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(54) **MULTICOMPONENT ALUMINIUM CASTING ALLOY**

(57) Aluminium casting alloy comprising 9.0-11.5% by weight of magnesium, 4.5-7.0% by weight of silicon, 3.2-6.5% by weight of copper, 0.15-0.40% by weight of iron, 0.15-0.40% by weight of manganese, less than 0.4% by weight of zinc, less than 0.25% by weight of

titanium, less than 0.15 of any other alloy element, and aluminium as a balance, with the proviso that the content of Fe is equal to or lower than the content of Mn. And a process for thermally treat said alloy and a method for obtaining it.

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Description**FIELD OF THE INVENTION**

[0001] The invention is related to aluminium casting alloys. Specifically, the present invention relates to a multi-component aluminium based AlMgSiCu alloy useful to produce, preferably by high-pressure die casting (HPDC), components or parts that fulfils the premium mechanical and abrasion resistance requirements of the automotive industry at room temperature and at high temperatures (in particular, up to 200°C).

BACKGROUND ART

[0002] Aluminium casting alloys (i.e., aluminium alloys used for manufacturing parts or components by casting) are broadly used in the automotive industry.

[0003] Among casting techniques already known in the art, the high-pressure die casting process (HPDC) has been dramatically expanded to new applications in the last twenty years due to its low cost-per-produced component ratio, high component reproducibility, and reliability. However, components obtained by HPDC have been traditionally limited to applications in which their structural functionality was of low responsibility, whereas components with key structural responsibility have been traditionally manufactured with steel or aluminium alternative production processes such as low-pressure die casting (LPDC) or gravity die casting (GC).

[0004] Some well-known parts or components of the automotive industry that must fulfil abrasion requirements are, among others, piston cylinders, brake discs, or steering boxes. Brake discs and piston cylinders must support not only abrasion but also thermal fatigue resistance, and if aluminium is employed instead of steel, hypereutectic aluminium alloys have been traditionally applied to produce automotive components by GC. Hypereutectic Al alloys present primary silicon grains that are normally refined with phosphorous and T5 thermal treated to resist abrasion. Nickel is the most important alloying element of those alloys, with also copper and dissolute zinc, to keep mechanical properties at high temperatures.

[0005] However, hypereutectic aluminium alloys are not so well suited for room temperature applications (in particular, steering boxes), since they do not fulfil the required hardness (above 115-120 HB), nickel is superfluous and phosphorous is so volatile that requires the alloy to be melt, which must be held at temperatures above 750°C.

[0006] To expand the application of the HPDC process, besides the HPDC technological development (Gigapress, vacuum casting, improved mold materials, thermal management, etc.), new alloys with new metallurgical and micro-structural properties should be developed. Said alloys must present high fluidity to fill the whole mold conveniently, low die soldering, easy weldability, high machinability and above all, high elongation and mechanical properties.

[0007] Alloys of primary quality with a Fe/Mn ratio of $\frac{1}{2}$ have been disclosed in the prior art. These alloys decrease die soldering and reduce as much as possible the negative effect of β -Al₅FeSi intermetallics on the elongation values. Primary quality means mainly iron content below 0.15% by weight, copper content below 0.03% by weight, and zinc content below 0.1% by weight, being those contents only achievable if aluminium is directly produced by smelting electrolysis from raw alumina. Refined aluminium produced from scraps, drosses, and chips coming from post-processing operations and end-of-life products is hence generally limited to low mechanical responsibility applications, which is a large limitation for the industry sustainability and aluminium recycling sector. Finally, the casted component made of primary aluminium can be thermally treated if desired, to reach mechanical properties like those produced in alternative manufacturing processes such as the LPDC or the GC.

[0008] Some alloys of the AlMg family have been later developed to eliminate thermal treatments, but always with a common characteristic, i.e., keeping very low percentages of impurity elements such as iron, copper, and zinc among others, only achievable by primary alloys, or with low percentages of premium scraps.

[0009] Other alloys have been later developed to eliminate the thermal treatments, such as those belonging to the AlZn families, which after 1 week of natural aging reach hardness values close to 120 HB. Unfortunately, the main disadvantage of these alloys is that quality requirements are only achievable by primary alloys, and in comparison, not heat-treated or as-cast alloys show smaller elongation values.

[0010] As previously mentioned, HPDC is preferred to other casting techniques such as GC due to its low cost for big series, high component reproducibility and reliability. Unfortunately, typical harnesses of hypoeutectic aluminium alloys used in HPDC lie on values around 80-100 HB, which is still below the values required for abrasion applications in the automotive industry. Therefore, when producing steering boxes, a steel sleeve is usually placed on the internal surface of the box to accommodate the steering shaft. Both shaft and box are typically AlSi₉Cu₃ as cast components produced by HPDC, and even the addition of an additional step (sleeve placement) is worth it when compared with expensive GC production with hypereutectic alloy with a T5 thermal treatment.

[0011] Depending on the process employed to produce a part or component (for example, sand, permanent mould casting, high pressure die casting (HPDC) or investment casting), the mechanical properties may change completely, as shown in the DIN 1706 Standard. Annex A of standard EN AC 43000 series discloses the mechanical properties of

pressure die-cast alloys (Table A.1 - Mechanical properties of pressure die-cast alloys).

[0012] A number of aluminium casting alloys and, in particular, die casting, have been disclosed in the art. For instance, patent application EP1612286 A2 discloses an aluminium die-casting alloy having 8 to 11.5% by weight of Si, 0.3 to 0.8% by weight of Mn, 0.08 to 0.4% by weight of Mg, max. 0.4% by weight of Fe, max. 0.1% by weight of Cu, max. 0.1% by weight of Zn, max. 0.15% by weight of Ti and 0.05 to 0.5% by weight of Mo. Thus, Cu and Zn content have been limited and, therefore, the content of secondary aluminium is very restricted, which leads to the production of the alloy by electrolysis.

[0013] Patent application US5573606 A discloses an aluminium based alloy comprising, among others, 2.7 to 4.0% by weight of Mg, and a Si content limited to less than 0.45% by weight, preferably of 0.2 to 0.45% by weight.

[0014] DE19524564 A1 discloses an aluminium-silicon alloy for casting cylinder heads, wherein said alloy comprises 5.0-11.0 wt.% of Si and 0.8-2.0 wt.% of Cu. In preferred embodiments, the amount of Si is of 8.0 to 11.0 wt.%. This document is silent about the obtained mechanical properties of the alloy, and it doesn't mention the HPDC process.

[0015] European patent application EP1978120 A1 discloses an aluminium-silicon casting alloy for engine components which comprises 5 to 25% by weight of Si and 0.0007 to 0.1 % by weight of C. More specifically, the aluminium-silicon alloy of this document comprises 5 to 25% by weight of silicon and 0.0007 to 0.1% by weight of carbon and up to 4% by weight of at least one of the following and in total up to 10% by weight of the following alloy components: magnesium, manganese, iron, cobalt, copper, zinc, nickel, vanadium, niobium, molybdenum, chromium, tungsten, beryllium, lead, lithium, yttrium, cerium, scandium, hafnium, silver, zirconium, titanium, boron, strontium, sodium, potassium, calcium, antimony, sulfur, barium, phosphorus and the remainder at least 65% by weight of aluminium including unavoidable impurities. In this patent application, there are no references to the HPDC process. All the samples disclosed in this document have Si values with a eutectic or hypereutectic composition.

