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(54) **DIE CASTING ALLOY**

(57) According to the invention, the following composition is proposed for a die casting alloy.

Iron (Fe)	0.8 - 2.0 wt. %
Magnesium (Mg)	0.3 - 6.0 wt. %
Silicon (Si)	0.3 - 1.2 wt. %
Calcium (Ca)	0.05 - 2.0 wt. %
Zinc (Zn)	0 - 4.0 wt. %
Copper (Cu)	0 - 2.5 wt. %
Manganese (Mn)	0 - 1.5 wt. %
Nickel (Ni)	0 - 0.6 wt. %

0 - 0.8% of an element or element group selected from the group consisting of , chromium (Cr), lead (Pb), lithium (Li), vanadium (V), Titan (Ti), phosphorus (P), molybdenum (Mo), zirconium (Zr), gallium (Ga), and the rest aluminium and unavoidable impurities.

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Description

[0001] The present invention relates to a die casting alloy based on aluminium, iron, magnesium and silicon.

5 **[0002]** The aluminium casting industry plays a crucial role in various applications, from the automotive industry to electronic devices. In recent years, the demand for environmentally friendly and cost-efficient casting alloys, especially die casting alloys, has increased. One of the challenges is to enable the use of low-grade aluminium scrap resp. secondary aluminium, which is obtained from aluminium scrap of various origins, in order to reduce waste and use resources more efficiently.

10 **[0003]** According to the state of the art, wheel scrap is used for the production of AlSi9MnMg alloys with a high recycled content, especially because of the low iron content of this type of scrap. Other types of scrap with a higher iron content or other impurities are generally not usable.

[0004] A die casting alloy based on aluminium, iron and magnesium is known from EP 3235916 B1, which is used in particular in the field of vehicle structural components.

15 **[0005]** One object of the invention is to provide an alloy composition which has a high content of secondary aluminium without having to compromise too much on properties such as strength, ductility, corrosion resistance and processability.

[0006] The die casting alloy according to the invention, consists of the following elements:

20	Iron (Fe)	0.8 - 2.0 wt. %
	Magnesium (Mg)	0.3 - 6.0 wt. %
	Silicon (Si)	0.3 - 1.2 wt. %
	Calcium (Ca)	0.05 - 2.0 wt. %
	Zinc (Zn)	0 - 4.0 wt. %
25	Copper (Cu)	0 - 2.5 wt. %
	Manganese (Mn)	0 - 1.5 wt. %
	Nickel (Ni)	0 - 0.6 wt. %

30 **[0007]** 0 - 0.8% of an element or element group selected from the group consisting of, chromium (Cr), lead (Pb), lithium (Li), vanadium (V), titanium (Ti), phosphorus (P), molybdenum (Mo), zirconium (Zr), gallium (Ga), and the rest aluminium and unavoidable impurities.

[0008] One embodiment of the die casting alloy according to the invention has a silicon content of 0.4 - 0.9 wt. % silicon.

[0009] A further embodiment of the die casting alloy according to the invention has a silicon content of 0.5 - 0.8 wt. % silicon.

35 **[0010]** A further embodiment of the die casting alloy according to the invention has an iron content of 1.0 - 1.7 wt. % iron.

[0011] A further embodiment of the die casting alloy according to the invention has an iron content of 1.1 - 1.5 wt. % iron.

[0012] A further embodiment of the die casting alloy according to the invention has a magnesium content of 2.5 - 6.0 wt. % magnesium.

40 **[0013]** A further embodiment of the die casting alloy according to the invention has a magnesium content of 3.5 - 5.0 wt. % magnesium.

[0014] A further embodiment of the die casting alloy according to the invention has a calcium content of 0.08 - 1.5 wt. % calcium, preferably 0.1 - 1.0 wt. % calcium, particularly preferably 0.1 - 0.5 wt. % calcium.

[0015] A further embodiment of the die casting alloy according to the invention has a vanadium content of 0.01 - 0.05 wt. % vanadium.

45 **[0016]** A further embodiment of the die casting alloy according to the invention has a zinc content of 0 - 1.0 wt. % zinc.

[0017] A further embodiment of the die casting alloy according to the invention has a zinc content of 0.1 - 0.5 wt. % zinc.

