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(54) **SAFETY COMPONENT MOULDED IN Al-SI ALLOY**

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(76) Inventors: **Michel Garat, Moirans (FR); Francois Cosse, Grenoble (FR)**

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Correspondence Address:

**DENNISON, SCHULTZ & DOUGHERTY
1745 JEFFERSON DAVIS HIGHWAY
ARLINGTON, VA 22202 (US)**

(57) **ABSTRACT**

The invention concerns a safety component with high mechanical strength and good ductility, moulded in Al—Si alloy consisting (in wt. %) of: Si: 2-11; Mg: 0.3-0.7; Cu: 0.3-0.9; other elements <1 each and <2 in total, the rest being aluminium, and solution heat treated, tempered and hardened resulting in Brinell hardness of more than 125. The invention also concerns a safety component with high mechanical resistance and good ductility, moulded in Al—Si alloy consisting (in wt. %) of: Si: 2-6; Mg: 0.3-0.7; Fe <0.20; other elements <0.3 each and <1 in total; the rest being aluminium; solution heat treated, hardened and tempered resulting in a quality index $Q=R_m+\log A>485$ MPa.

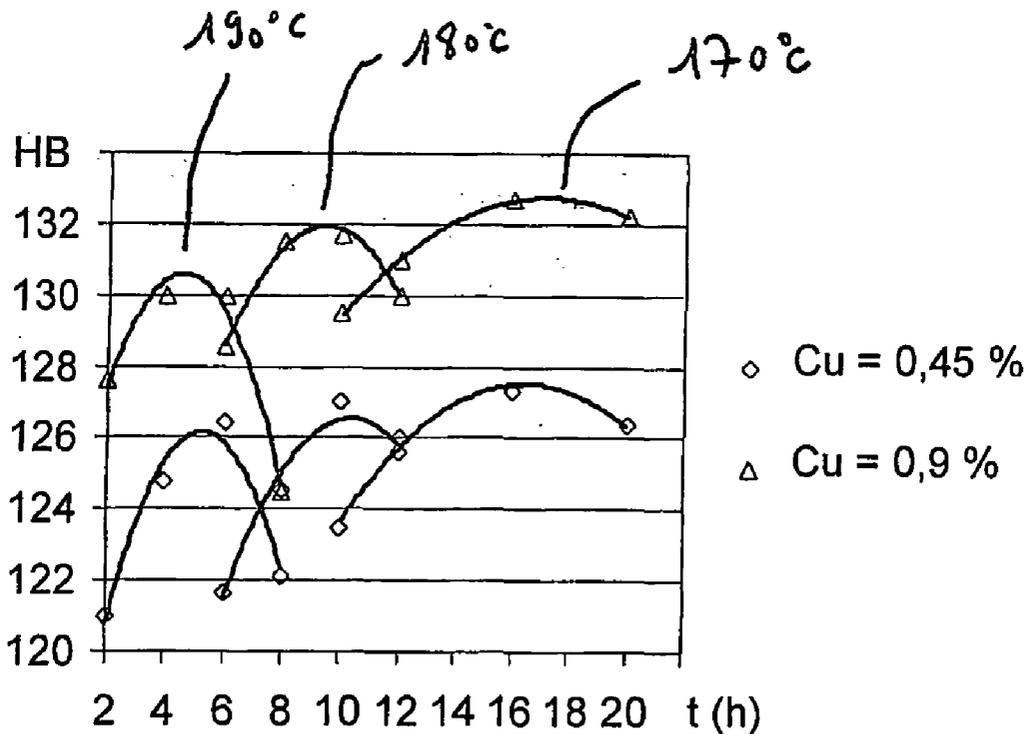
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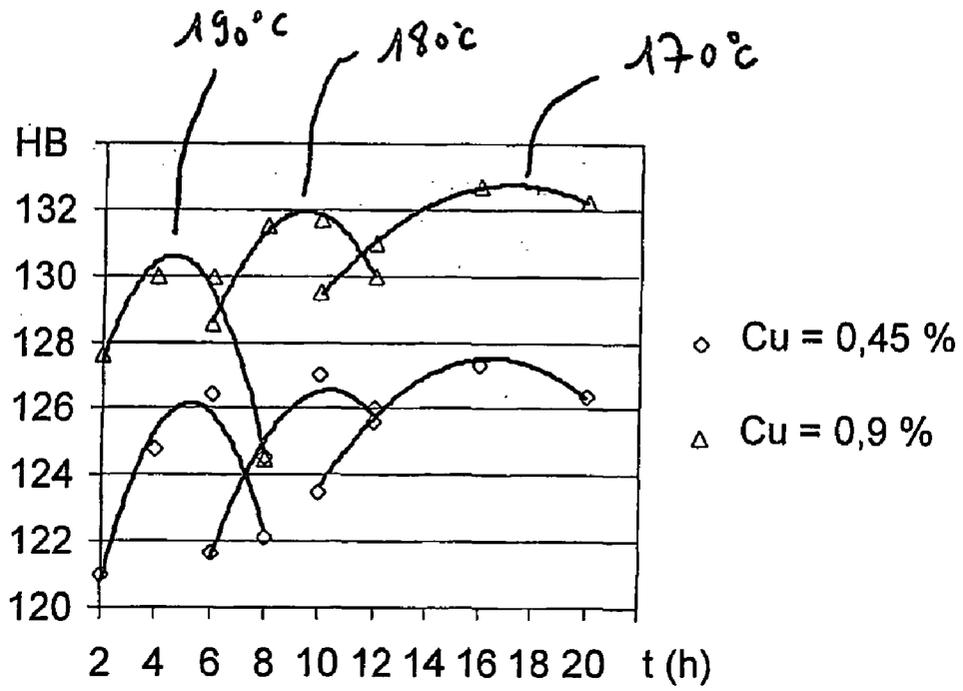
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SAFETY COMPONENT MOULDED IN Al-SI ALLOY

