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(71) Applicant: **RIO TINTO ALCAN INTERNATIONAL LIMITED** [CA/CA]; 400-1190 avenue des Canadiens-de-Montréal, Montréal, Québec H3B 0E3 (CA).

(72) Inventors: **PAN, Lei**; 2305 rue Johnson, Jonquière, Québec G7T 0J3 (CA). **BRETON, Francis**; 1764 rue des Cent-Associés, Saguenay, Québec G7H 7C3 (CA). **MOREL, Martin**; 1340 rue de l'Hôtel-de-Ville, Saint-Honoré, Québec G0V 1L0 (CA).

(74) Agent: **NORTON ROSE FULBRIGHT CANADA S.E.N.C.R.L., S.R.L. / LLP**; 2500-1 Place Ville-Marie, Montreal, Québec H3B 1R1 (CA).

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(54) Title: OXIDATION RESISTANT AL-MG HIGH STRENGTH DIE CASTING FOUNDRY ALLOYS

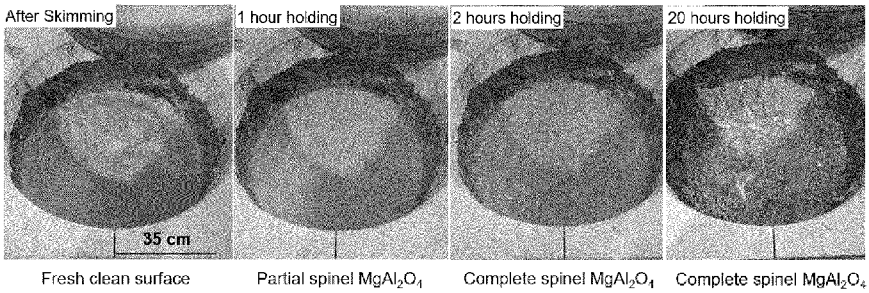


FIG. 3

(57) Abstract: The present disclosure concerns a foundry alloy suitable for casting operations which lack beryllium. The foundry alloy comprises, in weight percent, Mg (between about 1.0 and about 17.0), Fe (between about 0.5 and about 1.8), one of Ca (between about 0.003 and about 6.0) or Sr (between about 0.003 and about 2.5), optionally a grain refiner and the balance being aluminum and unavoidable impurities. The foundry alloy can be used in a process for making a cast aluminum product, for reducing Mg loss and/or dross generation during the casting operation.

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OXIDATION RESISTANT AL-MG HIGH STRENGTH DIE CASTING FOUNDRY ALLOYS

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This present application is claiming priority from U.S. Provisional Application No. 63/174,796 filed April 14, 2020, the content of which is hereby incorporated by reference in its entirety.

TECHNOLOGICAL FIELD

[0002] This disclosure concerns Al-Mg foundry alloys suitable for casting operations, such as high pressure vacuum die-casting operations.

BACKGROUND

[0003] The demand for structural die casting parts in the automotive sector is continuously growing. Most existing alloys require heat treatment to generate products having good mechanical properties. Therefore, an alloy without heat treatment would be required to reduce the production cost of structural die castings.

[0004] Al-Mg die casting foundry alloys have attracted considerable interest due to their superior mechanical properties in as-cast condition. In order to obtain sufficient solid solution strengthening, a high amount of Mg (> 3%) is added to create Al-Mg alloys. However, due to the strong affinity of Mg with oxygen, Al-Mg alloys suffer from problematic oxidation that can result in significant dross formation and loss of Mg from the melt. Beryllium can be used to minimize oxidation as it forms a protective BeO layer at the air-metal interface that inhibits further oxidation of the Mg. However, the use of Be poses health risks to operators who breathe or come into contact with Be dust.

[0005] Therefore, the aluminum die-casting market needs alternatives to Be in Al-Mg alloys to provide a similar oxidation inhibiting effect, but without the health risks. It is also sought to provide an alloy exhibiting improved properties during a casting operation such as die soldering resistance. It is further sought to provide a cast aluminum product exhibiting improved mechanical properties in the as-cast condition (F temper).

BRIEF SUMMARY

[0006] The present disclosure provides a beryllium-free foundry alloy. The foundry alloy of the present disclosure includes Ca or Sr. In some embodiments, the foundry alloy exhibits a reduction in Mg loss and/or in dross generation during the casting operation. In some embodiments, the foundry alloy exhibits increased die-soldering resistance during the casting

operations. In some embodiments, the cast aluminum product made from the foundry aluminum alloy exhibits improved mechanical properties, even in the as-cast state.

[0007] According to a first aspect, the present disclosure provides a foundry alloy comprising, in weight percent :

Mg between about 1.0 and about 17.0;

Fe between about 0.5 and about 1.8;

one of Ca between about 0.003 and about 6.0 or Sr between about 0.003 and about 2.5; and

the balance being aluminum and unavoidable impurities,

wherein the foundry alloy lacks Be as an alloying element.

[0008] In an embodiment, the foundry alloy further comprises a grain refiner. In another embodiment, further comprises Ca. In yet another embodiment, the foundry alloy comprises between about 0.01 and about 0.3 Ca in weight percent. In still another embodiment, the foundry alloy comprises between about 3.0 to about 8.0 Mg in weight percent. In yet another embodiment, the foundry alloy comprises between about 4.0 and about 6.0 Mg. In still another embodiment, the foundry alloy comprises between about 0.8 and about 1.8 Fe in weight percent.

[0009] According to a second aspect, the present disclosure provides a cast aluminum product comprising the foundry alloy described herein. In some embodiments, the cast aluminum is a structural automotive part. In additional embodiments, the cast aluminum product has at least one of the following properties: an ultimate tensile strength of at least about 200 MPa, a yield strength of at least about 100 MPa; an elongation of at least about 7%; and/or a VDA bend angle of at least about 30°. In additional embodiment, the cast aluminum product comprises Al_4Ca. In some further embodiments, the cast aluminum product has a $Al_{13}Fe_4$ phase, a Al_3Mg_2 phase and Al_4Ca. In some additional embodiments, the cast aluminum product has Al_4Ca jointed with the Al_3Mg_2 phase. In yet additional embodiments, the cast aluminum product of has a AlMgCa phase at the grain boundaries.

[0010] According to a third aspect, the present disclosure provides process for making a cast aluminum product, the process comprising casting the foundry aluminum described herein in a mold. In an embodiment, the process further comprises submitting the cast aluminum alloy

to high-pressure vacuum die casting. In yet another embodiment, the process lacks a post-cast thermal treatment step.

[0011] According to a third aspect, the present disclosure provides a cast aluminum product obtainable or obtained by the process described herein. In some embodiments, the cast aluminum is a structural automotive part. In additional embodiments, the cast aluminum product has at least one of the following properties: an ultimate tensile strength of at least about 200 MPa, a yield strength of at least about 100 MPa; an elongation of at least about 7%; and/or a VDA bend angle of at least about 30°. In additional embodiment, the cast aluminum product comprises Al_4Ca. In some further embodiments, the cast aluminum product has a $Al_{13}Fe_4$ phase, a Al_3Mg_2 phase and Al_4Ca. In some additional embodiments, the cast aluminum product has Al_4Ca jointed with the Al_3Mg_2 phase. In yet additional embodiments, the cast aluminum product of has a AlMgCa phase at the grain boundaries.

[0012] According to a fourth aspect, the present disclosure provides a process for limiting Mg loss and dross generation during a casting operation of an aluminum product compared to a control aluminum product. The process comprises adding one of Ca between about 0.003 and about 6.0 or Sr between about 0.003 and about 2.5 to a first aluminum alloy to obtain a foundry alloy intended to be cast. The first aluminum alloy comprises, in weight percent:

Mg	between about 1.0 and about 17.0;
Fe	between about 0.5 and about 1.8; and

the balance being aluminum and unavoidable impurities,

wherein the first aluminum alloy and the foundry alloy lack Be as an alloying element.

[0013] In some embodiments, the process further comprises melting the foundry alloy to obtain a molten foundry alloy. In an embodiment, the first aluminum alloy further comprises a grain refiner. In some additional embodiments, the process can be used for reducing Mg loss lower than about 12 weight percent, when the molten foundry alloy is held for a period of at least 6 hours. In some further embodiments, the process can be used for reducing dross generation lower than about 7 weight percent, when the molten foundry alloy is held for a period of at least 6 hours. In some embodiments, the process further comprises casting the molten foundry alloy to obtain a cast aluminum alloy. In yet additional embodiments, the process further comprises submitting the cast aluminum alloy to high-pressure vacuum die casting. In some embodiments, the process lacks a post-cast heat treatment step. In some

additional embodiments, the foundry aluminum alloy comprises Ca. In yet some further embodiments, the foundry aluminum alloy comprises between about 0.01 and about 0.3 Ca. In additional embodiments, the first aluminum alloy comprises between about 3.0 and about 8.0 Mg. In still some embodiments, the first aluminum alloy comprises between about 4.0 and about 6.0 Mg. In yet additional embodiments, the first aluminum alloy comprises between about 0.8 and about 1.8 Fe.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Having thus generally described the nature of the invention, reference will now be made to the accompanying drawings, showing by way of illustration, a preferred embodiment thereof, and in which:

[0015] Figure 1 provides the experimental procedure used in the Example.

[0016] Figure 2A provides a picture of the HPVDC plates used in the Example. The dotted line shows the section used for the tensile test presented in the Example.

[0017] Figure 2B provides a representation of ASTM B557 tensile test specimen dimensions used in the Example.

[0018] Figure 3 provides pictures of the melt surface evolution during air exposure oxidation tests (from left to right, after skimming, 1 hour, 2 hours or 20 hours holding).

[0019] Figure 4A provides a picture of the solid dross morphology.

[0020] Figure 4B provides an electron micrograph of the dross showing energy dispersive X-ray spectroscopy (EDX)-1 and EDX-2 particles. Scale bar 20 µm.

[0021] Figure 4C provides EDX-1 results from Figure 4B.

[0022] Figure 4D provides EDX-2 results from Figure 4B.

[0023] Figure 5A provides the weight percentage of Mg in a base alloy (Ca, Sr and/or a combination of Ca and Sr, stapled line), in an alloy comprising 100 ppm Ca (■), 1000 ppm Ca (▲), 100 ppm Sr (X) or 1000 ppm Sr (●) during a holding time of 0 to 6 hours.