[0016] Secondary aluminium alloys (i.e., aluminium alloys obtained from recycled materials) disclosed in the prior art have limited elongation properties due to the presence of detrimental β -iron Al_5FeSi needles. The prior art discloses different ways of suppressing the formation of β - Al_5FeSi phase such as the addition of sufficient manganese or, in alloys without manganese, high cooling rates. Another way to avoid this problem is based on the development of primary aluminium alloys with small percentages of iron, as the "Aural" alloys which comprises approximately less than 0.22% by weight of iron and less than 0.03% by weight of copper. It has also been disclosed other alloys with high elongation which have less than 0.2% by weight of iron content. It has also been disclosed limiting the silicon content of primary aluminium alloys to a maximum of 0.15% in weight to obtain high elongation alloys.

[0017] European patent application EP2771493 A2 refers to an AlSiMgCu casting alloy. More specifically, this document discloses an aluminium based alloy comprising 0.5-2% by weight of copper and, additionally, discloses the use of thermal treatments. According to this patent application, an increase of Cu content can increase the strength due to higher amounts of θ' - Al_2Cu and Q' precipitates, but reduce the ductility. This patent application aims to optimize the alloy composition, the solution, and aging heat treatments to minimize/eliminate un-dissolved Q-phase (AlSiMgSi) and maximize solid solution/precipitation strengthening.

[0018] Patent document JPH093610 (A) refers to a die-casting alloy having 5 to 13 wt.% Si, up to 0.5 wt.% Mg, 0.1 to 1.0 wt.% Mn, and 0.1 to 2.0 wt.% Fe. Cu and Zn are not taken into consideration, as these contaminants usually occur in significant amounts in the case of secondary aluminium. According to this document, thermal treatments are necessary to improve ductility because eutectic Si becomes roundish by heat treatment.

[0019] European patent application EP2657360 A1 discloses a die-casting Al-Si alloy containing 6-12% by weight of Si, at least 0.3% by weight of iron, at least 0.25% by weight of Mn, at least 0.1% by weight of Cu, 0.24 to 0.8% by weight of Mg and 0.4 to 1.5% by weight of Zn, wherein the total proportion of Fe and Mn in the alloy is 1.5% by weight, the weight percentage ratio of Fe and Mn is 0.35 to 1.5 and the weight percentage ratio of Cu and Mg is 0.2 to 0.8. This patent application discloses the use of eutectic modifiers, as Sr, Na, and Sb, alone or in combination, and grain refiners as Ti, Zr, V.

[0020] European Patent EP3342890 B1 discloses an Al-Si casting alloy for HPDC having enhanced tensile and yield strength whilst also having a high level of elongation. Said alloy consist of 11.5 to 12% by weight of Si, 0.3 to 1% by weight of Fe, 0.05 to 0.4% by weight of Cu, less than 0.75% by weight of Mn, less than 0.35% by weight of Zn, 0.45 to 0.8% by weight of Mg, less than 0.3% by weight of Ti, 0.05 to 0.2% by weight of Cr, less than 0.3% by weight of Ni, less than 0.05% by weight of Pb, less than 0.05% by weight of Sn, and aluminium the remainder. According to the disclosure of this patent, an increase in the Zn percentage led to lower corrosion resistance, and because of that, the Zn percentage was limited to less than 0.35% by weight according to the invention therein provided, to obtain parts that don't need extra surface treatments. Also, the alloy according to that invention has high ductility.

[0021] European patent application EP2653579 A1 discloses an Al-Si casting alloy having enhanced tensile and yield strength whilst also having a high level of elongation. The disclosed alloy is intended for use in the manufacture of structural parts for the automotive industry. Said aluminium alloy contains 9 to 11.5% by weight of Si, 0.5 to 0.8% by weight of Mn, 0.2 to 1.0% by weight of Mg, 0.1 to 1.0% by weight of Cu, 0.2 to 1.5% by weight of Zn, 0.05 to 0.4% by weight of Zr, 0.01 to 0.4% by weight of Cr, not more than 0.2% by weight of Fe, not more than 0.15% by weight of Ti, 0.01 to 0.02% by weight of Sr and as balance aluminium and production-related impurities up to a total of not more than 0.5% by weight.

[0022] PCT application published as WO2006/066314 A1 describes a process for the thermal treatment of parts

produced by high pressure die casting (HPDC). According to this document, the solution time is reduced to less than 30 minutes which can allow the improvement of mechanical properties for all the parts manufactured by HPDC. The described alloy has 4.5 to 20 wt. % Si, 0.05 to 5.5 wt. % Cu, 0.1 to 2.5 wt. % Fe, 0.01 to 1.5 wt. % Mg, optionally at least one of Ni up to 1.5 wt. %, Mn up to 1 wt. % and Zn up to 3.5 wt. %, and a balance of aluminium and incidental impurities. In WO2006/0066314 A1 alloys, the high percentage of Ni can be related to the development of a new thermal treatment for the alloys. Nickel is commonly used with copper to enhance elevated temperature properties. It also reduces the thermal expansion coefficient. Nickel is characterized by low solubility in aluminium (maximum 0.01 to 0.03% by weight) and does not form supersaturated solid solutions even after relatively rapid solidification. Their introduction into aluminum alloys always causes the formation of excessive phases (constituent particles) that often reduce formability and corrosion resistance. For this reason, in many cases, this element is undesirable as an alloying element. However, the refractory alloying elements and aluminides of nickel are very beneficial for improving the alloy's thermal stability, so when this property is the most important, Ni can be used as an alloying element. Using high-temperature heat treatments it is possible to spheroidize these eutectic particles (similar to silicon), in which case their negative influence upon formability and elongation is practically neutralized.

[0023] In the last years, new alloys have been developed. High Entropy Alloys (HEAs), Medium High Entropy Alloys, multiphase HEA alloys, multicomponent alloys, and similar provide a new paradigm, as they differ from conventional alloys in entropy-based mixing logic of various elements, which is different from the solvent/solute model. HEAs offer the opportunity to move out of the strength-ductility curve as well as the opportunity to increase the alloy's modulus. Normally these High Entropy Aluminium alloys (HEAl) are produced with pure or near pure alloying elements, with melting processes that employ several melting and remelting steps to homogenize the alloy and vacuum furnaces, improving some properties, but with high fragility and low elongation values in general.

[0024] It is well known that previously known die-cast aluminium alloys lose their mechanical strength abruptly at 150°C and above, so they cannot be used in applications at 150-200°C. Consequently, more expensive alloys are required for these temperatures, usually manufactured by lost wax casting. Timelli et al. (Design of Wear-Resistant Diecast AlSi9Cu3(Fe) Alloys for High-Temperature Components, Metals 2020, 10(1), 55; <https://doi.org/10.3390/met10010055>) showed that the most employed HPDC alloy, the AlSi₉Cu₃, had a drastic decrease in the Brinell hardness values with temperature, especially at 200°C, with Brinell hardness values of about 70 HB at 200°C (see figure 1). They appointed that the presence of higher amounts of Fe, Cr, and Mn increased the hardness values of the AlSi₉Cu₃(Fe) alloys.

[0025] In view of the foregoing, there is a need to develop a novel aluminium-based alloy and, more specifically a secondary aluminium based alloy, which can be obtained by HPDC and present the required mechanical properties, elongation and/or wear resistance to be used in structural and/or abrasive applications, in particular in the automotive industry, both at room temperature and at high temperatures (in particular, up to 200°C).

DESCRIPTION OF THE INVENTION

[0026] The present invention provides a novel aluminium casting alloy, preferably a secondary aluminium casting alloy, which can be obtained by HPDC, in particular by the method described in this document. This aluminium casting alloy is a multicomponent AlMgSiCu alloy, more specifically a multicomponent Al₈₀Mg₁₀Si₅Cu₅ alloy, which can be used directly as-cast or, alternatively, it can be used after being thermally treatment, preferably by a post-casting thermal treatment as described herein.