FIELD OF THE INVENTION

[0001] The invention relates to the manufacture of cast safety parts intended particularly for automobiles, for example such as suspension parts made of hypoeutectic Al—Si alloys, these parts having high mechanical strength, sufficient ductility, good corrosion resistance and good metallurgical soundness, after heat treatment.

STATE OF THE ART

[0002] The use of aluminium alloys for cast parts is developing quickly in automobiles, particularly for safety parts such as connections to the ground, in order to reduce the weight of the vehicle. This weight reduction is particularly significant because a high mechanical strength can also be obtained after heat treatment. Furthermore, for this type of part, it is essential to have sufficient ductility to prevent a brittle failure after a shock, good corrosion resistance, particularly stress corrosion, to prevent deterioration of the part in a corrosive environment such as road salt, and lack of shrinkage, particularly on the surface, which could generate cracks causing failure of the part.

[0003] Processes typically used for the production of such parts include casting in metallic moulds by gravity or at low pressure, "squeeze casting", casting in metallic moulds followed by forging, or stamping as described in U.S. Pat. No. 5,582,659 (Nippon Light Metal and Nissan Motor) or in certificate of utility FR 2614814 (Thomas DI SERIO), or forming in the semi-solid state by pressure injection or forging (thixocasting or rheocasting depending on whether the initial metal is in the solid state or the liquid state).

[0004] Casting with lost foam models under isostatic pressure, high quality die casting, possibly under a vacuum, and sand casting or casting in metallic moulds followed by hot isostatic compaction are also applicable.

[0005] The most frequently used alloys for this type of part are Al—Si—Mg alloys, particularly of the AlSi7Mg, AlSi9Mg or AlSi10Mg type. In the F, T5 and particularly T6 tempers, these alloys produce a good compromise between mechanical strength and elongation, and excellent resistance to corrosion. However, the mechanical strength is limited by the hardening capacity of the Mg₂Si phase.

[0006] Several patents illustrate the use of this type of alloy. U.S. Pat. No. 4,104,089 filed by Nippon Light Metal in 1976 applies to non-porous die cast parts for automobiles with high mechanical strength and shock resistance, and with the following composition (% by weight):

[0007] Si 7-12; Mg 0.2-0.5; Mn 0.55-1; Fe 0.65-1.2

[0008] Parts are solution heat treated at between 450° C. and 530° C., quenched and then aged for more than 1 hour at between 150 and 230° C.

[0009] U.S. Pat. No. 5,582,659, filed by Nippon Light Metal and Nissan Motor in 1993, discloses a process for manufacturing cast parts including casting of a blank containing the following (% by weight):

[0010] Si 2.0-3.3; Mg 0.2-0.6; Fe <0.15 and possibly Cu 0.2-0.5

[0011] Zr 0.01-0.2; Mn 0.02-0.5; Cr 0.01-0.3.

