A new secondary AlSi10MnMg (Fe) Alloy suitable for manufacturing of ductile Aluminium parts by vacuum assisted high pressure die casting technology

A. Niklas, A.I. Fernández-Calvo, A. Bakedano, S. Orden, M. da Silva, E. Nogués, E. Roset

Vacuum assisted high pressure die castings (VPDC) with high ductility requirements are usually manufactured with primary AlSi10MnMg alloy. However, secondary alloys could be an interesting alternative as they offer several advantages such as cheaper raw material and longer die life. But, the higher amount of Fe, reduces the ductility due to the formation of needle/platelet shaped β-Al5FeSi compounds. These compounds can be transformed into α-iron compounds with less harmful by microadditions of Mn. In this work a secondary type alloy with moderate iron content, 0.47-0.60 % Fe, and optimised Mn addition, has been cast in step test parts with different wall thicknesses using VPDC technology. The microstructure has been investigated to assure that no harmful β-Al5FeSi compounds are formed. Mechanical properties have been determined in different conditions: F (as-cast), T4, T5 and T6 temper. The results show that mechanical properties comparable to the corresponding primary alloy can be obtained. Finally, the high mechanical properties of the new alloy were validated in a real part.

KEYWORDS: ALUMINIUM ALLOY - HIGH PRESSURE DIE CASTING - VACUUM - SECONDARY ALLOY - DUCTILITY

INTRODUCTION

Primary aluminum-silicon-magnesium alloys are by far the most widely used type in the manufacturing of safety parts for the automotive industry, such as suspension components and wheels, due to their excellent castability and good mechanical properties which can be further improved by heat treatment: solution, followed by water quenching and artificial aging T6 or T7. The recent structural castings, being extremely thin walled (of the order of 2.5 mm) and of rather great dimensions usually require the use of High Pressure Die Casting. These parts must be defect free and heat treatable to attain the requested properties, ductility and weldability being the most difficult to achieve. Vacuum must be applied as well as a combination of precautions relative to the die design, die lubrication, melt quality and shot profile have to be taken.

Conventional HPDC alloys are usually secondary alloys, in which iron is intentionally in the range of 0.8-1.1 wt. % in order to prevent molten metal soldering to the die [1,2]. However, conventional HPDC alloys are not suitable for high ductility castings and safety parts due to the presence of β-Al_5FeSi. These phases are detrimental to the mechanical properties, especially ductility and must be kept at levels as low as possible. For this reason, the primary AlSi10MnMg alloy with a maximum iron content of 0.25 wt.% and high Mn to avoid die soldering was developed [3]. Nevertheless, the use of recycled alloys can reduce significantly the fabrication costs of a part by reducing the raw material cost and increasing die life, iron has been reported to have a greater effect on reducing die soldering than Mn [4]. On the other hand the effect of different micro-additions on the iron compounds,

A. Niklas, A.I. Fernández-Calvo, A. Bakedano, S. Orden
*IK4-AZTERLAN,
Engineering, R&D and Metallurgical Processes,
Aliendalde Auzunea 6 (48200 Durango, Spain)*

M. da Silva, E. Nogués
*Fundació Eurecat, Parc Tecnològic del Vallès,
Av. Universitat Autònoma 23,
08290 Cerdanyola del Vallès, (Spain)*

E. Roset
*Ruffini S.A., Avda. Bizet, 2
Polig. Ind. Can Jardí - Aptdo. 62 - 08191 Rubí, (Spain)*

such as Mn, Cr and Be, has investigated by several authors [5-6]. The present work investigates the mechanical properties and microstructure of a secondary alloy with moderate iron content and optimized manganese addition in a step test part with different wall thicknesses in comparison with the primary alloy. The aim was to substitute the AlSi10MnMg primary alloy with high Mn content by less expensive secondary alloy maintaining the high mechanical properties of the primary alloy.