[0024] Figure 5B provides the percentage in loss of Mg in a base alloy (Ca, Sr and/or a combination of Ca and Sr), in an alloy comprising 100 ppm Ca, 1000 ppm Ca, 100 ppm Sr or 1000 ppm Sr after a total of holding time of 6 hours.

[0025] Figure 6 provides pictures of the typical appearance of molten Al-1.5Fe-5Mg base alloy with no additive, with Ca only, Sr only and a combination of Ca and Sr after a 2-hour holding period at 770°C.

[0026] Figure 7 provides the total dross generated (in weight percentage) of a base Al-1.5Fe-5Mg alloy, an alloy supplemented with Ca only, Sr only or a combination of Ca and Sr after a total of holding time of 6 hours.

[0027] Figure 8 compares the mechanical properties of the base Al-1.5Fe-5Mg alloy and an alloy supplemented with Ca (0.1). Results are shown as ultimate tensile strength (left bars, in MPa), yield strength (middle bars, in MPa), elongation index (left bars, in %) and the quality index (■, in MPa) for the two alloys compared.

[0028] Figure 9 compares the mechanical properties of comparative alloy 1, comparative alloy 2 (which comprises Be) and the Al-1.5Fe-5Mg0.1Ca alloy. Results are shown as ultimate tensile strength (left bars, in MPa), yield strength (middle bars, in MPa), elongation index (left bars, in %) and the quality index (■, in MPa) for the three alloys compared.

[0029] Figure 10A provides a representative optical image of the base Al-1.5Fe-5Mg alloy. Arrows point to porosity in the material. Scale bar 100 µm.

[0030] Figure 10B provides a representative optical image of the Al-1.5Fe-5Mg0.1Ca alloy. Scale bar 100 µm.

[0031] Figure 10C provides a representative optical image of the base Al-1.5Fe-5Mg alloy. Scale bar 20 µm.

[0032] Figure 10D provides a representative optical image of the Al-1.5Fe-5Mg0.1Ca alloy. Scale bar 20 µm.

[0033] Figure 11A provides scanning electron microscopy (SEM) image, EDX and electron backscatter diffraction (EBSD) of the $Al_{13}Fe_4$ phase found in the Al-1.5Fe-5Mg0.1Ca alloy.

[0034] Figure 11B provides scanning electron microscopy (SEM) image and EDX of the Al_3Mg_2 phase found in the Al-1.5Fe-5Mg0.1Ca alloy.

[0035] Figure 11C provides scanning electron microscopy (SEM) image, EDX and electron backscatter diffraction (EBSD) of the Al_4Ca constituent found in the Al-1.5Fe-5Mg0.1Ca alloy.

[0036] Figure 11D provides scanning electron microscopy (SEM) image and EDX mapping of the Al-Mg-Ca phase found in the Al-1.5Fe-5Mg0.1Ca alloy.

[0037] Figure 12 provides results showing the effect of Mg on the yield strength of the alloy.

DETAILED DESCRIPTION

[0038] Aluminum alloys provide attractive solutions in the automotive industry to achieve lightweight objectives for improving fuel efficiency and reducing CO_2 emissions. As a fast and economical near-net shape manufacturing method, high pressure vacuum die casting

(HPVDC) is widely used to fabricate aluminum structural components. Alloys for structural die castings typically require good fluidity and die soldering resistance, high mechanical properties and sufficient corrosion resistance. Key challenges that are being addressed in the industry are die soldering, blistering during solution treatment, and requirement on the combination of strength and ductility. Well-designed aluminum alloys for F and T5 tempers are preferable from a broader cost and quality perspective.

[0039] In Al-Mg foundry alloys, Be is often used to limit or inhibit oxidation. However, in the present disclosure, it was sought to replace Be in Al-Mg foundry alloys intended to be used in casting operations. It was surprisingly found that the addition of Ca or Sr to an Al-Mg foundry alloy not only limited the oxidation of the alloy during the casting operations, but also provided a cast product exhibiting improved mechanical properties.

[0040] The foundry aluminum alloy of the present disclosure comprises either Ca or Sr. In some embodiments, the foundry aluminum alloy does not include a combination of Ca and Sr. As indicated above, Ca and Sr limit the oxidation of the alloy as well as, in some embodiments, improve the casting conditions. When the foundry aluminum alloy is used to make a cast product, in some embodiments, it can also improve one or more mechanical properties of the cast product (in some embodiments in its as-cast state).

[0041] The foundry aluminum alloy of the present disclosure can be any Al-Mg foundry alloy that is suitable for casting operations. In an embodiment, the foundry aluminum alloy of the present disclosure can be a 5xx.x aluminum alloy.

[0042] In some embodiments, Ca is present in the foundry aluminum alloy at a weight percentage equal to or higher than about 0.003. In some embodiments, Ca is present in the foundry aluminum alloy at a weight percentage equal to or higher than about 0.01. In some embodiments, Ca is present in the foundry aluminum alloy at a weight percentage equal to or higher than about 0.1. In additional embodiments, Ca is present at a weight percentage of at least about 0.003, 0.004, 0.005, 0.006, 0.007, 0.008, 0.009, 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 2.0, 3.0, 4.0, 5.0 or higher. When Ca is present in the alloy, it is present at a weight percentage equal to or below 6.0. In some embodiments, Ca is present in the alloy at a weight percentage of no more than about 6.0, 5.0, 4.0, 3.0, 2.0, 1.0, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.09, 0.08, 0.07, 0.06, 0.05, 0.04, 0.03, 0.02 or lower. In some specific embodiments, Ca is present in the alloy at a weight percentage between about 0.01 to about 6.0. In additional embodiments, Ca is present at a weight percentage of at least about 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0

or higher. In some embodiments, Ca is present in the alloy at a weight percentage of no more than about 6.0, 5.0, 4.0, 3.0, 2.0, 1.0, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2 or lower. In some specific embodiments, Ca is present in the alloy at a weight percentage between about 0.1 to about 6.0. In yet other embodiments, Ca is present in the alloy at a weight percentage of at least about 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1, 0.2 or higher. In yet further embodiments, Ca is present in the alloy at a weight percentage of no more than about 0.3, 0.2, 0.1, 0.09, 0.08, 0.07, 0.06, 0.05, 0.04, 0.03, 0.02 or lower. In yet additional embodiments, Ca is present in the alloy at a weight percentage between about 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1 or 0.2 and about 0.3, 0.2, 0.1, 0.09, 0.08, 0.07, 0.06, 0.05, 0.04, 0.03 or 0.02, such as, for example, at a weight percentage between about 0.01 and about 0.3. In yet other embodiments, Ca is present in the alloy at a weight percentage of at least about 0.1, 0.2 or higher. In yet further embodiments, Ca is present in the alloy at a weight percentage of no more than about 0.3, 0.2 or lower. In yet additional embodiments, Ca is present in the alloy at a weight percentage between about 0.1 or 0.2 and about 0.3 or 0.2, such as, for example, at a weight percentage between about 0.1 and about 0.3.

[0043] In some embodiments, Sr is present in the alloy at a weight percentage equal to or higher than about 0.003. In some embodiments, Sr is present in the alloy at a weight percentage equal to or higher than about 0.01. In some embodiments, Sr is present in the alloy at a weight percentage equal to or higher than about 0.1. In some additional embodiments, Sr is present at a weight percentage of at least about 0.003, 0.004, 0.005, 0.006, 0.007, 0.008, 0.009, 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2 , 2.3, 2.4 or higher. When Sr is present in the alloy, it is present at a weight percentage equal to or below 2.5. In some embodiments, Sr is present in the alloy at a weight percentage of no more than 2.5, 2.4, 2.3, 2.2, 2.1, 2.0, 1.9, 1.8, 1.7, 1.6, 1.5, 1.4, 1.3, 1.2, 1.1, 1.0, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.09, 0.08, 0.07, 0.06, 0.05, 0.04, 0.03, 0.02, 0.01, 0.009, 0.008, 0.007, 0.006, 0.005, 0.004 or lower. In some specific embodiments, Sr is present in the alloy at a weight percentage between about 0.003 to about 2.5. In some additional embodiments, Sr is present at a weight percentage of at least about 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2 , 2.3, 2.4 or higher. In some embodiments, Sr is present in the alloy at a weight percentage of no more than about 2.5, 2.4, 2.3, 2.2, 2.1, 2.0, 1.9, 1.8, 1.7, 1.6, 1.5, 1.4, 1.3, 1.2, 1.1, 1.0, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.09, 0.08, 0.07, 0.06, 0.05, 0.04, 0.03, 0.02 or lower. In some specific embodiments, Sr is present in the alloy

at a weight percentage between about 0.01 to about 2.5. In some additional embodiments, Sr is present at a weight percentage of at least about 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2 , 2.3, 2.4 or higher. In some embodiments, Sr is present in the alloy at a weight percentage of no more than about 2.5, 2.4, 2.3, 2.2, 2.1, 2.0, 1.9, 1.8, 1.7, 1.6, 1.5, 1.4, 1.3, 1.2, 1.1, 1.0, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2 or lower. In some specific embodiments, Sr is present in the alloy at a weight percentage between about 0.1 to about 2.5. In yet other embodiments, Sr is present in the alloy at a weight percentage of at least about 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1 or 0.2. In yet further embodiments, Sr is present in the alloy at a weight percentage of no more than about 0.3, 0.2, 0.1, 0.09, 0.08, 0.07, 0.06, 0.05, 0.04, 0.03, 0.02 or lower. In yet additional embodiments, Sr is present in the alloy at a weight percentage between about 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1 or 0.2 and about 0.3, 0.2, 0.1, 0.09, 0.08, 0.07, 0.06, 0.05, 0.04, 0.03 or 0.02, such as, for example, at a weight percentage between about 0.01 and about 0.3. Sr is present in the alloy at a weight percentage of at least about 0.1, 0.2 or higher. In yet further embodiments, Sr is present in the alloy at a weight percentage of no more than about 0.3, 0.2 or lower. In yet additional embodiments, Sr is present in the alloy at a weight percentage between 0.1 or 0.2 and about 0.3 or 0.2, such as, for example, at a weight percentage between about 0.1 and about 0.3.