[0012] Homogenisation of this blank between 500 and 550° C., forging of the blank and solution heat treatment for 0.5 to 2 h between 540 and 550° C., quenching in water and T6 ageing for between 2 and 20 h between 140 and 180° C.

[0013] Patent EP 0687742 filed by Aluminum Rheinfelden in 1994 describes a die casting alloy for use in making cast safety parts with the following composition (% by weight):

[0014] Si 9.5-11.5; Mg 0.1-0.5; Mn 0.5-0.8; Fe <0.15; Cu<0.03.

[0015] If a strength greater than that obtained by the precipitation of Mg₂Si is required while maintaining the appropriate casting properties, AlSiMgCu type alloys that can be hardened by the Al₂Cu, Al₂CuMg and w (AlCuMgSi) series of phases have to be used. There are many known and standardised alloys with a copper content equal to or exceeding 1%, and particularly AlSi5 alloys such as:

[0016] EN AC 45300 (type AlSi5Cu1Mg, similar to AA C355) containing between 1.0 and 1.5% Cu EN AC 45100 (type AlSi5Cu3Mg, similar to AA 319) containing between 2.6 and 3.6% Cu or AlSi8 or AlSi9 alloys such as:

[0017] EN AC 46000 (type AlSi9Cu3), 46200 (type AlSi8Cu3) or 46500 (type AlSi9Cu3FeZn). The alloy EN AC 46400 has a Cu content of between 0.8 and 1.3%. In general, it is accepted that Cu contents equal to or greater than 1% are necessary to increase the hardness and the yield strength at ambient temperature compared with AlSiMg alloys. But, due to the hardening caused by these Cu contents, the elongation becomes low and resistance to corrosion mediocre, and usually insufficient for automobile safety parts.

[0018] The article by F. J. Feikus "Optimization of Al—Si cast alloys for cylinder head applications" AFS Transactions 98-61, pp. 225-231, studies the addition of 0.5% and 1% of copper to an AlSi7Mg0.3 alloy to make cylinder heads for internal combustion engines. No improvement in the yield strength and no increase in the hardness at ambient temperature was observed after conventional T6 treatment involving 5 h solution heat treating at 525° C. followed by quenching in cold water and ageing for 4 h at 165° C. The added copper only makes a significant improvement to the yield strength and creep resistance at usage temperatures of more than 150° C.

[0019] The former French standard NF A57-702, February 1960, mentioned the A-S4G alloy with a very wide tolerance in iron (<0.65%), a wide range for the magnesium content (0.40-0.95%) and fairly low mechanical properties in the Y33 state: R_m>25 kgf/mm² (245 MPa) R_{p0.2}>18 kgf/mm² (176 MPa) A>1.5%.

[0020] These properties were lower than the properties of the A-S7G0.6 alloy, standardised in the February 1981 edition of the same standard, that were as follows respectively:

[0021] R_m>290-320 MPa; R_{p0.2}>210-240 MPa; A>4-6%

[0022] The purpose of this invention is to provide safety parts that can be cast using all casting processes and have a high mechanical strength, good resistance to stress corrosion and good ductility.

[0023] Purpose of the Invention

[0024] The purpose of the invention is a safety part with high mechanical strength and good ductility, cast from an Al—Si alloy with the following composition (% by weight):

[0025] Si 2-11; Mg 0.3-0.7; Cu 0.3-0.9; other elements <1 each and <2 total, remainder aluminium,

[0026] and solution heat treated, quenched and aged to give a hardness of more than 125 Brinell.

[0027] The alloy preferably contains 0.5 to 0.7% Mg and 0.3 to 0.9% Cu.

[0028] If the casting process can tolerate alloys with a greater tendency to shrinkage, for example die casting, "squeeze casting", casting followed by hot isostatic compaction, casting in the semi-solid state (thixocasting or rheocasting), casting followed by forging or die stamping, and casting with lost foam models under isostatic pressure, the alloy composition includes 2 to 7% of Si.