EXPERIMENTAL PROCEDURE

A Bühler cold chamber HPDC machine with a maximum locking force of 5250 kN was used. A ProVac Ultra Easy 2000 valve was employed to achieve 100 mbar. A 350 kg of the alloy, provided by a metal smelter, was melted and argon degassed using a rotor impeller. An automatic ladle was used to extract the metal from the furnace at 720 °C. The chemical composition of the alloys are shown in Tab. 1. Alloy A is a typical primary AlSi10MnMg alloy for VPDC castings with a Mn content of 0.68 wt. % and low Fe content of 0.17 wt. %. Alloys B and C are secondary alloys with 0.47-0.62 wt. % of Fe and a Mn content of 0.35-0.42 wt. %. The Mn content of the secondary alloy has been optimised previously regarding the elimination of β-iron compounds [7]. It is approximately 2/3 of the iron content. The higher Cu and Zn contents of the secondary alloys are typical of recycled aluminium. It should be noted that the primary alloy presents a higher Mg content than the secondary alloys. All alloys have Sr addition for eutectic Si modification.

The total amount of Mn + Fe is higher in alloy B than in alloy A and C, this is expected to have a positive effect with respect to die soldering. The higher iron content in alloy C reduces die soldering in comparison with alloy A as Fe is more effective than Mn [4]. Furthermore, both secondary alloys have a low sludge factor, (SF = [%Fe] + 2[%Mn] + 3[%Cr]). According to Gobrecht [8] at a pouring temperature around 680ºC (typical of conventional HPDC process), the sludge factor, should be less than 2.2. In all cases SF is well below this value. Thus, the precipitation of coarse intermetallics is not expected.

A wax-free release agent (SL-1697S) from Chem-Trend was used. The die was designed to cast a step test part with a width of 170 mm and wall thicknesses of 1, 2, 4, 6, 10 and 15 mm. The step test part was cast with primary alloy A and secondary B. A real part (transmission cover of a gear box) was manufactured with alloy C. The T4 and T6 heat treatment consisted of a solution heat treatment at 490 °C for 3 h followed by water quench and ageing at 20 °C for 120 h (T4) and 165 °C for 3 h (T6) . For the T5 heat treatment the parts were directly quenched in water just after die extraction and aged for 3 or 6 h. The characteristics of the intermetallic iron compounds were examined by scanning electron microscopy (SEM). The area fraction of the compounds was estimated using a LAS V4.2 image analyzer. Mechanical properties of alloy A and B have been determined in the 2 mm and 4 mm step casting and in 6.4 mm thick specimens extracted from the real part. Flat tensile specimens were tested according to UNE-EN ISO 6892-1:2010.

Tab. 1 - Chemical composition of the new alloy, total Fe +Mn and sludge factor (SF = [%Fe] + 2[%Mn] + 3[%Cr]) .

Chemical composition (wt. %)												
Part	Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Sr	Total Fe+Mn	SF
Test part	Primary A	10.7	0.17	<0.01	0.68	0.47	<0.01	0.01	0.05	0.006	0.85	1.53
	Secondary B	10.1	0.62	0.04	0.42	0.37	0.01	0.03	0.04	0.010	1.04	1.49
Real part	Secondary C	10.0	0.47	0.03	0.36	0.39	0.01	0.03	0.02	0.0147	0.83	1.22

RESULTS AND DISCUSSION

Microstructure

The microstructures formed in the as-cast (F) condition of the test parts of both, primary and secondary alloy are shown in Fig. 1a and 1c. The microstructure of the as-cast alloys present the following phases: primary aluminium (α-Al), eutectic Al-Si, Mg_2Si, α-$Al_{15}(FeMn)_3Si_2$ and π-$FeMg_3Si_6Al_8$ intermetallic iron compounds. After T6 heat treatment (490 °C for 3 h) no Mg_2Si phases are observed indicating that the solution heat treatment was effective (Fig. 1b and 1d). Furthermore, the eutectic Si grows in size and becomes globular; the iron compounds are apparently not affected by T6 heat treatment. Additionally, after T6 heat treatment small gas pores appear in the microstructure, porosity was below 0.3 %.