[0044] The foundry aluminum alloy of the present disclosure comprises Mg to provide acceptable mechanical properties in the resulting cast product. Since the main strengthening mechanism of Mg is solid solution strengthening, adding more than the Mg's solubility in aluminum would not further increase the mechanical properties of the corresponding aluminum cast product. As such, in the foundry aluminum alloy of the present disclosure, Mg is provided at a weight percentage of 17.0 or less. Mg is present in the alloy at a weight percentage of at least about 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 11.0, 12.0, 13.0, 14.0, 15.0, 16.0 or more. Mg is present in the alloy at a weigh percentage of no more than about 17.0, 16.0, 15.0, 14.0, 13.0, 12.0, 11.0, 10.0, 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 2.0 or less. In an embodiment, Mg is present in the alloy at a weight percentage of between about 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 11.0, 12.0, 13.0, 14.0, 15.0, 16.0 and about 17.0, 16.0, 15.0, 14.0, 13.0, 12.0, 11.0, 10.0, 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 2.0, such as, for example, between about 1.0 and 17.0. In some embodiments, Mg is present in the alloy at a weight percentage of at least about 3.0, 4.0, 5.0, 6.0, 7.0 or more. In some embodiments, Mg is present in the alloy at a weight percentage of no more than about 8.0, 7.0, 6.0, 5.0, 4.0 or less. In an embodiment, Mg is present in the alloy at a weight percentage of between about 3.0, 4.0, 5.0, 6.0, 7.0 and about 8.0, 7.0, 6.0, 5.0, 4.0, such as, for example, between about

3.0 and 8.0. In some embodiments, Mg is present in the alloy at a weight percentage of at least about 4.0, 5.0 or more. In some embodiments, Mg is present in the alloy at a weight percentage of no more than about 6.0, 5.0 or less. In an embodiment, Mg is present in the alloy at a weight percentage of between about 4.0, 5.0 and about 6.0, 5.0, such as, for example, between about 4.0 and 6.0.

[0045] The foundry aluminum alloy of the present disclosure comprises Fe to provide die soldering resistance during casting operations. However, the amount of Fe present in the foundry alloy of the present disclosure should be limited so as to avoid creating large iron phases that are brittle and could reduce the mechanical properties of the corresponding aluminum alloy product. As such, Fe is present in the alloy at a weight percentage of at least about 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7 or more. Fe is present in the alloy at a weight percentage of no more than about 1.8, 1.7, 1.6, 1.5, 1.4, 1.3, 1.2, 1.1, 1.0, 0.9, 0.8, 0.7, 0.6 or less. In an embodiment, Fe is present in the alloy at a weight percentage of between about 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7 and about 1.8, 1.7, 1.6, 1.5, 1.4, 1.3, 1.2, 1.1, 1.0, 0.9, 0.8, 0.7, 0.6, such as, for example, between about 0.5 and 1.8. In an embodiment, Fe is present in the alloy at a weight percentage of at least about 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7 or more. Fe is present in the alloy at a weight percentage of no more than about 1.8, 1.7, 1.6, 1.5, 1.4, 1.3, 1.2, 1.1, 1.0, 0.9, or less. In an embodiment, Fe is present in the alloy at a weight percentage of between about 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7 and about 1.8, 1.7, 1.6, 1.5, 1.4, 1.3, 1.2, 1.1, 1.0, 0.9, such as, for example, between about 0.8 and 1.8.

[0046] A grain refiner may be optionally included in the aluminum alloys of the present disclosure to solidify aluminum alloys with a fully equiaxed, fine grain structure, in the form of Ti, TiB2, TiB or TiC. When TiB is used as a grain refiner, this may result in a B content of up to 0.05 wt. % in the alloy. When TiC is used as a grain refiner, this may result in a C content of up to 0.01 wt. % in the alloy. The grain refiner can be added during manufacture of the ingot to be remelted or it can be added after remelting during production of the final casting.

[0047] The foundry alloys of the present disclosure lack Be as a deliberation addition or as an alloying element. When present, Be is considered to be an unavoidable impurity.

[0048] In some embodiments of the present disclosure, the foundry alloy lacks Cu as a deliberation addition or as an alloying element. As such, in some embodiments, when present, Cu can be considered to be an unavoidable impurity.

[0049] The balance of the aluminum alloy of the present disclosure is aluminum (Al) and unavoidable impurities. In an embodiment, each impurity is present, in weight percent, at a maximum of about 0.05 and the total unavoidable impurities is present, in weight percent, at less than about 0.15 (in weight percent).

[0050] The cast aluminum alloy of the present disclosure can be submitted to various casting operations including, but not limited to high-pressure vacuum die casting (HPVDC) so as to provide cast aluminum product. The presence of Ca or Sr can, in some embodiments, improve the casting operations by reducing the amount of Mg loss and/or of dross generation during the holding of the melted aluminum alloy. In some embodiments, the presence of Ca or Sr can reduce Mg loss during melting lower than about 12 weight percent (when compared to a corresponding base alloy - Ca, Sr and/or a combination of Ca and Sr) when the molten alloy is held for at least 6 hours. In some embodiment, the presence of Ca or Sr can reduce dross generation lower than about 7 weight percent (when compared to a corresponding base alloy lacking Ca and Sr) when the molten alloy is held for at least 6 hours.

[0051] The present disclosure therefore provides a process for making a cast aluminum product from the foundry aluminum alloy described herein. Broadly, the process encompasses casting the foundry aluminum alloy described herein in a mold and optionally submitting the cast aluminum alloy to high-pressure vacuum die casting (HPVDC). In some embodiments, the process avoids using a post-cast thermal treatment step. In such embodiments, the corresponding aluminum product is provided in the as-cast state (e.g., F temper).

[0052] In some embodiments of the process, the foundry aluminum alloy, which can be provided in the form of an ingot, is submitted to a melting step to obtain a melted aluminum alloy. The melting step includes heating and stirring the aluminum alloy and optionally holding the melted aluminum alloy prior to casting. If a dross is generated during the melting step (for example during the holding step), the process can include removing the dross prior to casting. Once a melted aluminum alloy is obtained, it is cast in a mold to obtain a cast aluminum product. The casting step can include submitting the cast aluminum alloy to a high-pressure vacuum die-casting step. In some embodiments, the process can include a step of removing the cast aluminum product from the mold. In some embodiments, the process for making the cast aluminum product lacks a post-cast thermal treatment step and the cast aluminum product is provided in the as-cast state (e.g., F temper). However, in some embodiments, the process for making the cast aluminum can include one or more post-cast

treatment step (e.g., an annealing step, a strain hardening step, a solution heat treatment step and/or a thermal treatment step).

[0053] In embodiments in which aluminum product is a cast product, the process can also exclude any post-cast treatment (e.g., it can be provided as cast or F temper). Alternatively, the process can include a post-cast heat treatment, such as, for example, a T5, T6 or T7 treatment (e.g., solution heat treatment and artificial aging steps). In the embodiments in which the aluminum product is a cast product, the latter can be an automotive part, such as a chassis or a rotor.

[0054] In some embodiments, the foundry alloys of the present disclosure can be used to reduce dross generation during the casting operation. In some embodiments, the foundry alloys of the present disclosure reduces the weight percent of the dross generated during the melting step (for example during the holding step) below 7, 6, 5, 4, 3, 2, 1% when the melted aluminum alloy is held for a period of at least 6 hours.

[0055] In some embodiments, the foundry alloys of the present disclosure can be used to reduce the loss of Mg during the casting operation. In some embodiments, the foundry alloys of the present disclosure reduces the weight percent of Mg lost during the melting step (for example during the holding step) below 12, 11, 10, 9, 8, 7, 6, 5, 4, 3, 2% or lower when the melted aluminum alloy is held for a period of at least 6 hours.

[0056] In some embodiments, the process of the present disclosure can include adding Ca or Sr to aluminum or to a first aluminum alloy to provide a master alloy or the foundry alloy of the present disclosure. In some embodiments, Ca or Sr is added to pure aluminum to provide a master alloy. In such embodiment, the master alloy can then be used to make the foundry alloy of the present disclosure and be supplemented with Mg, Fe and optionally a grain refiner. The pure aluminum or the master alloy lacks Be as an alloying element and, if Be is present, it is considered an impurity. In some embodiments, Ca or Sr is added to a first aluminum alloy comprises Mg and Fe, and optionally a grain refiner, the balance being aluminum and unavoidable impurities. The first aluminum alloy lacks Be as an alloying element and, if Be is present in the first aluminum alloy, it is considered an impurity.

[0057] The present disclosure also provides cast aluminum products are obtainable or can be obtained by the process described herein. In the context of the present disclosure, the term “cast aluminum product” can refer to a final cast products (such as a structural automotive part for example) or to an intermediary ingot which can further be remelted into a differently shaped aluminum product. In some embodiments, the cast aluminum product is a

shock tower, a A-pillar, a B-pillar or a torque box. In some embodiments, the cast aluminum product of the present disclosure exhibits an improved ultimate tensile strength, yield strength, quality index, VDA angle and/or percent elongation when compared to the characteristics of a corresponding aluminum product lacking Ca or Sr (and optionally comprising Be). In some embodiments, the improved ultimate tensile strength, yield strength, quality index, VDA angle and/or percent elongation are observed in the as-cast state of the aluminum product (e.g., F temper).

[0058] In some embodiments, the cast aluminum products made from the foundry alloy of the present disclosure have an ultimate tensile strength of at least about 200, 210, 220, 230, 240, 250 MPa or more. In a specific embodiment, the cast aluminum products made from the foundry alloy of the present disclosure have an ultimate tensile strength of at least about 200 MPa. In some additional embodiments, the cast aluminum products made from the foundry alloy of the present disclosure have a yield strength of at least about 100, 110, 120, 130, 140, 150 MPa or more. In some additional embodiments, the cast aluminum products made from the foundry alloy of the present disclosure have a yield strength of at least about 100 MPa. In some additional embodiments, the cast aluminum products made from the foundry alloy of the present disclosure have an elongation of at least about 7, 8, 9, 10% or more. In some additional embodiments, the cast aluminum products made from the foundry alloy of the present disclosure have an elongation of at least about 7%. In some additional embodiments, the cast aluminum products made from the foundry alloy of the present disclosure meets the standard VDA (Verband der Automobilindustrie) 238-100 angle of at least about 30° or more.

[0059] The present invention will be more readily understood by referring to the following examples which are given to illustrate the invention rather than to limit its scope.