[0027] Thus, an object of the present invention refers to an aluminium casting alloy, wherein said alloy comprises:

- 9.0-11.5% by weight of magnesium,
- 4.5-7.0% by weight of silicon,
- 3.2-6.5% by weight of copper,
- 0.15-0.40% by weight of iron,
- 0.15-0.40% by weight of manganese,
- less than 0.4% by weight of zinc,
- less than 0.25% by weight of titanium,
- less than 0.15% by weight of any other alloying element, and
- aluminium as balance,

with the proviso that the content of Fe is equal to or lower than the content of Mn.

[0028] The aluminium casting alloy of the invention can be obtained by high pressure die casting (HPDC), a casting process broadly known in the art to produce aluminium based components with reduced cost and, at the same time, high reproducibility and reliability.

[0029] Said aluminium casting alloy provides a great advantage over other previously known alloys due to its high mechanical properties and wear resistance, which can be maintained at high temperatures (up to 200°C). As a

consequence, the aluminium casting alloy of the invention can be used in abrasive applications, in particular in the automotive industry, both at room temperature and at high temperatures (in particular, up to 200°C).

[0030] In the context of this invention, it should be understood that room temperature refers to the temperature around an object, either inside or outside a building or the like, which this expression is referring to, in particular a part or component of the aluminum casting alloy of the invention. Typically, this temperature may range of -40°C to 50°C, preferably of -10°C to 40°C, more preferably of 15°C to 35°C, and even more preferably of 20°C to 30°C.

[0031] Besides, the thermally treated aluminium casting alloy as described in this document also presents a high elongation (in particular, equal to or higher than 1 % at 25°C and/or 200°C, measured after the tensile test according to the UNE-EN ISO 6892-1:2020 B standards) which makes this alloy particularly useful to support simultaneously high abrasion and high static bending/torsion loads, while maintaining a minimum ductility and other desired processing properties such as alloy fluidity, low die soldering, easy welding, or high machinability.

[0032] Another significant advantage of the aluminium casting alloy of the invention is that it can be at least partially obtained from recycled aluminium based materials such as, for example, but not limited to, scraps, drosses or chips from post-processing operations or end-of life products. Thus, the present invention also provides a secondary aluminium alloy obtained by HPDC with the required properties to be used in parts or components having structural and/or abrasive functions in the automotive industry.

[0033] Magnesium is a key element to maximize the hardness and mechanical properties of the aluminium casting alloy of the invention. Magnesium content must be coupled with the silicon and copper content as defined in this document to form Mg_2Si and Al_2CuMg , while avoiding the presence of primary silicon or Al_2Cu in the thermally treated alloy. The desired performance of the alloy can be achieved when the magnesium content is of 9.0% by weight to 11.5% by weight, preferably of 9.0-10.5% by weight, more preferably of 9.0-10.0% by weight, and even more preferably of 10.0% by weight, all amounts expressed as weight of magnesium with respect to the total weight of the aluminium casting alloy.

[0034] Silicon is another key element in the aluminium casting alloy of the invention. The content of this alloying element is restricted to the range 4.5-7.0% by weight, preferably 4.5-5.7% by weight, amounts expressed as weight of silicon with respect to the total weight of the aluminium casting alloy. This silicon content provides high fluidity, especially for thin wall castings and, due to the combination with Mg, reduces the primary Si eutectic fraction as much as possible, which helps to maximize the elongation while maintaining the fluidity at minimal values that allow an adequate mold filling. Thus, the specific combination of Mg and Si in the ranges defined in this document gives rise to the formation of Mg_2Si precipitates, so that the single presence of primary Si that could decrease the elongation and wearing resistance can be avoided.

[0035] The aluminium casting alloy of the invention comprises 3.2-6.5% by weight, preferably 4.5-6.5% by weight and more preferably 4.5-5.0% by weight of copper, wherein said amounts are expressed as weight of copper with respect to the total weight of the aluminium casting alloy. This content of copper is required to guarantee a minimum elastic yield and ultimate tensile strength and to obtain the required hardness above 105 HB, preferably equal to or higher than 115 HB. The combination of Cu with Al and Mg forms Al_2CuMg and Al_2Cu precipitates in the aluminium alloy as cast. According to simulations by FACTSAGE, the inventors found that the presence of Al_2Cu was expected for aluminium alloys having a low amount of Cu, but it was completely unexpected for aluminium alloys having a content of Cu as high as the aluminium casting alloy of the invention. Without being bound or limited to any theory, it is thought that the unexpected presence of very fine and homogeneous distributed Al_2Cu precipitates in the as cast alloy of the invention has an important role in the mechanical and wearing properties at high temperatures (in particular, up to 200°C). Said Al_2Cu precipitates are transformed to Al_2CuMg due to the post-casting thermal treatment, but the small size and homogenous distribution of the former Al_2Cu phase is maintained in the new Al_2CuMg formed and, consequently, the mechanical and wearing properties at high temperatures (in particular, up to 200°C) are maintained or even improved.

[0036] This high content of copper in the aluminium casting alloy of the invention is also advantageous because it allows the use of recycled materials such as scraps, drosses and chips from post-processing or end-of-life products in the manufacturing of casted components or parts comprising said aluminium alloy.

[0037] In preferred embodiments, the amount of Mg, Si y Cu in the aluminium casting alloy described herein is adjusted within the established limits, so that about 100 % of each of these elements can be present in the form of Mg_2Si and, after the post-casting thermal treatment, Al_2CuMg . In this way, the presence of primary silicon can be reduced and, as a result, the fraction of eutectic Si can also be reduced, thus improving elongation and wear resistance of the aluminium casting alloy of the invention.

[0038] Iron can also play a key role in the mechanical properties of the aluminium casting alloy of the invention and hence its content has been limited to 0.15-0.40% by weight with respect to the total weight of the aluminium casting alloy, preferably of 0.25-0.40% by weight. Said range contents allow both low mould soldering and a small volume fraction of Al_5FeSi intermetallics, which can be minimized by a manganese content of 0.15 % to 0.40 % by weight, preferably of 0.25-0.40% by weight. Said iron and manganese content may help to achieve an elongation equal to or higher than 1% at 25°C and/or 200°C (measured after the tensile test according to the UNE-EN ISO 6892-1:2020 B standards) in the post-casting thermal treated alloy as described in this document.

[0039] In the aluminium casting alloy of the invention, manganese content is restricted to 0.15-0.40% by weight with the

proviso that the content of Fe is equal to or lower than the content of Mn. In this way, the sludge problem that may occur when high percentages of Mn in combination with Fe and other alloying elements are present can be avoided and, additionally, the Al_5FeSi intermetallics can be transformed into $\alpha\text{-Al}_{12}(\text{Mn,Fe})\text{Si}_2$, thus reducing the negative effect of those intermetallics.

[0040] Additionally, the combination of Mn and Fe in the ranges herein specified are particularly useful in reducing mould soldering, which represent an important advantage in manufacturing components or parts of the aluminium casting alloy of the invention by HPDC.

[0041] In the aluminium casting alloy of the invention, Zn content is restricted to less than 0.4% by weight to avoid the presence of low melting point phases as the MgZn or Mg_7Zn_3 phases, which can reduce the mechanical and wearing properties at 200°C. An increase in the Zn percentage leads to a lower corrosion resistance, and because of that, the Zn percentage has been limited in the alloy according to the invention.

[0042] In preferred embodiments of the invention, the aluminium casting alloy comprises zinc in a minimum amount of 0.05% by weight, preferably the content of Zn is of 0.20-0.40% by weight, expressed as weight of zinc with respect to the total weight amount of the aluminium casting alloy. A minimum amount of 0.20% by weight of Zn can improve the mechanical properties of the alloy by the solid solution of Zn into the aluminium matrix. Also, these range amounts of Zn allow the use of complex scraps containing Zn in the elaboration of the alloy, avoiding or at least reducing the use of primary alloys.