The intermetallic iron compounds were characterized in the scanning electron microscope (Fig. 2a). The α-iron compounds are small and have a compact morphology, with a size of 2 - 6 µm. In none of the steps harmful β-iron compounds (> 20 µm) are observed due to the optimised addition of Mn. Fig. 2b shows the area fraction of the intermetallic α-iron compounds for the three alloys at different wall thicknesses. It can be seen that the primary alloy A shows a lower area faction of intermetallic iron compounds than the secondary alloy B in each step. Furthermore, a small decrease of area fraction with reduction of wall thickness is observed in both alloys. The same decrease of area fraction with increasing cooling rate was observed by other researchers, and they attributed this to a delay in the growth mechanism of the intermetallic iron compounds [9]. The secondary alloy C, which has a similar total amount of Fe + Mn as the primary alloy A reveals also an area fraction of intermetallics comparable to this alloy.

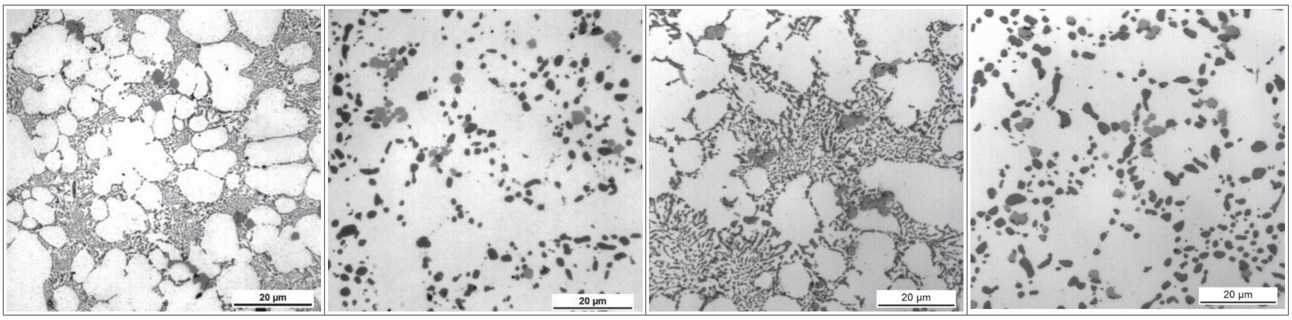

Fig.1 - Microstructures observed in the 2 mm step of the primary alloy A: a) F temper, b) T6 temper; and microstructures of secondary alloy C in the real part: c) F temper and d) T6 temper.

