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Effect of solution heat treatment on gas porosity and mechanical properties in a die cast step test part manufactured with a new AlSi10MnMg(Fe) secondary alloy

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ABSTRACT

The effect of heat treatment on gas porosity and mechanical properties was investigated in a step test part manufactured by vacuum assisted high pressure die casting using a new AlSi10MnMg(Fe) secondary alloy. Porosity and mechanical properties were investigated in the T6 temper with different solution heat treatments. Porosity was characterized by metallographic and fractographic analysis of the tensile specimens. Mechanical properties comparable to the corresponding primary alloy have been achieved for each solution heat treatment. It was found that increasing the solution temperature and time increased the yield and ultimate tensile strength, while elongation decreased and porosity observed on the metallographic sections and fracture surfaces increased. Porosity evaluation on the fracture surfaces indicates that the local area fraction rather than the one observed on the whole fracture surface determines ductility. The size of the largest pore appears to become more relevant above values of 200 μm.

1. Introduction

Primary aluminium-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 T6 heat treatment: solution in solid state at high temperature, followed by water quenching and artificial aging. Until the introduction of thin walled structural parts in the 1990s, these safety critical components were mostly produced in permanent mould. 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 (HPDC). This is a highly productive manufacturing process which allows producing near-net-shape castings of complex geometry and thin walled at relatively low production costs. Furthermore, parts with a smooth surface and accurate dimension can be obtained. However, a drawback of this technology is the presence of casting defects. These structural parts must be defect free and heat treatable to attain the requested properties of ductility and weldability.

Common defects in conventional HPDC parts are shrinkage cavities, gas porosity, oxide inclusions, cold shuts and coarse intermetallic particles. The influence of casting defects on the mechanical properties of cast aluminium alloys has been investigated by many researchers, concluding that defects in general affect adversely the tensile properties and can make the tensile behavior of castings unpredictable [1–3]. Among the typical defects found in die casting parts, porosity (shrinkage and gas) represents certainly a critical defect as it reduces elongation and may be cause of leakage. Porosity has also been reported to have a negative impact on fatigue life, as pores act as fatigue crack initiation sites [4,5]. Another important defect, that affects adversely to elongation, is the presence of oxide inclusions which form in aluminium alloys as soon as the molten aluminium comes in contact with air [1–3,6]. The formation of oxide bi-films has been studied in great detail by Campbell [6].

Conventionally produced high pressure die castings are usually not heat treatable because the entrapped gases expand during the high temperature solution treatment thereby causing undesired blistering. The presence of entrapped gases is due to the decomposition of die lubricant and/or entrapped air during die filling and can be reduced by using die lubricants with low gas development and vacuum assisted HPDC processes [3,7]. Proper design based on simulation and in some cases the use of local squeeze pins can solve shrinkage problems, but not the other types of gas porosity. The vacuum assisted processes have already proven successful in reducing porosity in automobile structural applications for some

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years, mostly chassis parts such as A, B, C pillars, shock towers and various nodes, to a lesser extent suspension parts [8–10]. 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 to avoid defect formation.

Common techniques used for porosity characterization in aluminium alloys are metallographic and X-ray computed tomography inspection (CT) [11,12]. The defect size of irregular shrinkage defects is usually better estimated by X-ray computed tomography than by random 2D metallographic cross sections [11]. However, high resolution equipment is necessary to detect small and disperse gas porosity typical of aluminium casting alloys. In the high pressure die casting industry the specification VDG P202 [13] is widely used, reference areas at critical locations are defined for quantitative porosity evaluation.

On the other hand, 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 [14,15]. However, conventional HPDC alloys are not suitable for high ductility castings and safety parts due to the presence of β-Al_5FeSi compounds. These compounds are detrimental to the mechanical properties, especially ductility and must be kept at levels as low as possible. For this reason, the primary AlSi9–10MnMg alloy with a maximum Fe content of 0.25 wt% and high Mn (0.5–0.8 wt%) to avoid die soldering was developed [16]. 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, Fe has been reported to have a greater effect on reducing die soldering than Mn [17]. On the other hand, different microadditions, such as Mn, Cr and Be, can neutralize the effect of the brittle β-iron compounds by substituting them by α-iron compounds with a less harmful morphology. The effect of these microadditions on the iron compounds in aluminium casting alloys has been investigated by several authors [18,19].