[0043] In the aluminium casting alloy of the invention, Ti content is restricted to less than 0.25% by weight to avoid the presence of TiAl_3 acicular type precipitates that can reduce the mechanical and wear properties at room temperature and at 200°C. Values of titanium above 0.25% by weight were found to allow the formation of new low-point melting phases.

[0044] In particular embodiments of the invention, the aluminium casting alloy comprises titanium in a minimum amount of 0.10% by weight, preferably the Ti content is of 0.10-0.25% by weight, expressed as weight of zinc with respect to the total weight amount of the aluminium casting alloy. A minimum amount of 0.10% by weight of Ti can improve the mechanical properties of the alloy by refining the aluminium matrix. Also, these range amounts of Ti allows the use of complex scraps containing Ti in the elaboration of the alloy, avoiding or at least reducing the use of primary alloys.

[0045] The amount of any other alloying element that might be comprised in the aluminium casting alloy of the invention is restricted to less than 0.15% by weight with respect to the total weight of the aluminium casting alloy, preferably less than 0.10% by weight. Thus, the formation of complex precipitates that could decrease the mechanical and wear properties can be avoided, but also secondary alloys and complex scraps can be used in the manufacture of the aluminium casting alloy of the invention.

[0046] In preferred embodiments of the invention, the aluminium casting alloy herein described may comprise:

9.0-10.5% by weight of magnesium,
4.5-5.7% by weight of silicon,
4.5-6.5% by weight of copper,
0.20-0.40% by weight of iron,
0.20-0.40% by weight of manganese,
0.20-0.40% by weight of zinc,
0.10-0.25% by weight of titanium,
less than 0.15% by weight of any other alloying element,
aluminium as balance,
with the proviso that the content of Fe is equal to or lower than the content of Mn.

[0047] In more preferred embodiments of the invention, the aluminium casting alloy herein described may comprise:

9.0-10.0% by weight of magnesium,
4.5-5.7% by weight of silicon,
4.5-5.0% by weight of copper,
0.20-0.40% by weight of iron,
0.20-0.40% by weight of manganese,
0.20-0.40% by weight of zinc,
0.10-0.25% by weight of titanium,
less than 0.15% by weight of any other alloying element,
aluminium as balance,
with the proviso that the content of Fe is equal to or lower than the content of Mn.

[0048] The aluminium casting alloy of the invention preferably have a Brinell Hardness (HB), measured either at 25°C or at 200°C, higher than 105 HB, more preferably equal to or higher than 115 HB, and even more preferably equal to or higher

than 120 HB. An important advantage of the aluminium casting alloy of the invention is that this hardness can be maintained up to 200°C.

[0049] In those embodiment of the invention wherein the aluminium casting alloy is as cast (i.e., without post-casting thermal treatment) the Brinell Hardness may be equal to or higher than 125 HB, measured both at 25°C and 200°C, and, in some preferred embodiments, the Brinell Hardness measured at 25°C may be equal to or higher than 150 HB.

[0050] The Brinell Hardness (HB) can be measured, either at 25°C or at 200°C, in plate specimens with 5 mm thickness, using the Vickers diamond indentation test (FV-700, Vickers Indenter, Leica) with a load of 3kg for 10 s according to UNE-EN ISO 6507-1 standard.

[0051] According to this invention, the aluminium casting alloy preferably has a yield strength (Rp0.2) equal to or higher than 120 MPa, more preferably equal to or higher than 200 MPa. Different to other aluminium casting alloys which lost its mechanical strength at a temperature of 150°C, the aluminium casting alloy according to the invention is able to maintain this yield strength (Rp0.2) even at 200°C.

[0052] The yield strength (Rp0.2) can be measured, either at 25°C or at 200°C, according to the UNE-EN ISO 6892-1 B:2010 standard.

[0053] Additionally, or alternatively to the above-mentioned Brinell Hardness (HB) and/or yield strength (Rp0.2), the aluminium casting alloy of the invention preferably has an ultimate tensile strength (Rm) equal to or higher than 220 MPa, more preferably equal to or higher than 300 MPa. Different to other aluminium casting alloys which lost its mechanical strength at a temperature of 150°C, the aluminium casting alloy of the invention is able to maintain an ultimate tensile strength (Rm) equal to or higher than 220 MPa even at 200°C.

[0054] The ultimate tensile strength (Rm) can also be measured, either at 25°C or at 200°C, according to the UNE-EN ISO 6892-1:2020 B standard.

[0055] Another important advantage of the aluminium casting alloy of the invention is that it preferably has a reduced wear rate coefficient compared to AlSi₉Cu₃ alloys, the most employed HPDC alloy up to date.

[0056] Thus, in particularly preferred embodiments, the aluminium casting alloy of the invention is characterized by having, measured at 25°C or at 200°C, the following properties:

- Brinell Hardness (HB) higher than 105 HB, preferably equal to or higher than 115 HB, measured according to UNE-EN ISO 6507-1 standard;
- Yield strength (Rp0.2) equal to or higher than 120 MPa, measured according to the UNE-EN ISO 6892-1:2020 B; and/or
- Ultimate tensile strength (Rm) equal to or higher than 220 MPa, measured according to the UNE-EN ISO 6892-1:2020 B standard.

[0057] Additionally, or alternatively to the above-mentioned mechanical and wearing properties, the thermally treated aluminium casting alloys of the invention, in particular those treated according to the post-casting thermal treatment described herein, preferably present an elongation equal to or higher than 1%, more preferably equal to or higher than 3%, measured at 25°C and/or 200°C, after the tensile test according to the UNE-EN ISO 6892-1:2020 B standards.

[0058] Without being bound or limited by any particular theory, it is thought that the above-mentioned properties are due to the formation of a very fine eutectic phases (Mg₂Si, Al₂Cu/Al₂CuMg), the semi-globular shape of the dendrites, the absence of fragile β-Al₅FeSi iron needles, and the presence of labyrinthine Al₁₅(Fe,Mn,Cr)₃Si₂ in the HPDC parts due to the combination of the different elements with the iron and, additionally, a good distribution of Mg₂Si. There are also very few micro-porosities in studied HPDC, probably related to the near eutectic composition of obtained parts.

[0059] The content of the alloying elements in the aluminium casting alloy according to the invention is related to the mechanical properties of said alloy. These mechanical properties can be adjusted with small changes in the composition of the alloy as described herein. This can be seen in the alloys of the example, which show changes of the properties with minor composition variations.

[0060] Another object of the present invention refers to a thermal treatment process for modifying properties (in particular, mechanical properties, wear resistance coefficient and/or elongation) of an aluminium casting alloy, preferably an aluminium alloy obtained by HPDC, having the composition as described in this document. Since this thermal treatment is performed once the component or part with the established composition according to the invention has been cast, the method herein provided is also referred to in this document as "post-casting thermal treatment process".

[0061] Thus, the present invention also provides a thermal treatment process comprising the following steps:

- a) thermally treating an aluminium casting alloy having the composition as described in this document (also referred to herein as aluminium alloy "as cast") at a temperature of 370°C to 470°C for a period of 24 hours to 72 hours, preferably at a temperature of 400°C to 460°C for a period of 18 hours to 28 hours, more preferably at a temperature of 410°C to 440°C for a period of 18 hours to 28 hours; and
- b) contacting the treated aluminium casting alloy of step a) with a quenching media, preferably water at a temperature

of 45°C to 80 °C.

[0062] The thermal treatment of step a) allows solute elements of the alloy to be taken into solid solution and, therefore, it is also referred to in this document and in the art as "solution treatment".