[0018] A further embodiment of the die casting alloy according to the invention has a manganese content of 0.1 - 1 wt. % manganese.

50 **[0019]** A further embodiment of the die casting alloy according to the invention has a copper content of max. 2.0 wt. %, preferably max. 0.1 wt. % copper.

[0020] A further embodiment of the die casting alloy according to the invention has a nickel content of max. 0.1 wt. % nickel.

55 **[0021]** The alloy according to the invention is a die casting alloy or, in other words, the alloy composition proposed according to the invention is used for die casting, preferably of structural components for automotive manufacture. The term die casting alloys covers alloy compositions which are processed into a die cast component by means of a die casting process. Die casting alloys must be clearly distinguished from wrought alloys. Die casting alloys are alloy compositions that are further processed in one step by means of a die casting process into the direct end product, the die cast component. The alloy composition can be introduced into the casting mould as a liquid melt or as a partially solidified melt.

[0022] If necessary, this product is subsequently heat-treated or such a heat treatment is to be deliberately avoided, as according to the present invention. The die-cast product then already exhibits the desired material properties in the casting state "state F". Examples of products are die-cast structural components of cars.

[0023] The following die casting processes are examples of die casting processes: HPDC (High Pressure Die Casting), Vacuum Die Casting and Rheo Die Casting (so-called Reocasting), Vacural Die Casting.

[0024] In die casting processes in general, the molten alloy is shot into a mould at high speed, the so-called gate speed, of 20-100 m/s and solidifies there at a holding pressure of about 500-1000 bar. There are process variants in which the gate speed is only 1-10 m/s.. In the case of aluminium, only cold chamber systems have been used up to now. For larger casting weights, these are usually arranged horizontally, in some cases vertically or at an oblique angle.

[0025] The alloy according to the invention is an alloy in which the aluminium comes from a secondary source. This includes aluminium scrap, such as AlMg profiles, lithographic material or can scrap. Can scrap includes so-called UBC material (Used Beverage Cans) according to DIN EN 13920-10.

[0026] These are die-cast structural components of cars such as suspension strut domes, side members or even larger components such as integral supports for the front or rear of the car.

[0027] Aluminium alloys used for structural components in automobiles generally have the following material properties: Good castability, material properties of $R_m = 200-270$ MPa, $R_{p0.2} = 100-180$ MPa, $A = 7-15$ %, good suitability for joining (riveting, welding, adhesive bonding, etc.) and corresponding corrosion resistance.

[0028] Due to the composition according to the invention, the end product shows a slightly increased strength compared to conventional casting alloys, for example AlSi alloys, which are also used for structural components in automotive manufacture. In addition, the alloy already has mechanical properties in the as-cast state (state F) that make it possible to dispense with heat treatment, which reduces manufacturing costs and energy consumption.

[0029] Foundries demand good castability of the alloy. In general, this is understood to mean that the alloy has good flowability when cast in die casting, good mould filling capacity, good solidification behaviour (i.e. for example low shrinkage and no tendency to crack) and favourable behaviour when ejected from the mould (i.e. for example low tendency to stick). In practical casting tests, this could also be shown for the alloy composition according to the invention.

[0030] The basis for the alloy composition according to the invention is the AlFe eutectic, mostly in the form Al₁₄Fe₃, which ensures the castability of the alloy. It reduces the shrinkage of the aluminium in the die-casting mould and considerably reduces its tendency to stick in the mould (usually a steel mould). The high iron content of the alloy according to the invention leads, in addition to the formation of an Al₁₄Fe₃ eutectic, to a low chemical attack against the mould steel. The consequences are a low, necessary use of release agents, a low adhesive bonding of the component on the mould during ejection and a low mould wear. The formation of the eutectic causes solidification at a constant temperature. These properties of an alloy are described among experts as good castability. In addition, the alloy has no tendency to hot cracking and a high formability in the temperature range of 250-500 °C. Both reduce the tendency to cold cracking during solidification, which also has a positive influence on castability.

[0031] Magnesium (Mg) serves as a solid solution strengthener to increase strength. Silicon (Si) together with magnesium (Mg) also increases the strength by forming Mg₂Si. It was found that despite the presence of silicon (Si) no embrittlement occurs, in particular no brittle AlFeSi phases are formed.