[0029] Another purpose of the invention is a safety part with high mechanical strength and good ductility, cast from an Al—Si alloy with the following composition (% by weight):

[0030] Si 2-6; Mg 0.3-0.7; Fe <0.20; other elements <0.3 each and <1 total, remainder aluminium,

[0031] and solution heat treated, quenched and aged to give a quality index $Q=R_m+150 \log A>485$ MPa.

DESCRIPTION OF THE FIGURES

[0032] The single figure shows the variation of the HB hardness for AlSi alloys with 7% of silicon containing 0.45% and 0.9% of copper respectively, as a function of the ageing time in hours, for 3 ageing temperatures equal to 170° C., 180° C. and 190° C.

DESCRIPTION OF THE INVENTION

[0033] The invention is based on the observation that the addition of copper with a content of between 0.3 and 0.9% to an AlSiMg alloy, is not only acceptable in terms of resistance to stress corrosion, but also improves the yield strength and the ultimate tensile strength under particular ageing conditions, without deteriorating elongation compared with an alloy with the same composition without copper.

[0034] If a conventional AlSi7Mg0.6 type alloy is compared with the same alloy with 0.45% of copper in the same T6 temper obtained by ageing for 6 h at 160° C., it is observed for the copper alloy that there is no variation in the yield strength, there is a slight increase in the elongation, a slight reduction in the HB hardness which changes from 119 to 114, and particularly there is a severe degradation in the resistance to stress corrosion measured according to the ASTM G49 standard. However, if ageing is done for example for 16 h at 170° C. instead of conventional ageing for 6 h at 160° C., such that the hardness of the treated part is of the order of 130 HB, it is observed that the yield

strength for the copper alloy increases (from 309 to 320 MPa), and that surprisingly this occurs without any degradation to the elongation, and particularly to the resistance to stress corrosion.

[0035] The invention is applicable to all AlSiMgCu alloys containing (by weight) from 2 to 11% of silicon, 0.3 to 0.7% of magnesium and 0.3 to 0.9% of copper, the other additive elements or impurities not exceeding 1% each and 2% total. Preferably, the magnesium content is between 0.5 and 0.7%, and the copper content is between 0.3 and 0.6%. Advantageously, the alloy may contain 0.05 to 0.3% of titanium for refining purposes, and one or several elements to modify or refine the eutectic, such as sodium (between 0.001 and 0.020%), strontium (between 0.004 and 0.050%) or antimony (between 0.03% and 0.3%).

[0036] The iron content is preferably kept below 0.15%, or even better below 0.12%, so as to prevent the formation of iron phases that are detrimental to elongation.

[0037] If a casting process is used that has better tolerance to alloys with a greater tendency to shrinkage, the compromise between the required properties can be improved even further. These casting processes that have been developed recently are particularly casting in the semi-solid state (thixocasting or rheocasting), squeeze casting, casting followed by forging or stamping, casting with lost foam models under isostatic pressure, vacuum die casting, and casting followed by hot isostatic compaction (HIP). In these cases, the silicon content can be reduced to significantly below 7% without affecting the soundness of the produced parts, which gives a significant increase in ductility. The drop in the silicon content can be as much as 2% and its magnitude depends on casting parameters; it is only limited by the castability, the behaviour in terms of shrinkage and the crackability.

[0038] When alloys according to the invention are used with a silicon content of between 7 and 11%, and when ageing is done according to the invention, for example for making thin parts requiring good castability, the loss of ductility induced by the high silicon content can be avoided by using a casting process such as squeeze casting, die casting, vacuum casting, thixocasting or rheocasting with a high solidification rate, such that the spacing between dendrite arms is less than 20 μm .

[0039] The degree of structural hardening leading to an HB hardness of more than 125 obtained by ageing within the 170-190° C. temperature range for a duration of between 4 h and 20 h, the duration decreasing when the temperature increases, as shown in the figure which shows hardnesses obtained at temperatures of 170, 180 and 190° C. respectively as a function of time for an alloy with 7% of silicon containing 0.45 or 0.9% of copper.

[0040] The invention also relates to use of a low silicon content alloy containing between 2 and 6% of silicon, 0.3 to 0.7% of magnesium and less than 0.20% of iron, for the same type of safety parts, together with other additive elements and impurities not exceeding 0.3% each and 1% in total. The magnesium content is preferably between 0.45 and 0.65%. The iron content is preferably kept below 0.15%, or even better below 0.12%. The alloy may contain 0.05 to 0.30% of titanium for refining purposes, and one or several eutectic modifying or refining elements such as sodium with

a content of between 0.01 and 0.20%, strontium between 0.004 and 0.050%, or antimony between 0.03 and 0.3%.