EXAMPLE

[0060] This present example presents the development of a new aluminum alloy to provide excellent mechanical properties and die soldering resistance for aluminum HPVDC structural components in as cast temper application. The microstructural evolution and mechanical properties were studied by scanning electron microscopy and tensile/bend tests. The relationship between the microstructure and properties are analyzed and the strengthening mechanisms of the studied alloy are discussed. Based on the experimental results, the new alloy demonstrates a promising solution for HPVDC components to be applied in as-cast condition.

[0061] As potential alternatives to Be, Ca and Sr were investigated for their effects on oxidation inhibition of liquid Al-1.5Fe-5Mg alloys through observations and measurements of oxidation morphology, dross generation and loss of magnesium.

[0062] *Molten Al-5Mg oxidation tests.* Various additions of Ca and Sr in Al-1.5Fe-5Mg alloys were tested. The alloys were prepared using P1020 aluminium, pure magnesium and pure iron powders. The Sr and Ca elements were batched using Al-10%Sr and Al-10%Ca master alloys. The chemical compositions of these alloys were analysed by optical emission spectroscopy (OES), and the results are shown in Table 1. The alloys were melted in laboratory using a 350-kg electric resistance furnace.

Table 1. Chemical compositions used in the oxidation tests (wt.%)

Codes	Fe	Mg	Ca	Sr	Al	Charge kg
Base Al-1.5Fe-5Mg	1.53	5.0	-	-	Rem.	290
100 ppm Ca	1.78	4.9	0.0087	-	Rem.	290
200 ppm Ca	1.70	4.9	0.0232		Rem.	287
1000 ppm Ca	1.80	5.1	0.0650	-	Rem.	298
0.13% Ca	1.70	5.2	0.0865	-	Rem.	293
0.3% Ca*	1.80	5.1	0.3		Rem.	297
100 ppm Sr	1.79	5.0	-	0.0233	Rem.	294
1000 ppm Sr	1.81	5.1	-	0.1380	Rem.	298
100 ppm Ca +100 ppm Sr*	1.50	5.0	0.01	0.01	Rem.	290

* marked alloys are the nominal composition

[0063] The experimental procedure is presented in Figure 1. The procedure includes two steps: alloy batching and holding process. A typical alloy batching process was used. More specifically, P1020 was charged into the furnace and batched with Fe and Mg. Then, the molten metal was stirred and degassed using Argon. Fluxing salt was used to clean the melt during degassing. After degassing, Ca and Sr were added in a proportion of 100 ppm to 0.3% for Ca and 100 to 1000 ppm for Sr, as per the chemistry design in Table 1. An interrupted thermal holding process was used to investigate oxidation generation during casting. The holding temperature of the metal was set to 770°C, which is the high limit for typical casting. As the oxide mass formed on liquid metal increases with temperature, the test demonstrates the effect of Ca and Sr on Al-Mg oxidation under the most aggressive oxidation conditions. As shown in Figure 1, three holding periods of two hours each followed the alloying. After each period, the molten metal surface appearance was captured. Complete skimming of the metal surface was carried out to quantify dross generation. Six OES samples were taken to evaluate the loss of magnesium. After each test, the crucible was thoroughly cleaned. For the base Al-1.5Fe-5Mg alloy, a prolonged thermal holding time of up to 20 hours was performed to study the oxidation evolution.

[0064] *Properties and microstructure analysis of Al-Mg alloys.* The effect of small amounts of Ca on the mechanical properties and bend ductility of the Al-1.5Fe-5Mg alloy was studied. Plates with a thickness of 3 mm obtained by high-pressure vacuum die casting (HPVDC) were produced on a 260 t Buhler machine. An Al-1.5Fe-5Mg base alloy and a new Al-1.5Fe-5Fe0.1Ca alloy were cast. The chemical compositions of the investigated alloys were determined using optical emission spectroscopy (OES), and the results are shown in Table 2.

Table 2. Chemistry of the studied alloys

Alloy	Si	Fe	Mg	Cu	Ca	Mn	Ti	Be
Al-1.5Fe-5Mg	0.05	1.46	4.9	0.001	0	0.01	0.002	0
Al-1.5Fe-5Mg0.1Ca	0.05	1.47	5.1	0.001	0.07	0.01	0.002	0
Comparative alloy 1	7.5	0.17	0.35	0.02	0	0.5	0.1	0
Comparative alloy 2	0.05	1.6	4.3	0.05	0	0.15	0.2	0.001

[0065] Samples for tensile tests were cut from casting blanks (rectangular part in the middle of the sample, as shown in Figure 2). The plates were then machined into the form of test samples with precise dimensions which meet the ASTM B557 standards. For each alloy, ten tensile samples in as-cast condition were pulled. Square samples of 60 x 60 mm were machined from 3 mm HPVDC plates for bend tests. Six samples of each alloy were tested according to VDA 238-100 norm.

[0066] Metallographic samples were taken from as-cast HPVDC plates. Optical microscopy and scanning electron microscopy (SEM) were used to analyze the as-cast microstructure and to identify the intermetallic phases.

[0067] *Effects of Ca and Sr on oxidation inhibition of molten Al-Mg alloys.* The oxidation phenomenon of Al-Mg was studied to understand the oxidation mechanisms. The effects of Ca and Sr on the Al-Mg alloy oxidation inhibition effect were investigated.

[0068] *Oxidation characterization of base Al-1.5Fe-5Mg alloy.* Figure 3 shows the melt surface of Al-1.5Fe-5Mg alloy during thermal holding at 770°C in air. The surface of the melt is very clean after thorough skimming. After a 1-hour exposure, the surface presents a partial popcorn-shaped oxidation near the crucible edge. After a 2-hour exposure, the surface of the melt becomes completely covered with popcorn-shaped oxides. The metal temperature increased to 800°C due to the exothermic oxidation reaction of aluminium and magnesium. After a 20-hour exposure, the colour of the oxides turns partially black. Solid popcorn-shaped oxides have a porous morphology, as shown in Figure 4A, which constitutes a large number

of pores and oxide clusters (see Figure 4B). EDX analysis shows that the dross is mainly composed of magnesium oxide (MgO) and spinel ($MgAl_2O_4$).

[0069] Figure 5A and 5B show that the Mg concentration changes during a holding time of 0 to 6 hours, as well as the percentage in loss of Mg after a total of holding time of 6 hours. It can be observed that the base Al-1.5Fe-5Mg alloy had the highest Mg loss. The total Mg loss after 6 hours holding period is 0.63 wt.%, or 12.6% loss. Additions of Ca or Sr effectively reduced the Mg loss during melting. The Mg loss was lower than 0.1 wt.%, or 2% loss for alloys containing Ca, and lower than 0.3 wt.%, or 6% loss for alloys containing Sr.

[0070] *Combination of Ca and Sr.* Figure 6 shows the visual appearance of molten Al-1.5Fe-5Mg base alloy with no additive, with Ca only, Sr only, and the combination of Ca and Sr. The alloy containing both Ca and Sr has a small wavy shape. This characteristic is similar to that of the alloy containing Sr. The oxidation layer appears to be thick. There is no porous dross. This result indicates that the combination of Ca and Sr can effectively help withstand Al-1.5Fe-5Mg oxidation.

[0071] Figure 7 shows the total dross generated (wt.% of the charge) after a total of holding time of 6 hours. It is noted that the combination of Ca and Sr effectively reduced dross generation. The alloy with both Ca and Sr showed a dross generation of 2.1 wt.%, which is lower than that of the base alloy (6.9 wt.%) and that of the alloy with Sr (2.9 wt.%). However, the amount of dross generated is higher than that of the alloy with Ca (1.0 wt.%).

[0072] In summary, the Mg in Al-1.5Fe-5Mg has a strong affinity for oxygen. Heavy oxides were found at the melt surface for the base alloy. Both Ca and Sr demonstrated a positive effect in inhibiting Al-1.5Fe-5Mg oxidation.

[0073] *Mechanical properties.* The properties of Al-1.5Fe-5Mg and Al-1.5Fe-5Mg0.1Ca were tested. Table 3 summarizes the tensile properties and VDA bend results for the studied alloy and reference alloys in the as-cast state. Figure 8 shows the effect of Ca on the mechanical properties of Al-1.5Fe-5Mg alloys. It was found that Al-1.5Fe-5Mg0.1Ca shows superior tensile properties compared to Al-1.5Fe-5Mg alloy. Both the tensile strength and ductility are higher for Al-1.5Fe-5Mg0.1Ca alloy than for Al-1.5Fe-5Mg alloy. The alloy quality index (QI) which is calculated using the equation of QI = UTS +150 * log(El%), is 459 MPa for Al-1.5Fe-5Mg0.1Ca, which is 81 MPa, or 21% higher than that of Al-1.5Fe-5Mg. Meanwhile, as shown in Table 3, Al-1.5Fe-5Mg0.1Ca alloy gives better bending ductility than Al-1.5Fe-5Mg alloy (bending angle of 37.7° for Al-1.5Fe-5Mg0.1Ca vs. 29.0° for Al-1.5Fe-5Mg alloy). The results highlight the beneficial effect of Ca on the mechanical performance of Al-1.5Fe-5Mg0.1Ca alloy.

Table 3. Property comparison of HPVDC alloys

Alloys	UTS (MPa)	YS (MPa)	El (%)	QI (MPa)	VDA Bend Angle (°)
Al-1.5Fe-5Mg F	261±16	136±3	6±1	378	29.0±0.8
Al-1.5Fe-5Mg0.1Ca F	309±12	147±3	10±2	459	37.7±2.2
Comparative alloy 1	250	115	11.5	409	32.4±1.9
Comparative alloy 2	254±5.1	123±4.1	14±1	427	

[0074] Figure 9 shows the comparison of the mechanical properties of the new Al-1.5Fe-5Mg0.1Ca alloy with those of other commercial die casting alloys (e.g., comparative alloys 1 and 2). The new alloy showed a higher quality index value than comparative alloys 1 and 2. It had the highest overall tensile strength and yield strength.

[0075] Compared to comparative alloy 1 which contains 7.5 wt.% Si and 0.17 wt.%Fe, the Al-1.5Fe-5Mg0.1Ca alloy had higher tensile strength and lower elongation. The elongation was 10% in the Al-1.5Fe-5Mg0.1Ca alloy vs. 11.5% in comparative alloy 1. Interestingly, the Al-1.5Fe-5Mg0.1Ca alloy showed better bending ductility than comparative alloy 1, with a bending angle of 37.7° in the Al-1.5Fe-5Mg0.1Ca alloy compared to 32.4° in the comparative alloy 1. The Al-1.5Fe-5Mg0.1Ca alloy is expected to have similar or better ductility than the comparative alloy 1. In terms of die soldering resistance, the Al-1.5Fe-5Mg0.1Ca alloy contains 1.5 wt.% Fe, which is expected to reduce the tendency to stick and significantly improve die life compared to the comparative alloy 1.