[0032] Calcium (Ca) reduces the oxidation tendency of the melt. By adding vanadium (V) in addition to calcium, the oxidation tendency of the melt could be reduced even further. The reduction of the oxidation tendency of the melt also reduces the magnesium melting loss and thus the magnesium loss during the production of the alloy composition according to the invention.

[0033] Further elements are not absolutely necessary, but can be tolerated to a greater extent than is the case with other ductile die casting alloys, such as conventional AlSi alloys, which are generally used as standard in structural components in automotive manufacture. These include, for example, the elements Mn, Cr, Cu and Zn.

[0034] Zinc leads to a slight improvement in castability in terms of mould filling capacity if between 0.2-0.5 % Zn is present. A higher content (3-4 %) increases the strength of the alloy considerably, but also the susceptibility to corrosion.

[0035] The effect of impurities on the corrosion tendency of the alloy according to the invention turned out to be less than that of conventional AlSi alloys. The compositions are listed in Table 4. Alloy named M1 is an example for a conventional AlSi alloy in comparison to the compositions A1, J2 according to the invention. A pH neutral salt spray test was carried out over 720 h at normal conditions on die pressure cast, non-surface treated, 3 x 60 x 60 mm plates. Table 1 shows the weight losses before and after the test.

Table 1: Corrosion test result

Sample/alloy	Weight loss [g/(m ² day)]
A1	0,14
J2	0,32

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(continued)

Sample/alloy	Weight loss [g/(m ² day)]
M1	1,0

5 **[0036]** As expected, the corrosion resistance of alloy A1 was higher than that of alloy J2. J2 contains relatively high contents of Mn, Cu and Zn compared to alloy A1.

10 **[0037]** Surprisingly, it was found that compared to a conventional AlSi alloy (see alloy composition M1), the corrosion resistance of the alloy according to the invention is better than that of the AlSi alloy, despite similar contents of Mn, Cu and Zn (see Table 4, M1, J2). In the alloy according to the invention, there is an insular structure of brittle, corrosion-prone intermetallic phases caused by impurities (for example, the elements Fe, Mn, Cr and Cu form such phases). The aluminium phase between these phases prevents a too strong reduction of ductility and a too fast progress of the corrosion attack.

15 **[0038]** In the alloy M1 (state F), intermetallic phases contaminated by impurities are often found within an AlSi eutectic connected in a net-like manner through the entire material. Such a structure is more brittle and clearly more susceptible to corrosion.

Examples of embodiments

20 **[0039]** The following table shows a composition of a can scrap used for the alloy according to the invention (so-called UBC material, see line "Recycled material"). An example of the composition according to the invention is listed in the line "Alloy composition J1". Depending on the composition of the recycled material, it is necessary to adapt the addition of the required alloying elements to the impurities found (see line "Addition of elements"). In this example, the addition of just under 3.2 % Mg already leads to a yield tensile strength of over 160 MPa. Without the content of 0.23 % Cu and 0.80 % Mn, among others, in the starting alloy, this strength would not have been achieved; the addition of a larger quantity of Mg would have been necessary.

Table 2 - Embodiment 1

Element	Si	Fe	Cu	Mn	Mg	Zn
Recycled material (UBC)	0,26	0,50	0,23	0,80	1,03	0,04
Alloy composition J1	0,53	1,21	0,23	0,79	4,20	0,04
Element addition	yes	yes	no	no	yes	no
Element	Cr	Ni	Ti	Ca	V	Al
Recycled material	0,02	0,01	0,02	0,00	0,00	rest
Alloy composition J1	0,02	0,01	0,02	0,08	0,02	rest
Element addition	no	no	no	yes	yes	no
Note: Further alloying elements were present in small quantities due to impurities.						

30 **[0040]** For the composition according to the invention listed in Table 2, the melting interval (solidus-liquidus) was calculated to be 571-660 °C with the aid of a phase simulation, and the heat of fusion was calculated to be 485 kJ/kg. Despite the high content of impurities, these values indicate good castability in die casting. The heat of fusion is comparable to that of conventional AlSi alloys, which are considered by experts to have good castability. The heat of fusion of rotor alloys rated as poor castability is, as an example, approx. 80 kJ/kg lower.

