MPa |
| Elongation at break | A5 > 6% |

**[0013]** The castability of the alloy should be comparable with the castability of the AlSiCu casting alloys currently used, and the alloy should not show any tendency to hot shortness.

## SUMMARY OF THE INVENTION

**[0014]** The object is achieved with the solution according to the invention in that the contents of the alloying elements magnesium and silicon in % w/w in a Cartesian coordinate system are limited by a polygon A with the coordinates [Mg; Si] [8.5; 2.7] [8.5; 4.7] [6.3; 2.7] [6.3; 3.4] and that the alloy also contains

0.1 to 1% w/w manganese
max. 1% w/w iron
max. 3% w/w copper
max. 2% w/w nickel
max. 0.5% w/w chromium
max. 0.6% w/w cobalt
max. 0.2% w/w zinc
max. 0.2% w/w titanium
max. 0.5% w/w zirconium
max. 0.008% w/w beryllium
max. 0.5% w/w vanadium

as well as aluminium as remainder with further elements and manufacturing-related impurities of individually max. 0.05% w/w and max. 0.2% w/w in total.

**[0015]** The following content ranges are preferred for the main alloying elements, Mg and Si:

Mg 6.9 to 7.9% w/w, in particular 7.1 to 7.7% w/w
Si 3.0 to 3.7% w/w, in particular 3.1 to 3.6% w/w

**[0016]** Particularly preferred are alloys whose contents of the alloying elements magnesium and silicon in % w/w in a Cartesian coordinate system are limited by a polygon B with the coordinates [Mg; Si] [7.9; 3.0] [7.9; 3.7] [6.9; 3.0] [6.9; 3.7], in particular by a polygon C with the coordinates [Mg; Si] [7.7; 3.1] [7.7; 3.6] [7.1; 3.1] [7.1; 3.6].

**[0017]** The alloying elements Mn and Fe allow sticking of the castings to the mould to be avoided. A higher iron content results in a higher high-temperature strength at the expense of reduced elongation. Mn contributes also significantly to red hardness. Depending on the field of application, the alloying elements Fe and Mn are therefore preferably balanced with one another as follows:

With a content of 0.4 to 1% w/w Fe, in particular 0.5 to 0.7% w/w Fe, a content of 0.1 to 0.5% w/w Mn, in particular 0.3 to 0.5% w/w Mn, is set.
With a content of max. 0.2% w/w Fe, in particular max. 0.15% w/w Fe, a content of 0.5 to 1% w/w Mn, in particular 0.5 to 0.8% w/w Mn, is set.

**[0018]** The following content ranges are preferred for the further alloying elements:
Cu 0.2 to 1.2% w/w, preferably 0.3 to 0.8% w/w, in particular 0.4 to 0.6% w/w

Ni 0.8 to 1.2% w/w

**[0019]** Cr max. 0.2% w/w, preferably max. 0.05% w/w

Co 0.3 to 0.6% w/w

Ti 0.05 to 0.15% w/w

Fe max. 0.15% w/w

Zr 0.1 to 0.4% w/w

**[0020]** Copper results in an additional increase in strength, but with increasing contents leads to a deterioration in the corrosion behaviour of the alloy.

**[0021]** The addition of cobalt allows the demoulding behaviour of the alloy to be further improved.

**[0022]** Titanium and zirconium improve the grain refinement. A good grain refinement contributes significantly to an improvement in the casting properties and mechanical properties.

**[0023]** Beryllium in combination with vanadium reduces the formation of dross. With an addition of 0.02 to 0.15% w/w V, preferably 0.02 to 0.08% w/w V, in particular 0.02 to 0.05% w/w V, less than 60 ppm Be are sufficient.

**[0024]** A preferred field of application of the aluminium alloy according to the invention is the production of components subject to high thermal and mechanical stresses by pressure die casting, mould casting or sand casting, in particular for cylinder crankcases for automotive engines produced by the pressure die casting method.