[0076] Compared with the comparative alloy 2, an Al-1.6Fe-4.2Mg-Be alloy, the Al-1.5Fe-5Mg0.1Ca alloy showed higher strength but lower ductility. Without wishing to be bound to theory, this may be due to the higher Mg content in the Al-1.5Fe-5Mg0.1Ca alloy (5.1 wt.% Mg) than in the comparative alloy 2 (4.3 wt.% Mg), which provided a higher solid solution strengthening effect. The ductility of the Al-1.5Fe-5Mg0.1Ca alloy can be improved by decreasing the Mg amount if a higher elongation is needed. In terms of alloy quality index, the Al-1.5Fe-5Mg0.1Ca alloy showed a higher quality index value (459 MPa) than the comparative alloy 2 (427 MPa). The Al-1.5Fe-5Mg0.1Ca alloy had overall better mechanical properties than the comparative alloy 2. Concerning the die soldering resistance, the Al-1.5Fe-5Mg0.1Ca alloy and the comparative alloy 2 contained similar Fe contents, 1.5 vs. 1.6 wt.%. The Al-1.5Fe-5Mg0.1Ca alloy is expected to perform similarly to the comparative alloy in terms of die life.

[0077] *As-cast microstructure analysis.* A microstructure analysis was carried out on the as-cast plates to understand the strengthening mechanism of Ca in Al-1.5Fe-5Mg alloy. The results are shown in Figure 10. Al-1.5Fe-5Mg shows shrinkage porosities while Al-1.5Fe-

5Mg0.1Ca shows a porosity-free microstructure. Since Ca is very efficient in reducing Al-Mg oxidation, it is logical that Al-1.5Fe-5Mg0.1Ca has lower oxides and lower porosity.

[0078] Phase morphology and chemistry identification were carried out using SEM/EDX and EBSD analyses. The results are shown in Figure 11. Table 4 summarizes the different stable phases identified in the two alloys of the study. The alloy matrix mainly consisted of $Al_{13}Fe_4$ and Al_3Mg_2 phases in Al-1.5Fe-5Mg alloy, and $Al_{13}Fe_4$ and Al_3Mg_2/Al_4Ca phases in Al-1.5Fe-5Mg0.1Ca alloy. Addition of Ca in the Al-5Mg-1.5Fe alloy allows the formation of the Al_4Ca phase jointed with the Al_3Mg_2 phase or AlMgCa phase at the grain boundaries in the matrix. In addition, Ca appears to slightly modify the morphology of the iron-rich phases. A greater presence of partially fragmented script Fe phases distributed very heterogeneously in the microstructure of the Al-1.5Fe-5Mg0.1Ca alloy was observed. Small particles promote a uniform deformation in the tensile test and result in a higher elongation.

Table 4. Phases in the studied alloys

Al-1.5Fe-5Mg	Al-1.5Fe-5Mg+Ca	Morphologies
▪ $Al_{13}Fe_4$	▪ $Al_{13}Fe_4$ *(Chinese script distributed heterogeneously)*	Acicular (3 to 30 µm)
▪ Mg_2Si *(--)*	▪ Mg_2Si *(+++)*	Fine particle (<300 nm)
▪ Al_3Mg_2	▪ Al_3Mg_2/Al_4Ca	"Eutectic" at grain boundaries (1 to 20 µm)

[0079] In addition, the effect of addition of Mg on the mechanical properties of the alloy where tested. Essentially, as seen in Table 5 below and in Fig. 12, the ultimate tensile strength (UTS) and yield strength (YS) are increased with increase of Mg content.

Table 5. Effect of addition Mg on mechanical properties

Alloys	Mg amount (%)	UTS (MPa)	YS (MPa)
Al-1.6Fe-4Mg	4.47	218,2	110,8
Al-1.6Fe-5Mg	5.43	231,8	125,4
Al-1.6Fe-6Mg	6.5	249,8	141,7

[0080] While the invention has been described in connection with specific embodiments thereof, it will be understood that the scope of the claims should not be limited by the preferred embodiments set forth in the examples, but should be given the broadest interpretation consistent with the description as a whole.

WHAT IS CLAIMED IS:

1. A foundry alloy comprising, in weight percent :

   Mg between about 1.0 and about 17.0;

   Fe between about 0.5 and about 1.8;

   one of Ca between about 0.003 and about 6.0 or Sr between about 0.003 and about 2.5; and

   the balance being aluminum and unavoidable impurities,

   wherein the foundry alloy lacks Be as an alloying element.

2. The foundry alloy of claim 1, further comprising a grain refiner.

3. The foundry alloy of claim 1 or 2, comprising Ca.

4. The foundry alloy of any one of claims 1 to 3, comprising between about 0.01 and about 0.3 Ca.

5. The foundry alloy of any one of claims 1 to 4, comprising between about 3.0 to about 8.0 Mg.

6. The foundry alloy of any one of claims 1 to 5, comprising between about 4.0 and about 6.0 Mg.

7. The foundry alloy of any one of claims 1 to 6, comprising between about 0.8 and about 1.8 Fe.

8. A cast aluminum product comprising the foundry alloy of any one of claims 1 to 7.

9. A process for making a cast aluminum product, the process comprising casting the foundry aluminum alloy of any one of claims 1 to 7 in a mold.

10. The process of claim 9, further comprising submitting the cast aluminum alloy to high-pressure vacuum die casting.

11. The process of claim 9 or 10 lacking a post-cast thermal treatment step.

12. A cast aluminum product obtainable or obtained by the process of any one of claims 9 to 11.

13. The cast aluminum product of claim 8 or 12 being a structural automotive part.

14. The cast aluminum product of any one of claims 8, 12 and 13, having at least one of the following properties:

   - an ultimate tensile strength of at least about 200 MPa,

- a yield strength of at least about 100 MPa;
- an elongation of at least about 7%; and
- a VDA bend angle of at least about 30°.

15. The cast aluminum product of any one of claims 8, 12 to 14, comprising Al_4Ca.

16. The cast aluminum product of any one of claims 8, 12 to 15, having a $Al_{13}Fe_4$ phase, a Al_3Mg_2 phase and a Al_4Ca phase.

17. The cast aluminum product of claim 16, having Al_4Ca jointed with the Al_3Mg_2 phase.

18. The cast aluminum product of any one of claims 8, 12 to 17, having a AlMgCa phase at the grain boundaries.

19. A process for limiting Mg loss and dross generation during a casting operation of an aluminum product compared to a control aluminum product, the process comprising adding one of Ca between about 0.003 and about 6.0 or Sr between about 0.003 and about 2.5 to a first aluminum alloy to obtain a foundry alloy intended to be cast, the first aluminum alloy comprising, in weight percent:

Mg between about 1.0 and about 17.0;

Fe between about 0.5 and about 1.8; and

the balance being aluminum and unavoidable impurities,

wherein the first aluminum alloy and the foundry alloy lack Be as an alloying element.

20. The process of claim 19, wherein the first aluminum alloy further comprises a grain refiner.

21. The process of claim 19 or 20, further comprising melting the foundry alloy to obtain a molten foundry alloy.

22. The process of claim 21, for reducing Mg loss lower than about 12 weight percent, when the molten foundry alloy is held for a period of at least 6 hours.

23. The process of claim 21, for reducing dross generation lower than about 7 weight percent, when the molten foundry alloy is held for a period of at least 6 hours.

24. The process of any one of claims 21 to 23, further comprising casting the molten foundry alloy to obtain a cast aluminum alloy.

25. The process of claim 24, further comprising submitting the cast aluminum alloy to high-pressure vacuum die casting.

26. The process of any one of claims 19 to 25, lacking a post-cast heat treatment step.

27. The process of any one of claims 19 to 26, wherein the foundry aluminum alloy comprises Ca.

28. The process of claim 27, wherein the foundry aluminum alloy comprises between about 0.01 and about 0.3 Ca.

29. The process of any one of claims 19 to 28, wherein the first aluminum alloy comprises between about 3.0 and about 8.0 Mg.

30. The process of any one of claims 19 to 29, wherein the first aluminum alloy comprises between about 4.0 and about 6.0 Mg.

31. The process of any one of claims 19 to 30, wherein the first aluminum alloy comprises between about 0.8 and about 1.8 Fe.