35 **[0041]** Table 3 discloses a further embodiment of the alloy composition according to the invention. As an example, the effect addition of Ca and V and the magnesium burn-off will be explained here. Table 3A shows the composition of the alloy at the start of the experiment and Table 3B the composition 7 days later.

Table 3 - Embodiment 2 (effect Ca, V)

55 **[0042]**

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Table 3A Start of experiment

No.	Si	Fe	Cu	Mn	Mg	Ca	V
V1	0,036	1,54	0,001	0,005	4,26	0,000	0,023
V2	0,038	1,58	0,002	0,005	4,26	0,082	0,023

Table 3B End of experiment 7 days later

No.	Si	Fe	Cu	Mn	Mg	Ca	V
V1	0,04	1,64	0,001	0,005	3,18	0,000	0,022
V2	0,04	1,59	0,002	0,005	4,28	0,076	0,022

[0043] Table 3A, 3B shows the effect on magnesium burn-off. Already an addition of 0.082 Ca and 0.023 V led to a no longer measurable loss of magnesium. In addition, a significantly lower oxide layer on the melt could be visually determined.

[0044] It was found that Ca in combination with V (see V2) reduced the loss of Mg.

[0045] The addition of V without Ca did not improve the oxidation tendency, i.e. the thickness of the oxide layer was not reduced. After the end of the test, a measurable loss of Mg resulted (see V1).

Comparative embodiments

[0046] Table 4 compares compositions of examples of alloys according to the invention. The figures are in wt. %.

Table 4

test	Si	Fe	Cu	Mn	Mg	Zn
A1	0,04	1,59	0,00	0,00	5,18	0,00
A2	0,04	1,60	0,00	0,00	5,39	0,00
A3	0,04	1,57	0,00	0,00	5,96	0,00
B1	0,45	1,13	0,05	0,01	3,74	0,00
B2	0,47	1,19	0,05	0,01	3,79	0,00
B3	0,58	1,15	0,05	0,01	3,66	0,00
C1	0,13	1,20	0,03	0,21	3,41	0,01
C2	0,51	1,21	0,04	0,17	4,51	0,01
C3	0,53	1,35	0,04	0,64	4,61	0,01
D1	0,13	1,19	0,03	0,17	3,41	0,01
D2	0,13	1,24	0,03	0,60	3,40	0,01
D3	0,51	1,28	0,04	0,61	3,38	0,01
D4	0,51	1,28	0,04	0,98	3,30	0,01
E1	0,39	1,20	0,06	0,01	4,32	0,05
E2	0,40	1,16	0,05	0,01	5,15	0,05
E3	0,60	1,21	0,05	0,01	5,18	0,05
F1	0,51	1,04	0,05	0,05	3,46	0,05
F2	0,52	1,04	0,05	0,05	4,03	0,05
F3	0,52	1,05	0,05	0,05	5,01	0,05
F4	0,51	1,03	0,05	0,35	4,89	0,05
G1	0,47	1,13	0,05	0,05	4,66	0,05
G2	0,46	1,10	0,19	0,05	4,60	0,05

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(continued)