In the present work the effect of different solution heat treatments on porosity and mechanical properties of a new secondary AlSi10MnMg(Fe) with optimised Fe and Mn content, manufactured by vacuum assisted HPDC technology, is studied in a step test part in the T6 temper. Porosity was characterized on metallographic sections and on the fracture surfaces of the tensile specimens.

2. Experimental procedure

A Bühler cold chamber HPDC machine with a maximum locking force of 5250 kN, a plunger with a diameter of 60 mm and a stroke of 450 mm was used for manufacturing the test parts. 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, as shown in Fig. 1. The metal velocity at the ingate section was 44 m/s. A ProVac Ultra Easy 2000 valve and a ProVac CV 300 chill vent were employed to achieve a residual air pressure of 100 mbar in the die cavity.

350 kg of the secondary alloy were melted in an electric furnace. AlSr10 master alloy was added for eutectic Si modification. The melt was argon degassed using a rotor impeller and poured at 750 °C into the shot sleeve.

The chemical composition of the alloy used in this work is shown in Table 1. It is a secondary alloy with moderate Fe content. The Mn addition of the secondary alloy has been optimised previously regarding the elimination of harmful β-iron compounds [20]. The total of Mn+Fe is 1.04 wt%, this is expected to have a positive effect on die soldering. The higher iron content of the secondary alloy compared to the corresponding primary alloy (Fe $<$ 0.25 wt%, Mn=0.50–0.80 wt%) is expected to reduce die soldering as Fe has been reported to be more effective than Mn [7].

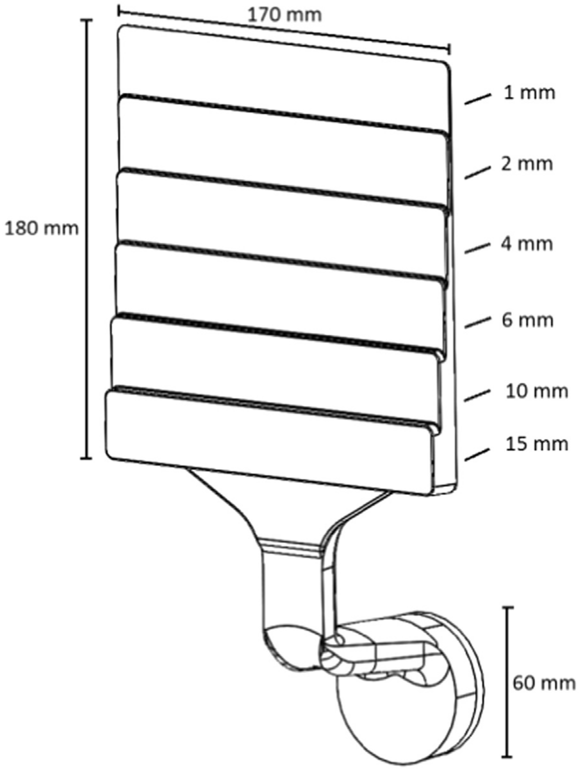

Fig. 1. Design of the step test part. The measures are indicated in mm.

Table 1
Chemical composition, total Fe+Mn and sludge factor SF in wt%.

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Sr	Total Fe+Mn	SF
10.1	0.62	0.04	0.42	0.37	0.01	0.03	0.04	0.010	1.04	1.49

Furthermore, the sludge factor, SF was calculated according to Eq. (1):

$$SF = [\%Fe] + 2[\%Mn] + 3[\%Cr] \quad (1)$$

According to the Gobrecht [21] at a pouring temperature around 680 °C (typical of HPDC process), the sludge factor, should be less than 2.2. The sludge factor of the secondary alloy is 1.49 and well below this value. Thus, the precipitation of coarse intermetallics is not expected.

A wax-free release agent (SL-1697S) at dilution 1:80 was used for die lubrication in order to minimize gas porosity due to die lubricant decomposition.

Table 2 summarizes the different solutions heat treatments studied. For each T6 heat treatment mechanical properties have been determined in the 2 mm step. Flat tensile specimens were prepared maintaining the casting skin and tested according to

Table 2
Different solution heat treatments followed by water quench at 20 °C and ageing at 165 °C for 3 h.

Solution Temperature (°C)	Time (h)
490	3
	6
	9
500	3
510	
520	