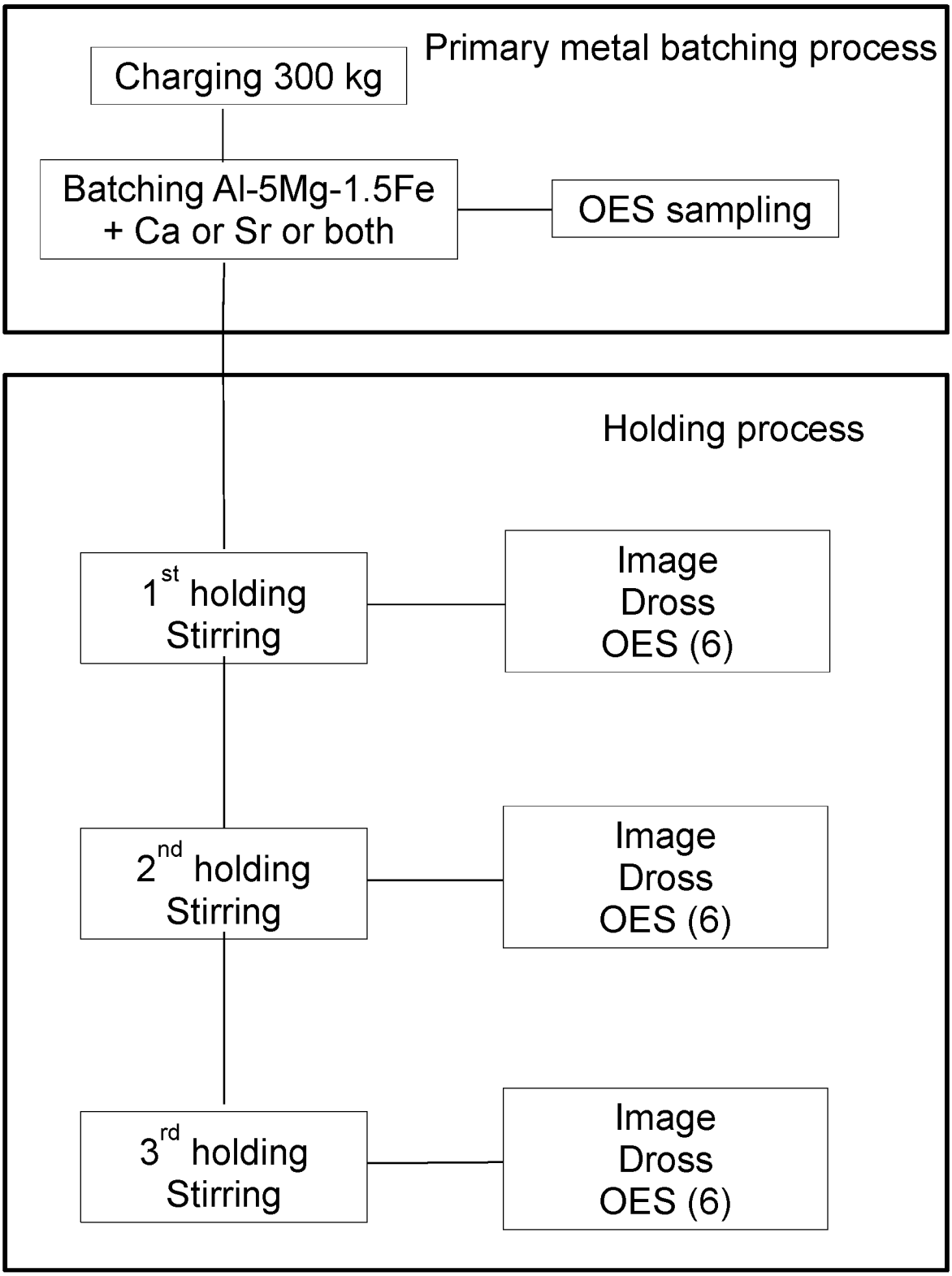

Primary metal batching process
Charging 300 kg
Batching Al-5Mg-1.5Fe + Ca or Sr or both
OES sampling
Holding process
1st holding Stirring
Image Dross OES (6)
2nd holding Stirring
Image Dross OES (6)
3rd holding Stirring
Image Dross OES (6)

FIG. 1

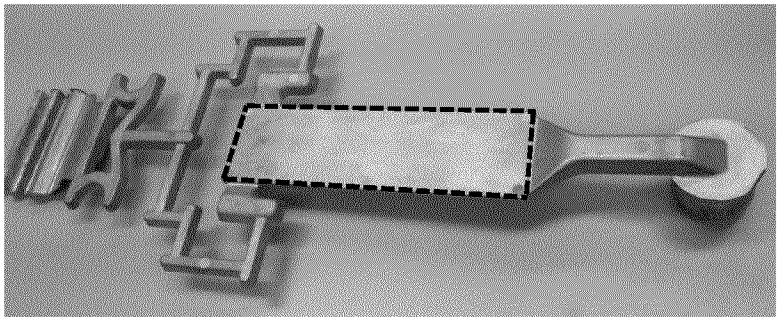


FIG. 2A

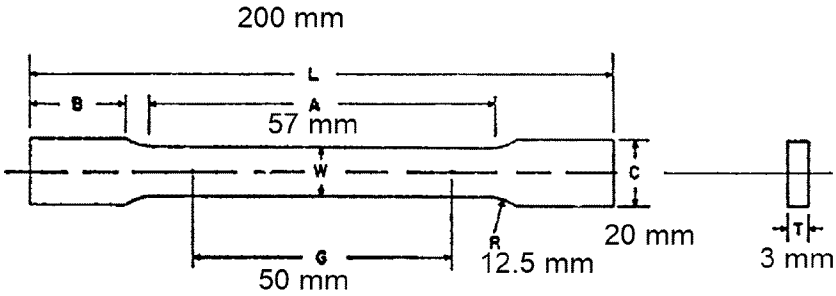


FIG. 2B

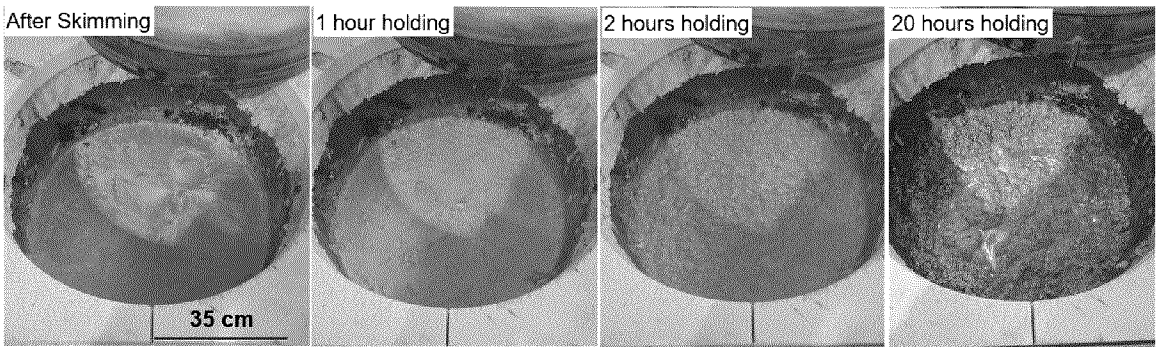


FIG. 3

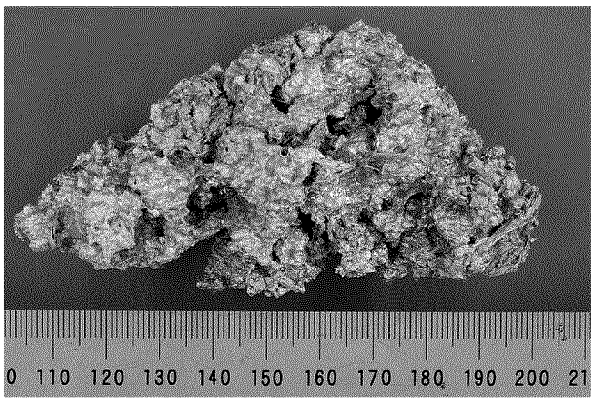


FIG. 4A

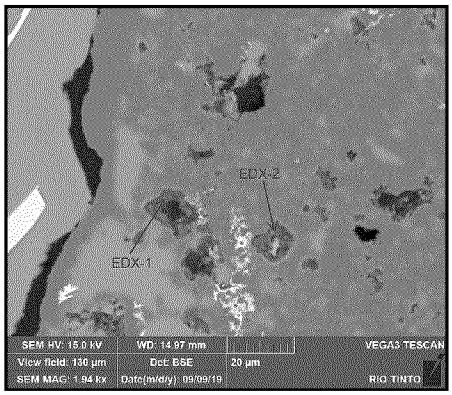


FIG. 4B

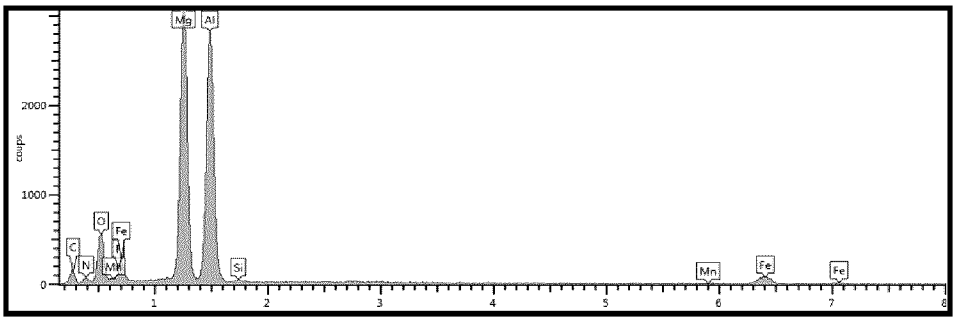

Mg
Al
O
Fe
C
N
Mn
Si
Fe
Fe
coups
2000
1000
0
1
2
3
4
5
6
7

FIG. 4C

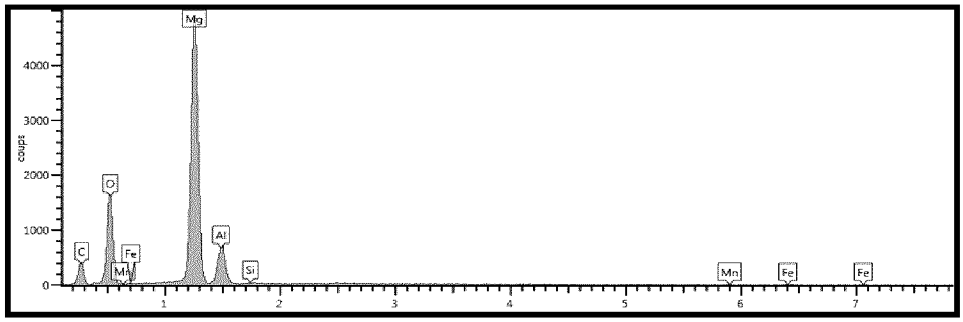

Mg
O
Al
C
Fe
Mn
Si
Mn
Fe
Fe
coups
4000
3000
2000
1000
0
1
2
3
4
5
6
7

FIG. 4D

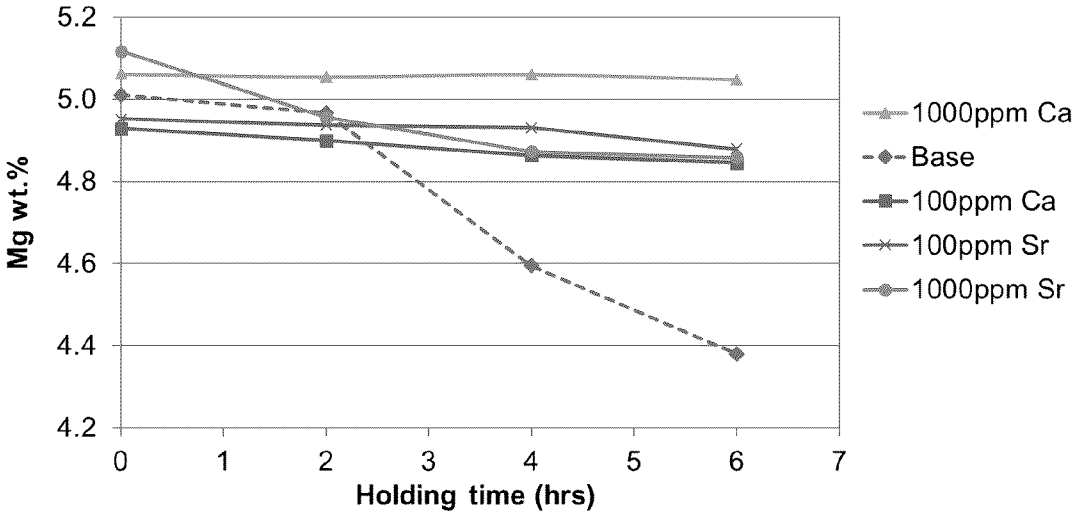

5.2
5.0
4.8
4.6
4.4
4.2
Mg wt.%
0
1
2
3
4
5
6
7
Holding time (hrs)
1000ppm Ca
Base
100ppm Ca
100ppm Sr
1000ppm Sr