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test	Si	Fe	Cu	Mn	Mg	Zn
G3	0,49	1,25	0,21	0,05	4,89	0,19
G4	0,48	1,26	0,21	0,19	4,83	0,19
H1	0,31	1,14	0,17	0,69	3,46	0,04
H2	0,31	1,15	0,17	0,71	3,57	0,20
H3	0,51	1,27	0,17	0,72	3,58	0,20
I1	0,30	1,17	0,17	0,77	5,06	0,25
J1	0,53	1,21	0,23	0,79	4,20	0,04
J2	0,54	1,27	0,21	0,83	4,31	0,60
J3	0,53	1,23	0,21	0,80	4,21	0,99
K1	0,50	1,15	0,17	0,77	4,06	0,20
K2	0,52	1,24	0,75	0,81	4,14	0,20
K3	0,53	1,29	1,24	0,80	4,14	0,19
K4	0,52	1,29	2,03	0,80	4,06	0,19
L1	0,04	1,93	0,00	0,01	0,48	0,01
M1	9,49	0,11	0,21	0,51	0,35	0,29
N1	0,36	1,52	0,01	0,01	4,06	3,36
N2	0,37	1,51	0,01	0,01	4,23	3,26
N3	0,37	1,52	0,01	0,01	4,12	3,24
O1	0,32	1,25	0,00	0,01	0,36	0,02
test	Cr	Ni	Ti	Ca	V	
A1	0,00	0,01	0,01	0,10	0,03	
A2	0,00	0,01	0,01	0,10	0,03	
A3	0,00	0,01	0,01	0,10	0,03	
B1	0,00	0,01	0,01	0,25	0,02	
B2	0,00	0,01	0,01	0,25	0,02	
B3	0,00	0,01	0,01	0,25	0,02	
C1	0,07	0,00	0,03	0,16	0,03	
C2	0,07	0,01	0,02	0,08	0,02	
C3	0,07	0,01	0,03	0,08	0,02	
D1	0,07	0,01	0,02	0,09	0,02	
D2	0,07	0,00	0,02	0,09	0,02	
D3	0,07	0,00	0,02	0,51	0,02	
D4	0,07	0,00	0,02	0,51	0,02	
E1	0,00	0,01	0,01	0,08	0,02	
E2	0,00	0,01	0,01	0,07	0,02	
E3	0,00	0,01	0,01	0,07	0,02	
F1	0,00	0,01	0,01	0,10	0,03	
F2	0,00	0,01	0,01	0,10	0,03	
F3	0,00	0,01	0,01	0,10	0,03	

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test	Cr	Ni	Ti	Ca	V
F4	0,00	0,01	0,01	0,10	0,03
G1	0,00	0,01	0,01	0,08	0,03
G2	0,00	0,01	0,01	0,08	0,03
G3	0,00	0,01	0,01	0,08	0,03
G4	0,00	0,01	0,01	0,08	0,03
H1	0,02	0,01	0,02	0,09	0,02
H2	0,02	0,01	0,02	0,10	0,02
H3	0,02	0,01	0,02	0,09	0,02
I1	0,03	0,01	0,02	0,08	0,02
J1	0,02	0,01	0,02	0,08	0,02
J2	0,02	0,01	0,02	0,08	0,02
J3	0,02	0,01	0,02	0,08	0,02
K1	0,03	0,01	0,02	0,09	0,02
K2	0,03	0,01	0,02	0,09	0,02
K3	0,02	0,01	0,02	0,09	0,02
K4	0,02	0,01	0,02	0,09	0,02
L1	0,00	0,01	0,01	0,05	0,01
M1	0,00	0,01	0,10	0,00	0,01
N1	0,00	0,01	0,02	0,00	0,01
N2	0,00	0,01	0,02	0,11	0,01
N3	0,00	0,01	0,02	0,50	0,01
O1	0,00	0,53	0,01	0,05	0,01

Results obtained

[0047] For the cast samples in Tables 4, the mechanical properties (Rm, Rp0.2, A5) were measured on die-casted 3 mm plates. The mean value from at least 6 tensile tests is shown in each case.

[0048] The results of the tests in the as-cast state (state F) yielded remarkable mechanical properties despite a high recycling rate and high contamination with different elements (see Table 5).

Table 5 (Material properties, die casting, state F)

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test	Rm [MPa]	Rp _{0,2} [MPa]	A ₅ [%]	Recycled content [%]
A1	270	128	13,0	10
A2	277	131	13,5	10
A3	284	139	11,8	10
B1	246	125	15,0	25
B2	248	124	14,0	25
B3	251	127	14,0	25
C1	275	133	14,6	100
C2	279	146	12,4	100
C3	283	154	10,3	100