**[0025]** The alloy according to the invention also satisfies the mechanical properties demanded for structural components in automotive construction after a single-stage heat treatment without separate solution annealing.

## BRIEF DESCRIPTION OF THE DRAWING

**[0026]** Further advantage, features and properties of the invention can be seen from the following description of preferred exemplary embodiments and from the drawing that shows in

**[0027]** FIG. **1** a diagram with the content limits for the alloying elements Mg and Si according to the invention.

## DETAILED DESCRIPTION OF THE INVENTION

**[0028]** The polygon A shown in FIG. **1** defines the content range for the alloying elements Mg and Si, the polygons B and C refer to preferred ranges. The straight line E corresponds to the composition of the quasi-binary eutectic Al—$Mg_2Si$. The alloy compositions according to the invention thus lie on the side with an excess of magnesium.

**[0029]** The alloy according to the invention was cast into pressure die cast plates with different wall thicknesses. Tensile strength test specimens were manufactured from the pressure die cast plates. The mechanical properties proof strength (Rp0.2), tensile strength (Rm) and elongation at break (A) were determined on the tensile strength test specimens in the conditions

**[0030]** F As cast

**[0031]** Water/F As cast, quenched in water after demoulding

**[0032]** F>24 h As cast, >24 h storage at room temperature

**[0033]** Water/F>24 As cast, quenched in water after demoulding, >24 h storage at room temperature

and after various single-stage heat treatment processes at temperatures in the range from 250° C. to 380° C. and after long-term storage at temperatures in the range from 150° C. to 250° C.

**[0034]** The alloys examined are summarized in Table 1. The letter A indicates alloys with copper additive, the letter B alloys without copper additive.

**[0035]** Table 2 shows the results of the mechanical properties determined on tensile strength test specimens of the alloys in Table 1.

**[0036]** An alloy not included in Tables 1 and 2 with good creep strength at elevated temperatures exhibited the following composition (in % w/w, wherein the expression "% w/w" used in the specification and claims means "% by weight"):

3.4 Si, 0.6 Fe, 0.42 Cu, 0.32 Mn, 7.4 Mg, 0.07 Ti, 0.9 Ni, 0.024 V and 0.004 Be

**[0037]** The results of the long-term tests underline the good creep strength at elevated temperatures of the alloy according to the invention. The mechanical properties after a single-stage heat treatment at 350° C. and 380° C. for 90 minutes indicate furthermore that the alloy according to the invention also satisfies the demands made for structural components in automotive construction.

TABLE 1

Chemical composition of the alloys in % w/w

| Alloy variant | Wall thickness of flat specimen | Si | Fe | Cu | Mn | Mg | Ti | V | Be |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 mm | 3.469 | 0.1138 | | 0.787 | 7.396 | 0.106 | 0.0221 | 0.0025 |
| 1A | 3 mm | 3.4 | 0.117 | 0.527 | 0.781 | 7.151 | 0.119 | 0.0223 | 0.0019 |
| 2 | 2 mm | 3.366 | 0.0936 | | 0.774 | 7.246 | 0.117 | 0.0263 | 0.0024 |
| 2A | 2 mm | 3.251 | 0.0841 | 0.507 | 0.76 | 7.499 | 0.1 | 0.0246 | 0.0023 |
| 3 | 4 mm | 3.352 | 0.0917 | | 0.774 | 7.221 | 0.118 | 0.026 | 0.0024 |
| 3A | 4 mm | 3.198 | 0.0848 | 0.522 | 0.747 | 7.351 | 0.101 | 0.0255 | 0.0023 |
| 4 | 6 mm | 3.28 | 0.0921 | | 0.766 | 7.024 | 0.119 | 0.0268 | 0.0024 |
| 4A | 6 mm | 3.181 | 0.862 | 0.535 | 0.745 | 7.273 | 0.1 | 0.0257 | 0.0023 |