FIG. 5A

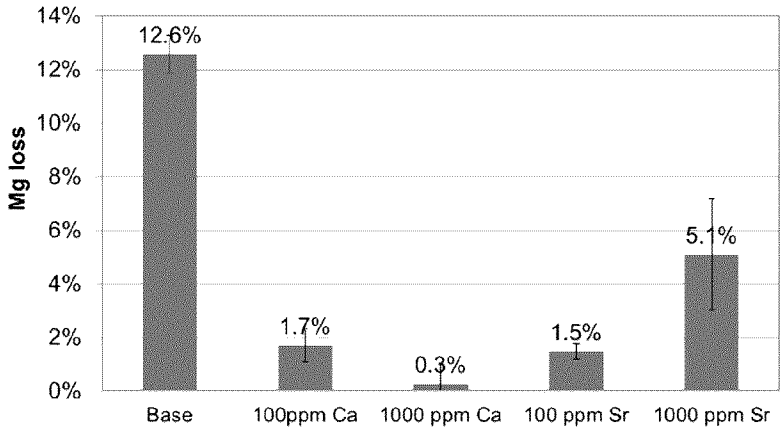

14%
12%
10%
8%
6%
4%
2%
0%
Mg loss
12.6%
1.7%
0.3%
1.5%
5.1%
Base
100ppm Ca
1000 ppm Ca
100 ppm Sr
1000 ppm Sr

FIG. 5B

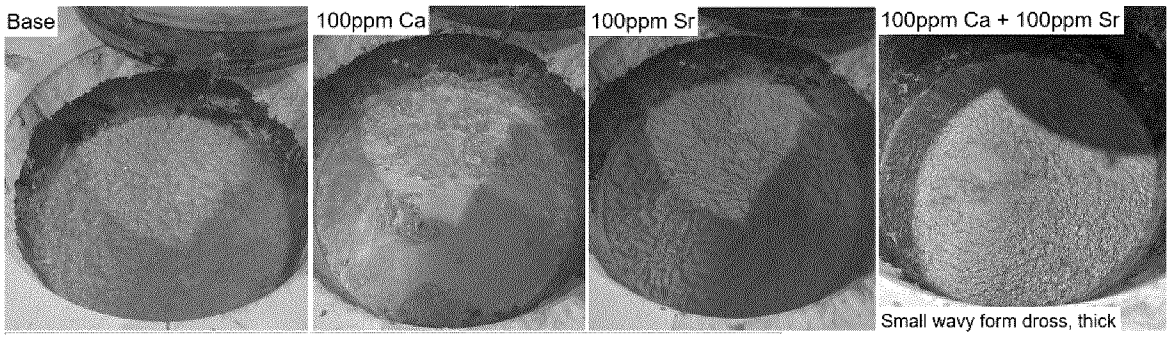

Base
100ppm Ca
100ppm Sr
100ppm Ca + 100ppm Sr
Small wavy form dross, thick

FIG. 6

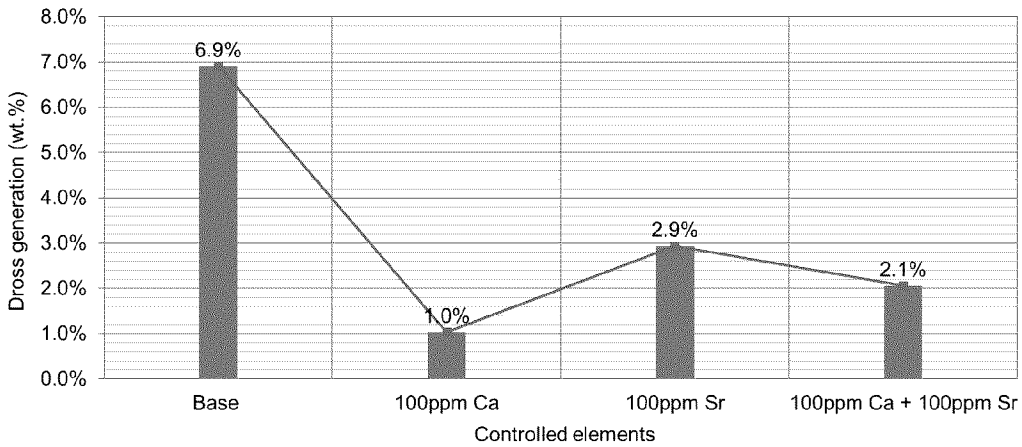

8.0%
7.0%
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
Dross generation (wt.%)
6.9%
1.0%
2.9%
2.1%
Base
100ppm Ca
100ppm Sr
100ppm Ca + 100ppm Sr
Controlled elements

FIG. 7

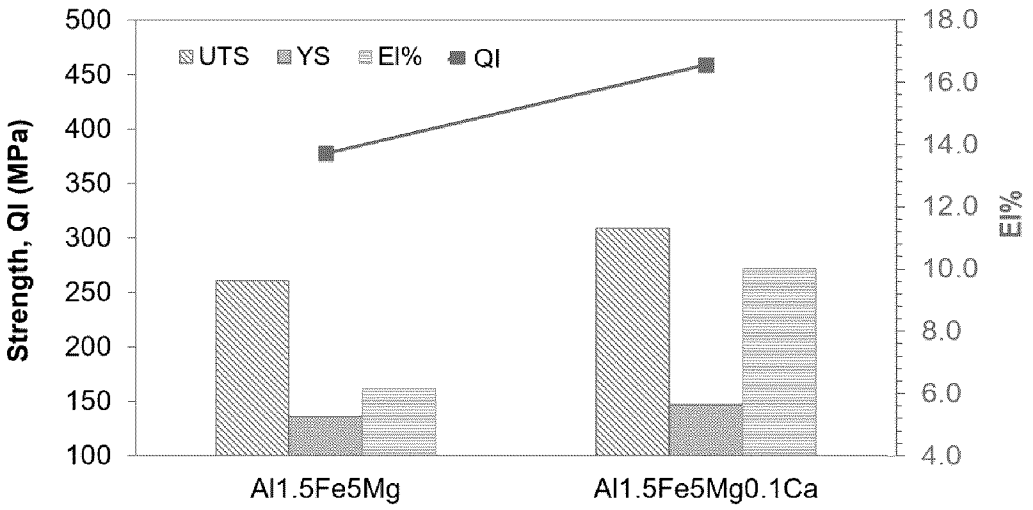

500
450
400
350
300
250
200
150
100
Strength, QI (MPa)
UTS
YS
El%
QI
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
El%
Al1.5Fe5Mg
Al1.5Fe5Mg0.1Ca

FIG. 8

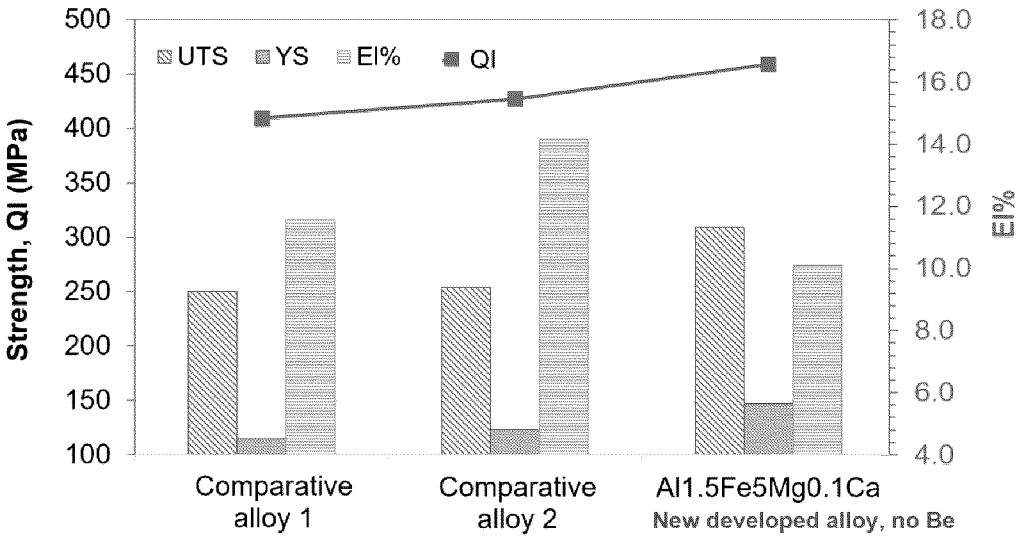

500
450
400
350
300
250
200
150
100
Strength, QI (MPa)
UTS
YS
El%
QI
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
El%
Comparative alloy 1
Comparative alloy 2
Al1.5Fe5Mg0.1Ca
New developed alloy, no Be