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test	Rm [MPa]	Rp _{0,2} [MPa]	A ₅ [%]	Recycled content [%]
D1	244	117	14,9	50
D2	254	126	14,1	50
D3	263	142	11,9	50
D4	253	146	8,8	50
E1	263	133	14,0	75
E2	285	145	12,6	75
E3	284	150	11,8	75
F1	249	128	14,7	75
F2	259	133	14,5	75
F3	278	144	12,0	75
F4	291	153	11,4	75
G1	273	140	12,9	75
G2	279	146	11,5	75
G3	281	148	11,9	75
G4	286	151	11,3	75
H1	265	145	9,1	100
H2	267	144	10,6	100
H3	262	152	7,7	100
I1	292	160	8,8	100
J1	283	162	8,9	100
J2	285	164	7,5	100
J3	285	168	7,0	100
K1	272	157	7,5	100
K2	286	170	6,8	100
K3	292	179	5,8	100
K4	306	189	5,3	100
L1	169	82	15,3	10
M1	280	143	5,1	0
N1	322	175	7,8	50
N2	316	172	8,4	50
N3	285	165	5,1	50
O1	184	83	14,8	10

[0049] The cast samples from test B1 and B3 were subjected to a T5 heat treatment (1h, 200°C). Table 6 below shows the results:

Table 6

test	Rm [MPa]	Rp _{0,2} [MPa]	A ₅ [%]	Recycled content [%]
B1	252	138	13,6	25
B3	252	137	13,5	25

[0050] The results of the tests with a heat treatment T5 (1 h 200 °C) show a hardly changed tensile strength, a slight increase of the yield tensile strength by 10-13 MPa and a decrease of the elongation at fracture by 0.5-1.5 % compared to the state F. The alloy according to the invention can thus be used without heat treatment for structural components for automotive manufacture.

[0051] The recycling content indicates the approximate secondary aluminium content obtained from consumer scrap, so-called post consumer recycling (PCR). Industrial waste (pre-consumer recycling) was not used.

Claims

1. Die casting alloy consisting of:

Iron (Fe)	0.8 - 2.0 wt. %
Magnesium (Mg)	0.3 - 6.0 wt. %
Silicon (Si)	0.3 - 1.2 wt. %
Calcium (Ca)	0.05 - 2.0 wt. %
Zinc (Zn)	0 - 4.0 wt. %
Copper (Cu)	0 - 2.5 wt. %
Manganese (Mn)	0 - 1.5 wt. %
Nickel (Ni)	0 - 0.6 wt. %

0 - 0.8% of an element or element group selected from the group consisting of, chromium (Cr), lead (Pb), lithium (Li), vanadium (V), titanium (Ti), phosphorus (P), molybdenum (Mo), zirconium (Zr), gallium (Ga), and the rest aluminium and unavoidable impurities.

2. Die casting alloy according to claim 1, **characterized by** 0.4 - 0.9 wt. % silicon.

3. Die casting alloy according to any of the preceding claims, **characterized by** 0.5 - 0.8 wt. % silicon.

4. Die casting alloy according to any of the preceding claims, **characterized by** 1.0 - 1.7 wt. % iron.

5. Die casting alloy according to any of the preceding claims, **characterized by** 1.1 - 1.5 wt. % iron.

6. Die casting alloy according to any of the preceding claims, **characterized by** 2.5 - 6.0 wt. % magnesium.

7. Casting alloy according to any of the preceding claims, **characterized by** 3.5 - 5.0 wt. % magnesium.

8. Casting alloy according to any of the preceding claims, **characterized by** 0.08 - 1.5 wt. % calcium, preferably 0.1 - 1.0 wt. % calcium, particularly preferably 0.1 - 0.5 wt. % calcium.

9. Casting alloy according to any of the preceding claims, **characterized by** 0.01 - 0.05 wt. % vanadium.

10. Casting alloy according to any of the preceding claims, **characterized by** 0 - 1.0 wt. % zinc.

11. Casting alloy according to any of the preceding claims, **characterized by** 0.1 - 0.5 wt. % zinc.

12. Casting alloy according to any of the preceding claims, **characterized by** 0.1 - 1 wt. % manganese.

13. Casting alloy according to any of the preceding claims, **characterized by** max. 2.0 wt. % copper, preferably max. 0.1 wt. % copper.

14. Casting alloy according to any of the preceding claims, **characterized by** max. 0.1 wt. % nickel.

15. Use of a casting alloy according to any one of the preceding claims for die casting structural components for automotive manufacture.



EUROPEAN SEARCH REPORT

Application Number
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