TABLE 2

Mechanical properties of the alloys

| Alloy variant | Initial state | Heat treatment | Rp0.2 [MPa] | Rm [MPa] | A5 [%] |
|---|---|---|---|---|---|
| 1 | F | | 210 | 359 | 8.6 |
| | Water/F | | 181 | 347 | 9.6 |
| | F > 24 h | | 204 | 353 | 8.9 |
| | Water/F > 24 h | | 176 | 347 | 13.4 |
| | F > 24 h | 250° C./10 min | 216 | 352 | 7.4 |
| | | 250° C./20 min | 218 | 352 | 6.8 |
| | | 250° C./90 min | 207 | 349 | 10.8 |
| | | 350° C./10 min | 154 | 315 | 12.5 |
| | | 350° C./20 min | 158 | 315 | 10.6 |
| | | 350° C./90 min | 147 | 306 | 11.4 |
| | | 380° C./10 min | 145 | 304 | 14.1 |
| | | 380° C./20 min | 139 | 299 | 13.9 |
| | | 380° C./90 min | 137 | 299 | 16.7 |
| | | 150° C./100 h | 221 | 365 | 9.4 |
| | | 180° C./100 h | 214 | 346 | 6 |
| | | 200° C./100 h | 211 | 354 | 9.4 |
| | | 250° C./100 h | 184 | 336 | 11.7 |
| | | 150° C./500 h | 223 | 353 | 6 |
| | | 180° C./500 h | 216 | 357 | 9.7 |
| | | 200° C./500 h | 202 | 349 | 9.2 |
| | | 250° C./500 h | 170 | 327 | 12.3 |
| 1A | F | | 234 | 345 | 4.2 |
| | Water/F | | 170 | 319 | 4.9 |
| | F > 24 h | | 205 | 355 | 7.1 |
| | Water/F > 24 h | | 188 | 340 | 5.6 |
| | F > 24 h | 250° C./10 min | 227 | 355 | 6.6 |
| | | 250° C./20 min | 217 | 354 | 7.5 |
| | | 250° C./90 min | 213 | 350 | 7.9 |
| | | 350° C./10 min | 157 | 328 | 10.4 |
| | | 350° C./20 min | 151 | 317 | 9.3 |
| | | 350° C./90 min | 142 | 312 | 12.1 |
| | | 380° C./10 min | 141 | 315 | 12.6 |
| | | 380° C./20 min | 137 | 312 | 12.4 |
| | | 380° C./90 min | 133 | 309 | 12.2 |
| | | 150° C./100 h | 248 | 370 | 5 |
| | | 180° C./100 h | 249 | 373 | 6.3 |
| | | 200° C./100 h | 215 | 346 | 6.2 |
| | | 250° C./100 h | 185 | 329 | 7.6 |
| | | 150° C./500 h | 239 | 368 | 6.5 |
| | | 180° C./500 h | 227 | 352 | 6.9 |
| | | 200° C./500 h | 215 | 350 | 7.8 |
| | | 250° C./500 h | 162 | 317 | 8.9 |
| 2 | F > 24 h | | 212 | 364 | 10.7 |
| | | 250° C./90 min | 223 | 358 | 9.9 |
| | | 350° C./90 min | 152 | 312 | 13.9 |
| | | 380° C./90 min | 139 | 297 | 17.9 |
| 2A | F > 24 h | | 241 | 394 | 7.8 |
| | | 250° C./90 min | 234 | 375 | 8.5 |
| | | 350° C./90 min | 163 | 332 | 9 |
| | | 380° C./90 min | 144 | 328 | 13.7 |
| 3 | F > 24 h | | 158 | 321 | 9.9 |
| | | 250° C./90 min | 164 | 324 | 10.4 |
| | | 350° C./90 min | 143 | 307 | 12 |
| | | 380° C./90 min | 129 | 292 | 16.4 |
| 3A | F > 24 h | | 173 | 326 | 6 |
| | | 250° C./90 min | 181 | 325 | 5.9 |
| | | 350° C./90 min | 151 | 315 | 6.9 |
| | | 380° C./90 min | 137 | 312 | 9.5 |
| 4 | F > 24 h | | 138 | 304 | 8.2 |
| | | 250° C./90 min | 145 | 309 | 9 |
| | | 350° C./90 min | 133 | 297 | 8.4 |
| | | 380° C./90 min | 123 | 286 | 12.7 |
| 4A | F > 24 h | | 152 | 284 | 4.3 |
| | | 250° C./90 min | 163 | 278 | 3.7 |
| | | 350° C./90 min | 139 | 286 | 5.2 |
| | | 380° C./90 min | 131 | 285 | 5.7 |