[0063] The quenching media may be any media suitable for a quick but not very severe cooling the thermally treated alloy of step a). Preferably, hot water at a temperature of 45°C to 80 °C, preferably about 75°C, is used as quenching media in step b) of the post-casting thermal treatment process herein described, since it can reduce internal stresses.

[0064] In preferred embodiments of the invention the thermal treatment process herein described further comprises an additional step c) of artificial aging at a temperature of 150°C to 250°C for a period of 2 hours to 8 hours, preferably at a temperature of 180°C to 230°C for a period of 3 hours to 5 hours.

[0065] In other preferred embodiments of the invention, the thermal treatment process herein described further comprises an additional step c') of natural aging at room temperature for a period of about 1 week. According to these embodiments, the thermally treated alloy can be stored for the required period of time indoor or outdoor.

[0066] This thermal treatment process allows for customizing the alloy properties, so that aluminium casting alloys with a combination of very high yield strengths, ultimate tensile strength, elongation, and hardness can be obtained.

[0067] Other object of the invention refers to a method for obtaining an aluminium casting alloy as described in this document, wherein said method comprises:

i) obtaining a molten metal mixture having the composition of the aluminium casting alloy as described in this document;

ii) high pressure die casting of the molten metal mixture of step i) thereby obtaining an aluminium casting alloy (also referred to as aluminium alloy "as cast" in this document); and

iii) optionally, thermally treating the aluminium casting alloy of step ii) by the thermal treatment process as described in this document thereby obtaining a thermally treated aluminium casting alloy.

[0068] Step i) of the method of the invention can be carried out by heating the required charge materials to obtain an alloy with the desired composition according to the invention at a temperature suitable for providing a complete molten mixture, preferably at a temperature of 630°C to 750°C. In particular embodiments of the invention, at least part of these charge materials are recycled materials such as, for example, but not limited to, scraps, drosses or drips from post-processing operations or end-of-life products.

[0069] The high pressure die casting (HPDC) process of step ii) can be done by adjusting the temperature of the molten mixture of step i) between 630°C and 750°C, followed by injecting the molten metal at the required temperature into a metal die at a temperature of 620°C to 750°C with a die temperature of 150°C to 400°C. Once solidified, the aluminium alloy casting parts thereby obtained (aluminium alloy "as cast") may be cold at a room temperature or, alternatively, it may be thermally treated according to the thermal treatment process described in this document.

[0070] A further object of the present invention refers to the aluminium casting alloy obtained or obtainable by either the thermal treatment process or the method as described in this document.

[0071] Besides, the present invention also refers to the use of the aluminium casting alloy described in this document in the automotive industry, preferably for manufacturing parts or components to be used in structural applications such as shock towers or b-pillars. More preferably, the aluminium casting alloy of the invention can be used for manufacturing parts or components that must fulfil abrasion requirements such as, for example but not limited to, piston cylinders, brake discs, or steering boxes.

BRIEF DESCRIPTION OF DRAWINGS

[0072]

Figure 1. Variation of Brinell hardness values with the sludge factor and temperature for $\text{AlSi}_9\text{Cu}_3(\text{Fe})$ alloys (prior art). In Figure 1 it can be observed the decrease of the Brinell hardness at 150°C and 200°C with different AlSi_9Cu_3 alloy compositions (not part of the invention) and the effect of the sludge factor percentage in weight.

Figure 2. XRD analysis of as-cast $\text{Al}_{50}\text{Mg}_{10}\text{Si}_5\text{Cu}_5$ alloy according to the invention (also referred to as "Alloy 2 as cast" in this document). Mg_2Si (circle), Al (triangle), CuAl_2 khatyrkite (square) and Al_2CuMg (rhomboid).

Figure 3. XRD analysis of heat-treated $\text{Al}_{50}\text{Mg}_{10}\text{Si}_5\text{Cu}_5$ alloy according to the invention (also referred to as "Alloy 2 TT" in this document). Mg_2Si (circle), Al (triangle), CuAl_2 khatyrkite (square) and Al_2CuMg (rhomboid).

Figure 4. SEM images (x400) corresponding to the surface cast layer (fig. 4a)) and inner area (fig. 4b) of a sample of

the as-cast $\text{Al}_{50}\text{Mg}_{10}\text{Si}_5\text{Cu}_5$ alloy according to the invention (also referred to as "Alloy 2 as cast" in this document).

[0073] According to Fig 4a, Al, Al_2CuMg and primary Mg_2Si are present in the surface cast layer of the aluminium alloy sample, whereas Al, CuAl_2 , primary Mg_2Si , Al_2CuMg and eutectic Mg_2Si are present in the inner area of said tested sample.

[0074] Figure 5. SEM images (x800) corresponding to the surface cast layer (fig. 5a) and inner part (fig. 5b) of a sample of the thermal-treated $\text{Al}_{50}\text{Mg}_{10}\text{Si}_5\text{Cu}_5$ alloy according to the invention (also referred to as "Alloy 2 TT" in this document).

[0075] According to Fig 5a, Al, primary Mg_2Si , Al_2CuMg and eutectic Mg_2Si are present in both the surface cast layer and the inner area of the tested sample.

EXAMPLES

Example 1. Aluminium casting alloys (preparation, composition, and mechanical properties)

[0076] The experimental $\text{Al}_{50}\text{Mg}_{10}\text{Si}_5\text{Cu}_5$ and AlSi_9Cu_3 alloys were manufactured by HPDC, with a 950t injection machine (PT-650, Pretansa). For melting and holding the alloys, an electrical furnace of 500 kg capacity (Dugo EBC, Dugopa) was employed. As charge material, ingots of AlSi_7Mg , AM60B, and AlSi_9Cu_3 alloys were employed, acting as melting bath bases. When the target composition of the specific alloy was obtained, the working temperature was adjusted to 700°C, and the molten metal was injected into the metal die at 680°C and with a die temperature of 250°C. Once solidified, casting parts were extracted and instantly immersed in water at the temperature of 50°C.

[0077] A serial of 50 specimens were produced, for each composition. Specimen dimensions and later mechanical characterization were set and carried out following, respectively, UNE-EN ISO 6892-1:2020 B standards. For the hardness determination, plate specimens with 5 mm thickness have been cast and tested using the Vickers diamond indentation test (FV-700, Vickers Indenter, Leica) with a load of 3kg for 10 s according to UNE-EN ISO 6507-1 standard.

[0078] Some of casting samples were subjected to different thermal treatments to modify the mechanical properties. Thus, different thermal treatments between 380°C and 460°C for 24 hours, followed by water quenching at 75°C and, if applicable natural or artificial aging for 4 hours were performed to obtain comparable results. For the solution and artificial aging treatment, a chamber furnace with radiation heating was employed (LH 60/13, Nabertherm).

[0079] Table 1 below specifies the obtained results for references as-cast, T1, T2, T3 and T4 at the different solubilizing temperatures specified in the table. References as-cast, T1, T2 and T3 correspond to Alloy 1, whereas references T4 correspond to Alloy 2, with their chemical compositions defined in Table 2 (see below).