FIG. 9

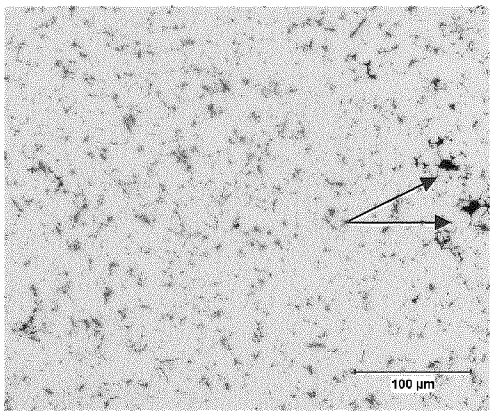


FIG. 10A

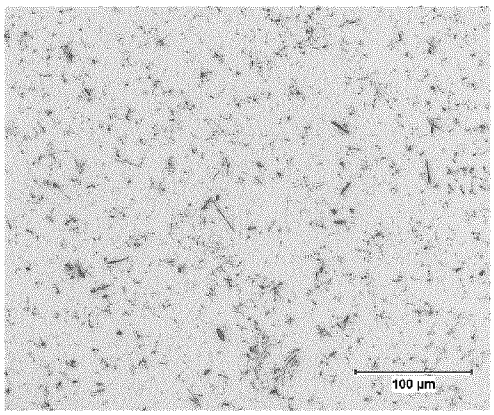


FIG. 10B

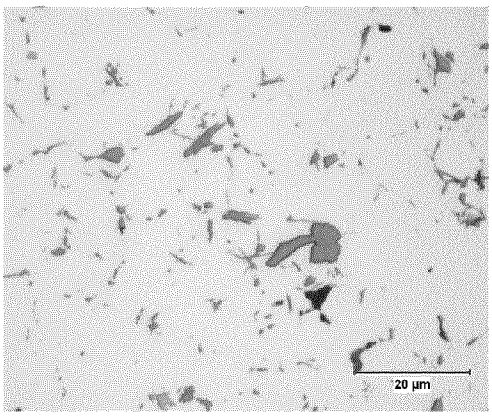


FIG. 10C

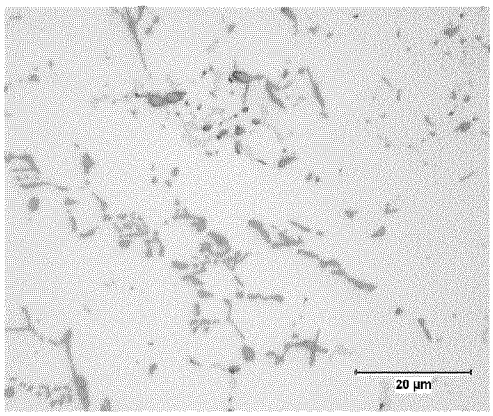


FIG. 10D

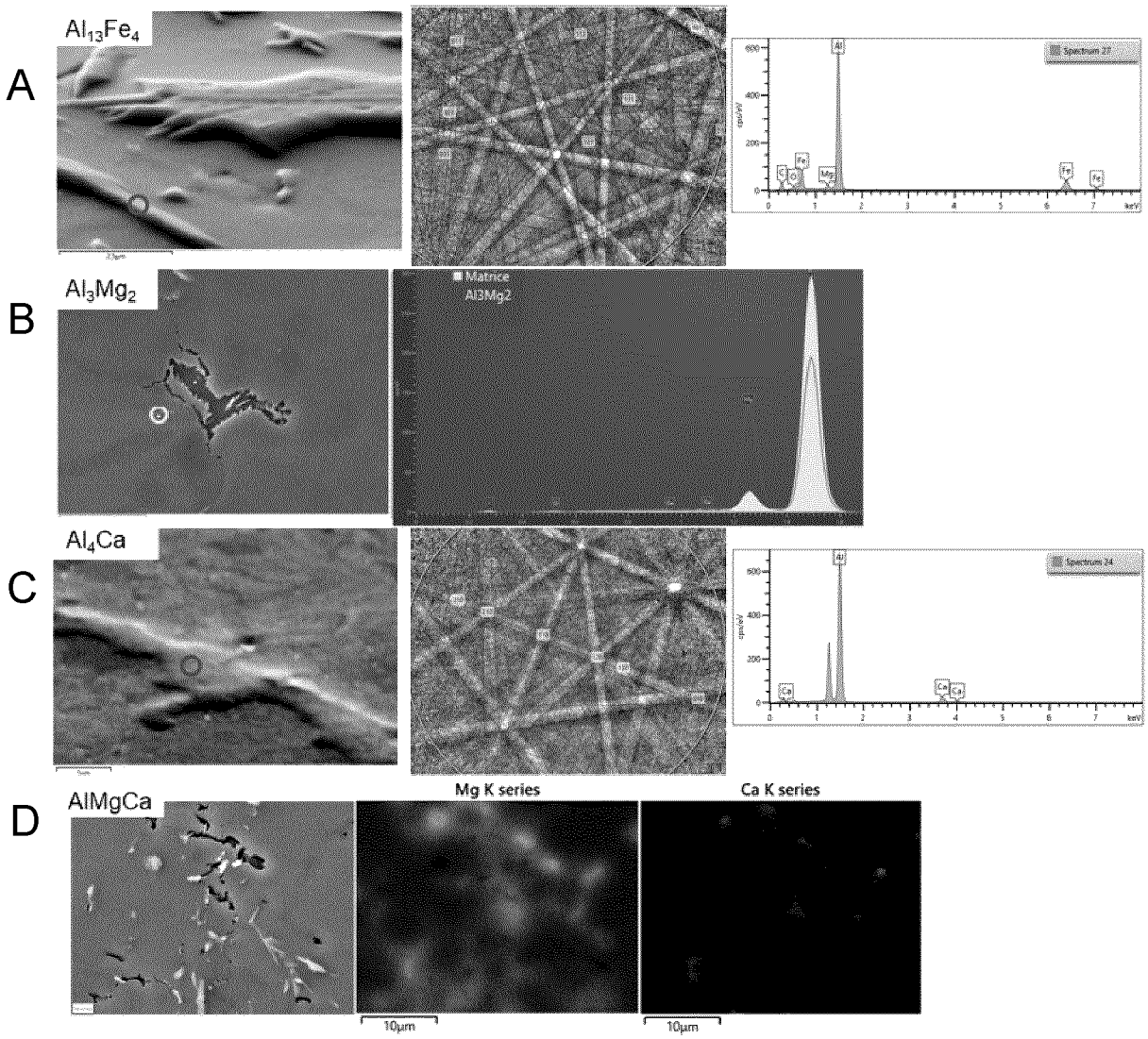

A
$Al_{13}Fe_4$
B
Al_3Mg_2
Matrice
Al3Mg2
C
Al_4Ca
D
AlMgCa
Mg K series
Ca K series
10µm
10µm

FIG. 11

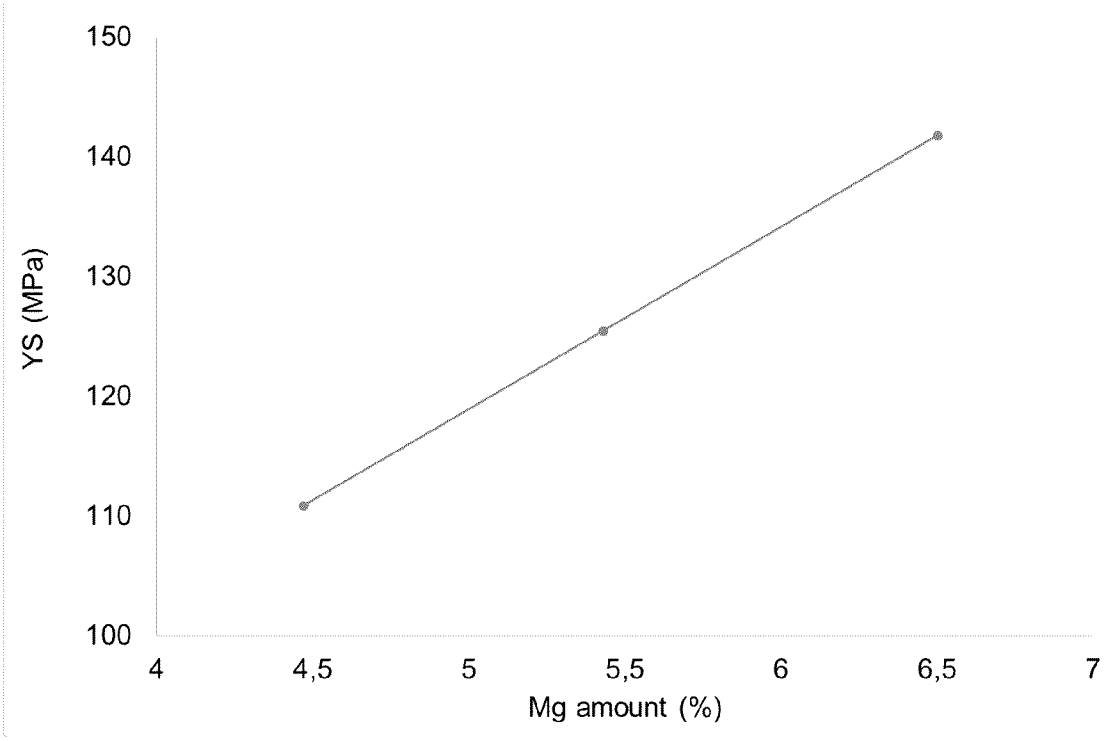


FIG. 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2022/050497

A. CLASSIFICATION OF SUBJECT MATTER

IPC: ***C22C 21/06*** (2006.01) , ***B22D 18/06*** (2006.01) , ***C22C 21/00*** (2006.01)

CPC: **C22C 21/06** (2020.01) , B22D 18/06 (2020.01) , C22C 21/00 (2021.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: ***C22C 21/06*** (2006.01) , ***B22D 18/06*** (2006.01) , ***C22C 21/00*** (2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Keywords: alloy, aluminum, magnesium, foundry, casting, high pressure vacuum die-casting, beryllium, dross, oxidation
Databases: FamPat (Orbit), Scopus

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	D1: The Development Of Ignition Resistant Magnesium Alloys Via Strontium And Calcium Alloying, VILLEGAS-ARMENTA Department of Mining and Materials Engineering McGill University, Montréal, QC, Canada, April 2020 *the entire document*	
A	D2: Beryllium Reduction Potential in AlMg Cast Alloys. The Minerals, Metals & Materials Series. Springer, Cham., STEGLICH, (2020). *the entire document*	
A	D3: Effect Of Strontium On The Oxidation Behavior Of Molten Aluminum Magnesium Alloys, OZDEMIR, Department of Mining, Metals and Materials Engineering, McGill University, Montreal, March 2006 *the entire document*	

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance		
"D"	document cited by the applicant in the international application	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier application or patent but published on or after the international filing date		
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search 21 June 2022 (21-06-2022)	Date of mailing of the international search report 29 June 2022 (29-06-2022)
Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 819-953-2476	Authorized officer: Patrick Mamputu Tel.: 01-819-639-5527