**1**. Aluminium alloy of type AlMgSi with good creep strength at elevated temperatures for the production of castings subject to high thermal and mechanical stresses, characterized in that

the contents of the alloying elements magnesium and silicon in % w/w in a Cartesian coordinate system are limited by a polygon A with the coordinates [Mg; Si] [8.5; 2.7] [8.5; 4.7] [6.3; 2.7] [6.3; 3.4] and that the alloy also contains

0.1 to 1% w/w manganese
max. 1% w/w iron
max. 3% w/w copper
max. 2% w/w nickel
max. 0.5% w/w chromium
max. 0.6% w/w cobalt
max. 0.2% w/w zinc
max. 0.2% w/w titanium
max. 0.5% w/w zirconium
max. 0.008% w/w beryllium
max. 0.5% w/w vanadium

as well as aluminium as remainder with further elements and manufacturing-related impurities of individually max. 0.05% w/w and max. 0.2% w/w in total.

**2**. Aluminium alloy according to claim **1**, containing 6.9 to 7.9% w/w Mg.

**3**. Aluminium alloy according to claim **1**, containing 3.0 to 3.7% w/w Si.

**4**. Aluminium alloy according to claim **1**, characterized in that the contents of the alloying elements magnesium and silicon in % w/w in a Cartesian coordinate system are limited by a polygon B with the coordinates [Mg; Si] [7.9; 3.0] [7.9; 3.7] [6.9; 3.0] [6.9; 3.7].

**5**. Aluminium alloy according to claim **4**, characterized in that the contents of the alloying elements magnesium and silicon in % w/w in a Cartesian coordinate system are limited by a polygon C with the coordinates [Mg; Si] [7.7; 3.1] [7.7; 3.6] [7.1; 3.1] [7.1; 3.6].

**6**. Aluminium alloy according to claim **1**, containing 0.4 to 1% w/w Fe, and 0.1 to 0.5% w/w Mn.

**7**. Aluminium alloy according to claim **1**, containing max. 0.20% w/w Fe and 0.5 to 1% w/w Mn.

**8**. Aluminium alloy according to claim **1**, containing 0.2 to 1.2% w/w Cu.

**9**. Aluminium alloy according to claim **1**, containing 0.8 to 1.2% w/w Ni.

**10**. Aluminium alloy according to claim **1**, containing max. 0.2% w/w Cr.

**11**. Aluminium alloy according to claim **1**, containing 0.3 to 0.6% w/w Co.

**12**. Aluminium alloy according to claim **1**, containing 0.05 to 0.15% w/w Ti.

**13**. Aluminium alloy according to claim **1**, containing 0.1 to 0.4% w/w Zr.

**14**. Aluminium alloy according to claim **1**, containing 0.02 to 0.15% w/w V, and less than 60 ppm Be.

**15**. Use of an aluminium alloy according to claim **1** for components subject to high thermal and mechanical stresses produced by pressure die casting, mould casting or sand casting.

**16**. Use according to claim **15** for cylinder crankcases produced by the pressure die casting method in automotive engine construction.

**17**. Use of an aluminium alloy according to claim **1** for safety components produced by the pressure die casting method in automotive construction.

**18**. Aluminium alloy according to claim **1** containing 7.1 to 7.7% w/w Mg.

**19**. Aluminium alloy according to claim **1** containing 3.1 to 3.6% w/w Si.

**20**. Aluminium alloy according to claim **2** containing 3.0 to 3.7% w/w Si.

* * * * *