[0041] Parts cast from such an alloy have an ultimate tensile strength when treated in the T6 temper at least equivalent to the ultimate tensile strength of an alloy with 7% silicon, and better elongation, giving them a significantly better quality index Q of the order of 515 MPa instead of 480 to 485 MPa. This quality index $Q=R_m+150 \log A$ was defined in the article by M. Drouzy, S. Jacob and M. Richard at the Centre Technique des Industries de la Fonderie (Foundry Industries Technical Centre) entitled <<Le diagramme charge de rupture allongement des alliages d'aluminium. L'indice de qualité. Application aux A-S7G>> ("The ultimate load—elongation diagram for aluminium alloys. The Quality Index. Application to A-S7G"), Fonderie, No. 355, April 1976, pp. 139-147. This index is a good indicator of the global mechanical performance of this type of alloy.

EXAMPLES

Example 1

[0042] The three alloys A, B and C with the composition (by weight %) shown in Table 1 below, which differ essentially in their copper content, were cast in the form of 18 mm diameter test shell pieces according to standard NF A 57-702.

TABLE 1

Alloy	Si	Fe	Cu	Mg	Ti
A	6.95	0.12	0.01	0.60	0.12
B	6.85	0.13	0.47	0.58	0.13
C	6.87	0.13	0.94	0.59	0.13

[0043] After casting, the test pieces are hot isostatically compacted in order to eliminate all microporosity, this compaction being representative of the different moulding processes including a high pressure compaction phase during solidification such as die casting, squeeze casting, thixocasting, rheocasting or casting with lost foam models under isostatic pressure, or after solidification, such as casting—die stamping.

[0044] The test pieces are then solution heat treated with preliminary levels in order to redissolve eutectics containing copper, and a main level for homogenisation and globulisation of eutectic silicon lasting for 16 h at 530° C. They are then quenched in water and the ageing treatments indicated in Table 2 are carried out on them. Ageing for 6 h at 160° C. is conform with prior art, and 10 h and 16 h ageings at 170° C. are conform with the invention.

[0045] Table 2 indicates the static mechanical characteristics of the test pieces treated:

[0046] ultimate tensile strength R_m (in MPa)

[0047] conventional yield strength at 0.2% elongation $R_{p0.2}$ (in MPa)

[0048] elongation at failure A (in %)

[0049] Brinell hardness (HB)

[0050] The quality index $Q=R_m+150 \log A$ is also given.

TABLE 2

Alloy	Ageing	R_m	$R_{p0.2}$	A	HB	Q
A	6 h-160°	319	243	12.8	119	485
A	10 h-170°	343	304	8.3	124	480
A	16 h-170°	341	309	7.8	125	474
B	6 h-160°	345	246	14.2	114	518
B	16 h-170°	374	320	8.3	128	512
C	6 h-160°	361	244	15.7	115	540
C	16 h-170°	388	320	9.1	131	532

[0051] It is found that the ultimate tensile strength R_m and the yield strength $R_{p0.2}$ for copper alloys B and C are higher than for alloy A with ageing according to the invention, whereas $R_{p0.2}$ remains almost unchanged from ageing according to prior art. With ageing according to the invention, elongation is not reduced, which is contrary to what might have been expected, and even increases slightly as the copper content increases, which substantially increases the quality index Q due to the increase in R_m .

[0052] Test pieces made of the same alloys B and C were used to machine 2 mm thick flat test pieces on which the stress corrosion test was carried out by immersion—emersion in artificial sea water according to standard ASTM G49, with stresses equal to 75% of the yield strength mentioned in Table 2. The results are summarized in Table 3:

TABLE 3

Cu content	Ageing	Test piece failure
0.45%	6 h-160° C.	100% fail between 5 and 11 days
0.45%	16 h-170° C.	100% resist more than 60 days
0.90%	6 h-160° C.	100% fail between 5 and 7 days
0.90%	16 h-170° C.	75% resist more than 60 days, 25% fail between 15 and 60 days

[0053] It is found that ageing according to the invention very significantly improves the resistance to stress corrosion compared with T6 ageing.