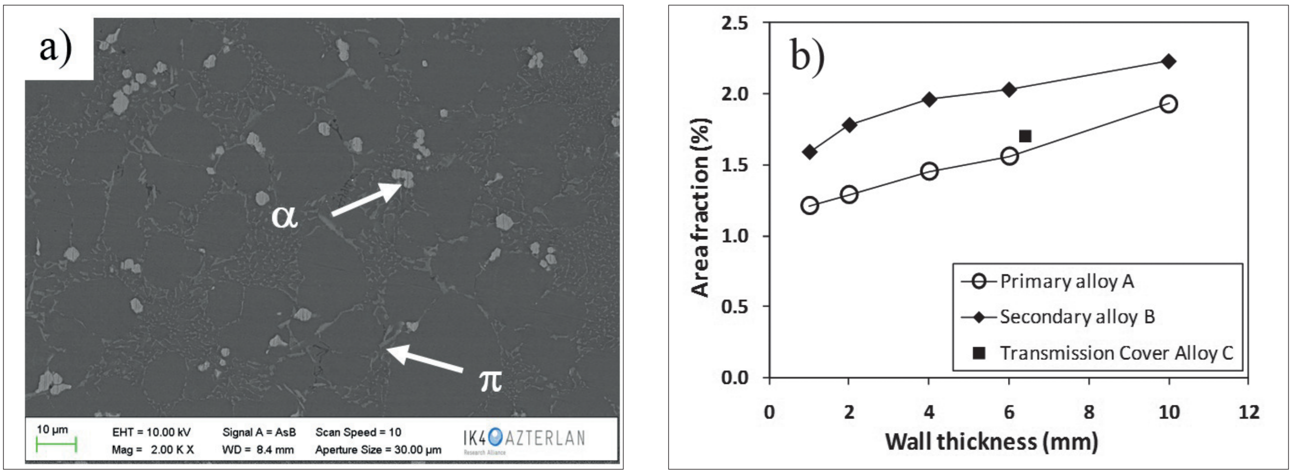

Fig. 2 - a) Intermetallic iron compounds of the secondary alloy C in the transmission cover of a gear box and b) effect of wall thickness and alloy on the area fraction of the α–intermetallic iron compounds

Mechanical properties

The yield strength and elongation achieved in the different castings and alloys are shown in the Fig. 3 at different tempers. The data of specimens which exhibited casting defects on the fracture surface, such as cold flakes and cold shuts, were not included in the graph as it has been demonstrated in a previous work that they affect adversely elongation independent of the alloy quality [10]. The mechanical property range of a commercial AlSi10MnMg primary alloy Trimal-05 [11] is indicated by rectangles. The primary A and secondary B alloy, in the F and T6 temper present elongation values within the specified property range of the primary alloy. However, the primary alloy A presents in the T6 temper a slightly higher yield strength than specified in the primary alloy data sheet and much higher than the secondary alloy B, while elongation is lower than in alloy B. This could be related to the higher Mg content of the primary alloy compared to the secondary alloys. This is supported by the fact that in the F temper, where the amount of Mg contributes less to strengthening, the primary alloy presents only slightly higher yield strength than the secondary alloy B.

The secondary alloy B, used for casting of the step test parts, has been also tested in the T4 and T5 temper. The properties obtained are also within the specified range of the primary alloy. For T4 temper the achieved results are in the left top corner of the commercial AlSi10MnMg primary alloy. If higher elongation is required the Mg content should be reduced to 0.15-0.25 wt.%.

Furthermore, the transmission cover was tested in the same T6 temper. Its yield strength is similar to the step part manufactured with secondary alloy B, but its elongation is slightly lower, although still in the range of the primary alloy. This could be associated to the coarser structure due to the higher wall thickness of the real part.

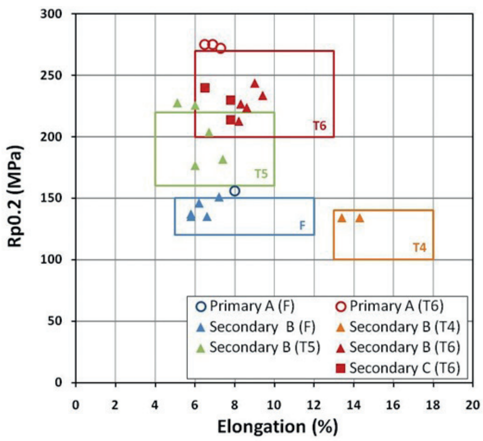

Fig. 3 - Mechanical properties of primary and secondary alloys in different tempers. The mechanical property range of the primary AlSi10MnMg alloy Trimal-05 [11] in the different tempers is indicated by rectangles.

CONCLUSIONS

In this work a secondary AlSi10MnMg(Fe) alloy with moderate iron content, 0.47 - 0.60 % Fe, and with an optimized Mn addition (approximately 2/3 of the Fe content), has been cast in test parts with different wall thicknesses and in a real part using VPDC technology. The following conclusions have been obtained:

- The new secondary alloy presents a microstructure free from undesirable β-iron compounds (> 20 μm), which are substituted by small compact α-iron compounds, with a less harmful morphology.
- The mechanical properties obtained in both, the step test part (F, T4, T5 and T6 temper) and the real part (T6 temper), are within the property range of the corresponding primary alloy.
- For applications which require very high ductility, in the T4 or T7 temper, it is recommended to use a alloy with lower Mg content (0.15-0.25 wt.%).

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