Table 1

Reference	Solubilizing Temperature (°C)	Aging Temperature (°C)	Yield Strength (Mpa)	Ultimate Tensile Strength (Mpa)	Elongation (%)	Hardness (HB)
As-cast	-	-		316	0.1	156
T1	380	-	184	251	2.15	108
T1R1	380	160	163	223	1.83	117
T1R2	380	190	182	251	2.33	137
T1R3	380	220	180	246	2.50	107
T2	410	-	212	257	2.03	125
T2R1	410	160	196	277	3.10	110
T2R2	410	190	224	283	2.57	109
T2R3	410	220	200	261	2.15	130
T3	440	-	246	310	1.95	136
T3R1	440	160	229	302	3.20	106
T3R2	440	190	272	310	1.70	112
T3R3	440	220	247	302	2.30	118
T4	460	-	252	292	1.30	130

(continued)

Reference	Solubilizing Temperature (°C)	Aging Temperature (°C)	Yield Strength (Mpa)	Ultimate Tensile Strength (Mpa)	Elongation (%)	Hardness (HB)
T4R4	460	200	-	299	0.00	136
T4R3	460	220	237	272	1.45	155
T4R5	460	240	214	206	0.27	95

The mechanical characterization and hardness values reported in this table were measured according to the above-identified measurement methods, whereas the elongation values was measured by comparing the distance between different marks made on the sample to be tested (initially at 50 mm) prior and after the tensile test according to UNE-EN ISO 6892-1:2020 B standards. Results reported in this table were obtained at a temperature of 25°C.

[0080] As it can be observed, small modifications in the temperature of the thermal treatments imply a high variation in the final properties, determining an optimum heat-treatment temperature for tuning the values of a determinate mechanical property. For example, a lower solubilizing temperature promotes smaller yield strength and ultimate tensile strength values. However, with a defined solubilizing temperature, the aging process can increase both values.

[0081] The composition of the different alloys tested (Alloys 1 and 2, as well as comparative Alloy 3) are included in Table 2. In this table, the Alloy 1 and Alloy 2 properties are shown as-cast (according to the process described above) and thermal treated (TT) with the aim to improve the mechanical properties. The thermal treatment involved a solution treatment at 440°C for 72 hours (the residence time was increased to obtain a full solubilization of alloy components), followed by water quenching at 75°C and natural aging for a week. The value of 75°C for water quenching temperature after solution treatment was selected to reduce internal stresses. For the solution treatment, a chamber furnace with radiation heating was employed (LH 60/13, Nabertherm). Alloy 3 corresponds to an AlSi₉Cu₃ alloy for comparative purpose only).

Table 2

	Alloy 1 as-cast	Alloy 1 TT	Alloy 2 as-cast	Alloy 2 TT	Alloy 3
Mg (% by weight)	9.23	9.23	10.32	10.32	0.22
Si (% by weight)	4.69	4.69	5.63	5.63	8.26
Cu (% by weight)	6.12	6.12	4.67	4.67	2.41
Fe (% by weight)	0.38	0.38	0.25	0.25	0.60
Mn (% by weight)	0.34	0.34	0.13	0.13	0.16
Zn (% by weight)	0.39	0.39	0.08	0.08	0.69
Ti (% by weight)	0.10	0.1	0.13	0.13	0.08
Cr (% by weight)	0.01	0.01	0.01	0.01	0.02
Ni (% by weight)	0.03	0.03	0.01	0.01	0.05
Individual impurities	<0.15	<0.15	<0.15	<0.15	<0.15
Al	as balance	as balance	as balance	as balance	as balance
Rm (MPa)	316	302	258	250	311
Rp0.2 (MPa)	-	229	-	226	182
E (%)	0.2	3.2	-	1	4

The mechanical characterization and hardness values reported in this table were measured according to the above-identified measurement methods, and the elongation values was measured by comparing the distance between different marks made on the sample to be tested (initially at 50 mm) prior and after the tensile test according to UNE-EN ISO 6892-1:2020 B standards. Results reported in this table were obtained at a temperature of 25°C.

[0082] Alloys 1 and 2 had yield strength (Rp0.2) values above 226 Mpa and ultimate tensile strength values (Rm) above 250 Mpa and elongation values above 1%.

[0083] The comparison between the Brinell Hardness values at 25°C and at 200°C are shown in Table 3.

Table 3

	25°C	200°C
	HB	HB
Alloy 1 as-cast	156	139
Alloy 1 TT	137	129
Alloy 2 as-cast	136	125
Alloy 2 TT	126	115
Alloy 3	105	65

[0084] It can be observed how Alloy 3 (AlSi_9Cu_3) has very low HB values in comparison with Alloy 1 and Alloy 2, especially at 200°C, where the HB value of Alloy 3 decreases very sharply. In the as-cast condition, Alloy 1 and Alloy 2 according to the invention have the highest HB values (156 and 136 HB at 25°C and 139 and 125 HB at 200°C respectively), with a slight reduction of about 10 HB in the thermal treated (TT) state. It's remarkable the reduced decrease at 200°C of both Alloy 1 and 2 according to the invention.

[0085] The values obtained after the compression test at 25°C and at 200°C are shown in Table 4. The test was stopped at room temperature around 600 Mpa, due to the limitations of the test machine, and cracks were not observed.

Table 4

Reference	25°C			200°C		
	Rp0.2 (MPa)	Rm (MPa)	E (%)	Rp (MPa)	Rm (MPa)	E (%)
Alloy 1 as-cast	-	645	11.7	No data	No data	No data
Alloy 2 as-cast	235	531	11.1	251	487	18.5
Alloy 2 TT	217	665	28.2	211	468	25.3

The mechanical characterization reported in this table were measured according to UNE-EN ISO 6892-1 B:2010 standards. In particular, the elongation values were measured by comparing the distance between different marks made on the sample to be tested (initially at 50 mm) prior and after the compression test according to UNE-EN ISO 6892-1:2020 B standards.

[0086] As it can be observed, the alloys in the as-cast state have good elongation values (>10%), which allow their use in the as-cast state for applications under compression forces. There is a very limited decrease in the compression values at 25°C and at 200°C, with Rp values up to 251Mpa, Rm values up to 487 Mpa, and up to 25.3% of elongation to compression.

[0087] The values obtained after the wear rate test at 25°C and at 200°C are shown in Table 5. The wearing rate coefficients were tested in a sphere-on-plate reciprocating configuration using a tribometer with ball-on-disk mode (MT2/60/NI/HT, Microtest S.A). Alumina balls with a 6 mm diameter were used for each test as counter-face body. These alumina spheres have a hardness of 1250-1700 HV. Test conditions can be summarized as: load (10N), velocity (0.1 m/s), rotation speed (127,33 rpm), sliding distance (500 m), track diameter (7.5 mm) and environment (dry air). After each experiment, the determination of the wear rate was analysed by 3D laser scanning confocal microscopy (DCM 3D, Leica).

Table 5: Wear rate coefficients at 25°C and 200°C

Reference	K (mm ³ /Nm)	
	25°C	200°C
Alloy 2 as-cast	0.99e-03	3.9e-03
Alloy 2 TT	1.3e-03	5.1e-03
Alloy 3	1.4e-03	6.4e-03

[0088] As can be observed the obtained wear rate coefficients at 25°C have the lowest value for the as-cast state of Alloy 2, with similar values in Alloy 2 to the ones of Alloy 3 (AlSi_9Cu_3) after the thermal treatment. In the case of the test at 200°C, it's also clear the reduced wear rate in Alloy 2 in the as-cast state and thermal treatment in comparison with Alloy 3 (AlSi_9Cu_3). So, the alloy with the composition according to the invention shows an improved resistance to wear at 25°C and

at 200°C.

Characterisation of the alloy according to the invention

[0089] An XRD analysis were performed to determine the metallurgical phases that are in the as-cast and thermal-treated samples of the Alloy 2 (see example 1 above). It can be observed in Figure 2 the XRD analysis of the as-cast $\text{Al}_{50}\text{Mg}_{10}\text{Si}_5\text{Cu}_5$ alloy. Surprisingly, an Al_2Cu phase is presented in the XRD analysis (Yellow points), and it was not expected to appear. The Cu was supposed to be combined as Al_2CuMg .