Example 2

[0054] Test pieces with three alloys D, E and F at 4% silicon were prepared under the same conditions as in example 1. The composition of each test piece (% by weight) is given in Table 4:

TABLE 4

Alloy	Si	Fe	Cu	Mg	Ti
D	4.0	0.11	0.03	0.63	0.13
E	3.9	0.08	0.44	0.63	0.13
F	4.1	0.09	0.85	0.64	0.13

[0055] After the different ageings, the same parameters were measured as for example 1, and the values are given in Table 5:

TABLE 5

Alloy	Ageing	R _m	R _{p0.2}	A	HB	Q
D	6 h/160° C.	342	266	15.0	119	518
D	10 h/170° C.	358	309	11.2	124	515
E	16 h/170° C.	378	322	11.6	132	538
F	16 h/170° C.	388	319	9.3	132	533

[0056] Firstly, it was observed that the alloy D without any copper and with 4% silicon has better ultimate tensile strength and better elongation, and therefore a substantially improved quality index, than alloy A in example 1 with 7% of silicon.

[0057] It is also observed that with copper alloys and ageing according to the invention, the ultimate tensile strength, the yield strength and the quality index are all improved compared with the copper free alloy, due to the fact that elongation does not reduce, and even increases slightly, which is contrary to what would have been expected.

Example 3

[0058] Alloys E and F in example 2 were replaced by alloys E' and F' with the same composition except for iron, and the iron content of these two alloys was modified to 0.18 and 0.16% respectively. With the same heat treatment comprising 16 h ageing at 170° C., the elongations A obtained were equal to 7.5% and 6.8% respectively, representing reductions of 35% and 27% respectively.

1. Safety part with high mechanical strength and good ductility, cast from an Al—Si alloy with the following composition (% by weight):

Si 2-11; Mg 0.3-0.7; Cu 0.3-0.9; other elements <1 each and <2 total, remainder aluminium,

and solution heat treated, quenched and aged to give a hardness of more than 125 Brinell.

2. Safety part according to claim 1, characterised in that the Mg content is between 0.5 and 0.7%.

3. Safety part according to claim 1 or 2, characterised in that the Cu content is between 0.3 and 0.6%.

4. Safety part according to one of claims 1 to 3, characterised in that the Ti content is between 0.05 and 0.3%.

5. Safety part according to one of claims 1 to 4, characterised in that the iron content is less than 0.15%, and preferably less than 0.12%.

6. Safety part according to one of claims 1 to 5, characterised in that it contains at least one element modifying or refining the eutectic such as sodium (with a content of between 0.001 and 0.020%), strontium (between 0.004 and 0.050%) and antimony (between 0.03 and 0.30%).

7. Safety part according to one of claims 1 to 6, characterised in that the Si content is between 2 and 7%.

8. Safety part according to claim 7, characterised in that it is cast using one of the following casting processes: casting in the semi-solid state (thixocasting), squeeze casting, casting followed by forging or stamping, casting with lost foam models under isostatic pressure, vacuum die casting, and casting followed by hot isostatic compaction (HIP).

9. Safety part according to one of claims 1 to 6, characterised in that the Si content is between 7 and 11%.

10. Safety part according to claim 9, characterised in that it is moulded using a casting process with a high solidification rate, such that the spacing between dendrite arms is less than 20 μm.

11. Safety part according to one of claims 1 to 10, characterised in that ageing is done within the 170-190° C. temperature range for a duration of between 4 h and 20 h.

12. Safety part with high mechanical strength and good ductility, cast from an Al—Si alloy with the following composition (% by weight):

Si 2-6; Mg 0.3-0.7; Fe <0.20; other elements <0.3 each and <1 total, remainder aluminium,

and solution heat treated, quenched and aged to give a quality index $Q=R_m+150 \log A>485$ MPa.

13. Safety part according to claim 12, characterised in that the Mg content is between 0.45 and 0.65%.

14. Safety part according to claim 12 or 13, characterised in that the Ti content is between 0.05 and 0.3%.

15. Safety part according to one of claims 12 to 14, characterised in that the iron content is less than 0.15%, and preferably less than 0.12%.

16. Safety part according to one of claims 12 to 15, characterised in that it contains at least one element modifying or refining the eutectic such as sodium (between 0.001 and 0.020%), strontium (between 0.004 and 0.050%) and antimony (between 0.03 and 0.30%).

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