[0090] It can be observed in Figure 3 the XRD analysis of the thermally-treated $\text{Al}_{50}\text{Mg}_{10}\text{Si}_5\text{Cu}_5$ alloy. In this case, the Al_2Cu phase is not observed, and the expected phases are detected in the analysis.

[0091] It can be observed in Figure 4 an example of the described micro-structures at x400 augmentations into different areas of the HPDC cast sample, in the surface area (with higher cooling rates and smaller precipitates) and the inner area of the parts (with smaller cooling rates and bigger precipitates). As can be observed, very small Al_2Cu precipitates are detected in the interdendritic area in combination with Al_2CuMg precipitates. Al_2Cu are rounder and smaller than the Al_2CuMg precipitates.

[0092] It can be observed in Figure 5 an example of the described micro-structures at x800 augmentations into different areas of the HPDC thermal-treated sample, in the surface area and in the inner area of the parts. No Al_2Cu precipitates are detected, but yes Al_2CuMg precipitates in the interdendritic area.

[0093] The transformation of Al_2Cu particles to Al_2CuMg can explain the reduction in the hardness of thermal treated samples and the increase of the ductility. Al_2CuMg can promote a minor change of the mechanical and wear properties at 200°C, with well-distributed small phases in the interdendritic space.

Claims

1. An aluminium casting alloy, **characterized in that** said alloy comprises:

9.0-11.5% by weight of magnesium,
4.5-7.0% by weight of silicon,
3.2-6.5% by weight of copper,
0.15-0.40% by weight of iron,
0.15-0.40% by weight of manganese,
less than 0.4% by weight of zinc,
less than 0.25% by weight of titanium,
less than 0.15% by weight of any other alloying element, and
aluminium as balance,
with the proviso that the content of Fe is equal to or lower than the content of Mn.

2. The aluminium casting alloy according to claim 1, wherein said alloy comprises 9.0-10.5% by weight of magnesium, preferably 9.0-10.0% by weight of magnesium.

3. The aluminium casting alloy according to claim 1 or claim 2, wherein said alloy comprises 4.5-5.7% by weight of silicon.

4. The aluminium casting alloy according to any one of claims 1 to 3, wherein said alloy comprises 4.5-6.5% by weight of copper, preferably 4.5-5.0% by weight of copper.

5. The aluminium casting alloy according to any one of claims 1 to 4, wherein said alloy comprises 0.25-0.40% by weight of iron and 0.25-0.40% by weight of manganese.

6. The aluminium casting alloy according to any one of claims 1 to 5, wherein said alloy comprises 0.20-0.40% by weight of Zn.

7. The aluminium casting alloy according to any one of claims 1 to 6, wherein said alloy comprises 0.10-0.25% by weight of Ti.

8. The aluminium casting alloy according to any one of claims 1 to 7 complying with one or more of the following parameters, measured at a temperature of 25°C or 200°C:

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- Brinell Hardness (HB) higher than 105 HB, preferably equal to or higher than 115 HB, measured according to UNE-EN ISO 6507-1 standard;
- Yield strength (Rp0.2) equal to or higher than 120 MPa, measured according to the UNE-EN ISO 6892-1:2020 B standard; and/or
- Ultimate tensile strength (Rm) equal to or higher than 220 MPa, measured according to the UNE-EN ISO 6892-1:2020 B standard.

9. The aluminium casting alloy according to any one of claims 1 to 8, wherein said alloy has been thermally treated and had an elongation equal to or higher than 1%, preferably equal to or higher than 3%, measured at 25°C and/or 200°C after the tensile test according to the UNE-EN ISO 6892-1:2020 B standards.

10. A thermal treatment process comprising the following stages:

- a) thermally treating an aluminium casting alloy as defined in any one of claims 1 to 7 at a temperature of 370°C to 470°C for a period of 24 hours to 72 hours; and
- b) contacting the treated aluminium casting alloy of step a) with a quenching media, preferably water at a temperature of 45°C to 80 °C.

11. The process of claim 10, wherein the process further comprises an additional step c) of artificial aging at a temperature of 150 °C to 250 °C for a period of 2 hours to 8 hours.

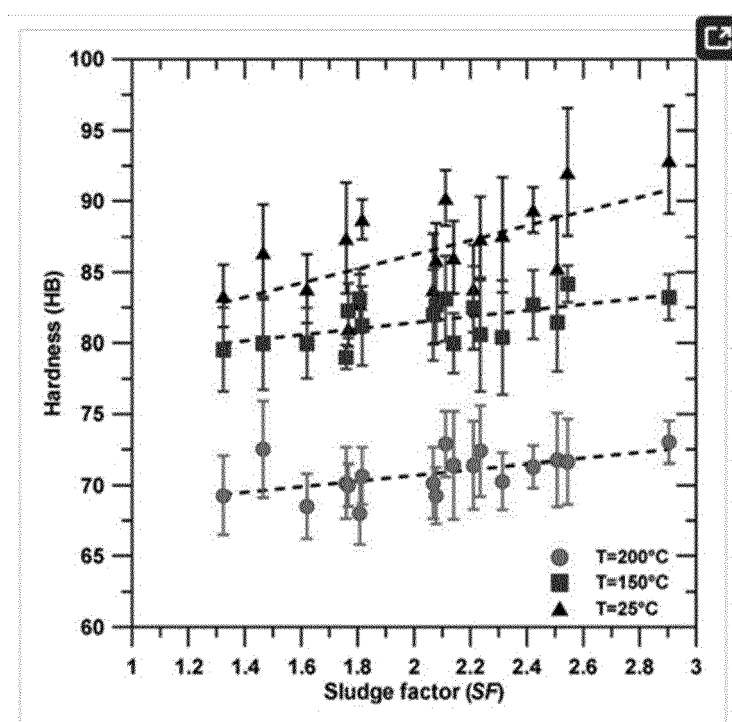
12. The process of claims 10 or 11, wherein the thermal treatment of step a) is carried out at a temperature of 400 °C to 460 °C for a period of 18 hours to 28 hours.

13. The process of claims 11 or 12, wherein the artificial aging is carried out at a temperature of 180°C to 230°C for a period of 3 hours to 5 hours.

14. A method for obtaining an aluminium casting alloy as defined in any one of claims 1 to 9, **characterized in that** said method comprises:

- i) obtaining a molten metal mixture having the composition of the aluminium casting alloy as defined in any one of claims 1 to 7;
- ii) high pressure die casting of the molten metal mixture of step i) thereby obtaining an aluminium casting alloy; and
- iii) optionally, thermally treating the aluminium casting alloy of step ii) by the thermal treatment process as defined in any one of claims 10 to 13.

15. Use of the aluminium casting alloy as defined in any one of claims 1 to 7 in the automotive industry, preferably in the manufacture of parts or components having a structural or abrasive function.

**Fig. 1** (prior art)

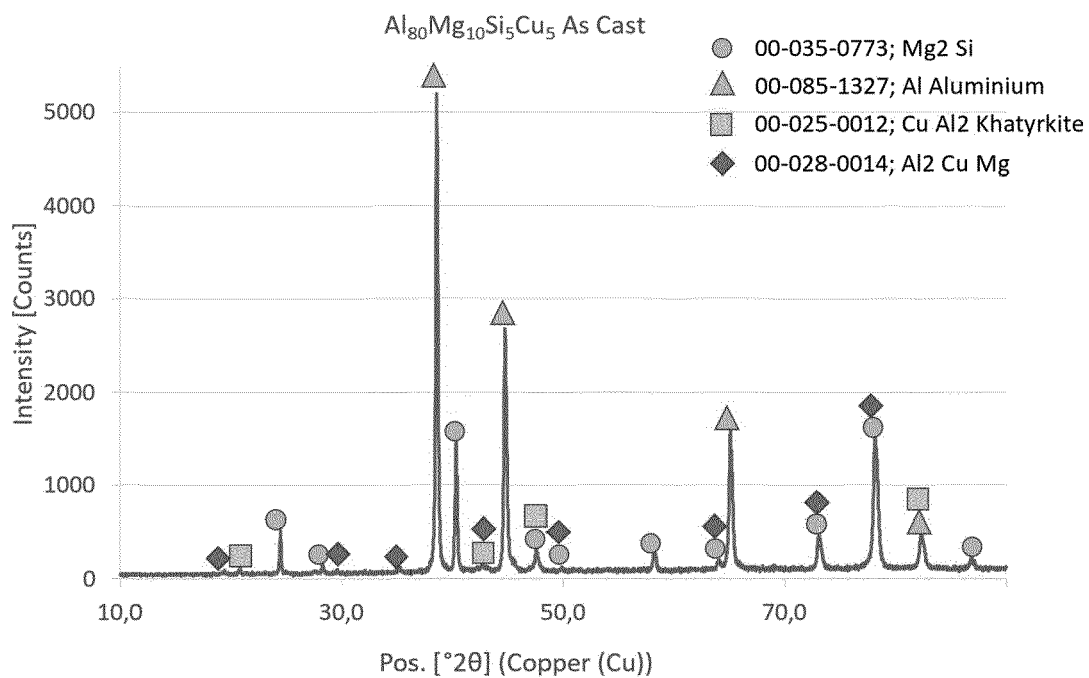


Fig. 2

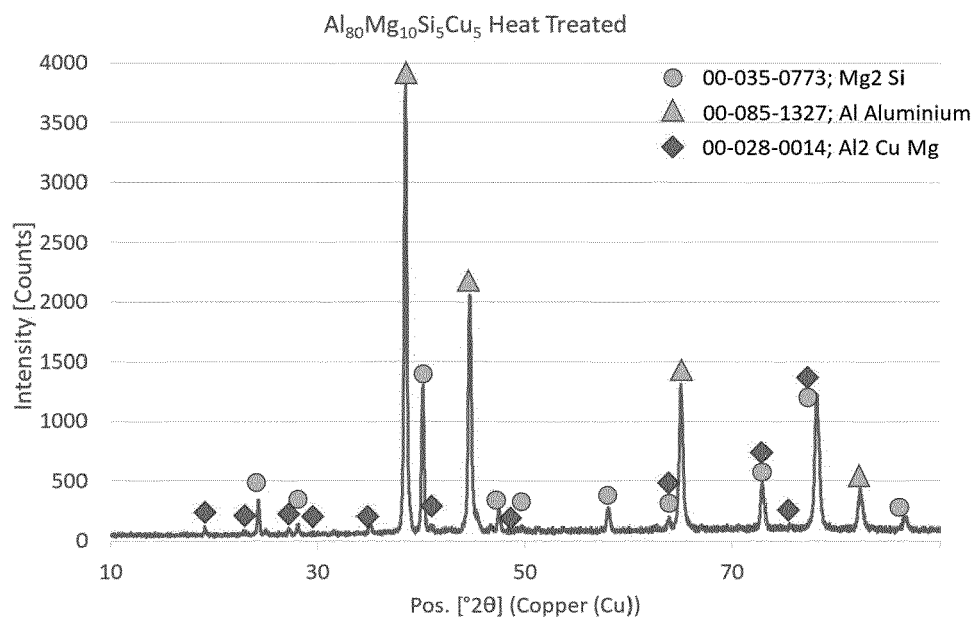


Fig. 3

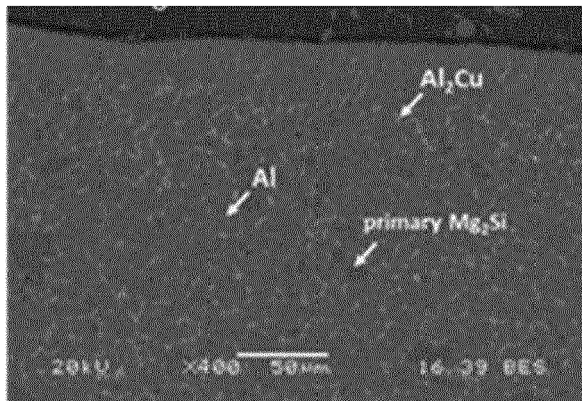


Fig. 4a

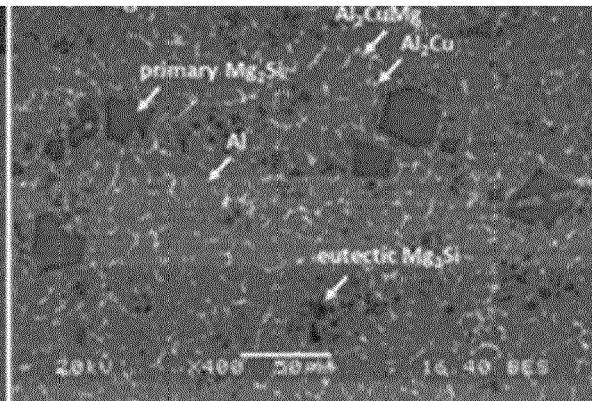


Fig. 4b

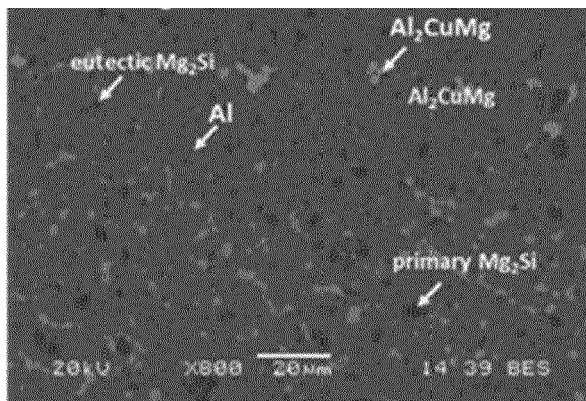


Fig. 5a

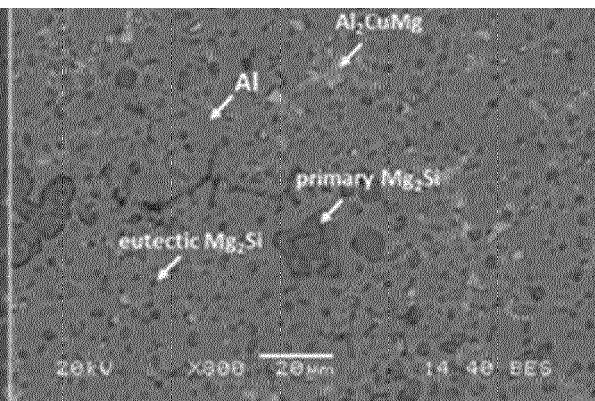


Fig. 5b



EUROPEAN SEARCH REPORT

Application Number

EP 23 38 3372

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	A.H. SHAFIEIZAD: "The Mg ₂ Si phase evolution during thermomechanical processing of in-situ aluminum matrix macro-composite", MATERIALS SCIENCE, vol. 644, 1 September 2015 (2015-09-01), pages 310-317, XP093167611, AMSTERDAM, NL ISSN: 0921-5093, DOI: 10.1016/j.msea.2015.07.060 * table 1 *	1-15	INV. C22C1/02 C22C21/08 C22F1/00 C22F1/047
A	CN 106 282 691 A (UNIV TIANJIN) 4 January 2017 (2017-01-04) * paragraphs [0026] - [0031]; example 3 *	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)
			C22C C22F
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
The Hague		28 May 2024	Rausch, Elisabeth
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