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Semi-solid processing of the primary aluminium die casting alloy A365

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ABSTRACT

A365 (AlSi9MgMn) is a primary die casting alloy widely used to manufacture automotive parts. Low superheat casting with and without a cooling plate was employed in the present work to produce A365 thixoforming feedstock. The dendritic features were more frequent in the latter, suggesting that the degeneration of the dendritic structure was promoted by casting over the cooling plate. It was possible to thixoform the non-dendritic A365 feedstock into a simple part after it was held at 580 °C for 5 min. The thixoforming process was very challenging, however, since even the slightest deviation from 580 °C has either led to shape distortion of the slug or degraded its thixoformability, resulting in incomplete die filling in both cases. Once thixoformed, the A365 part attained hardness values as high as 84 HB after T6 heat treatment.

1. Introduction

Al–Si–Mg alloys are the material of choice for many automotive castings [1]. The main production process is high pressure die casting and the predominant alloy is A365 (AlSi9MgMn) because of its outstanding mechanical properties and good welding behaviour [2,3]. Besides, with a Si content between 9.5% and 11.5%, this alloy provides excellent die-filling capability, a great advantage for large parts and complicated die designs. The strength level can be adjusted by varying the Mg content, yet, only at the expense of ductility. The minimum fracture elongation of 15%, demanded by the automotive industry in safety-critical parts, is hard to achieve by die casting. Forming in the semi-solid state [4–8] may be attractive in this regard as it helps with the porosity and segregation problems inevitable in conventional casting and provides a sound, globular microstructure with relatively higher ductility values. This is essentially why thixoforming has attracted a great deal of attention for the production of automotive parts [9].

The predominant alloys for the thixoforming route are A356 and A357 while alloys nearer to the eutectic composition, such as A365, are restricted in their applicability because of their narrow solidification interval. The present work was undertaken to explore forming of the A365 alloy, primarily used in the die casting manufacturing route for the production of automotive components, in the semi-solid state. Low superheat casting with [10–12] and without a cooling plate [12–14] was employed to produce the non-dendritic A365 feedstock which was tested for its thixoforming potential.

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2. Experimental procedures

The alloy used in this study was a commercial A365 alloy (Table 1) supplied in the form of a direct chill (DC) cast ingot. Differential scanning calorimetry (DSC) was employed to determine its solidification interval. 3 mm diameter disc samples, weighing 30–40 mg were scanned between 500 °C and 700 °C at 2.5 K min^{-1} in an argon atmosphere. The heat flow vs. temperature curves obtained during heating were used to calculate the change in solid fraction with temperature inside the solidification interval.

The as-received A365 ingot was melted in an induction furnace set at 700 °C. The melt thus obtained was inoculated with Al–5Ti–1B and Al–10Sr master alloys in accordance with the standard commercial practice. The cooling slope (CS) casting process, the reheating practice and the thixoforming experiments employed in the present work are described in detail in [11,12,15–17]. Various cooling lengths and pouring temperatures were employed. Cooling length refers to the contact length between the cooling plate and the molten alloy. A second set of ingots were produced by casting the molten A365 alloy with limited superheat directly into the permanent mould without the cooling plate. Slugs sectioned from these ingots were isothermally held at semi-solid temperatures before they were quenched in water and analyzed for their microstructures in order to identify the optimum reheating practice.

The thixoformed parts (Fig. 1) were heat treated to the T6 temper by solutionising at 510 °C for 2 h, followed by forced air cooling before ageing at 175 °C for 6 h. Samples sectioned from as-cast ingots, reheated and quenched slugs, thixoformed and heat treated parts were all prepared with standard metallographic practices. They were etched with a 0.5% HF solution before they were examined with an optical microscope. The hardness of the thixoformed and heat treated samples were measured in Brinel (HB) units with a load of 31.25 kg and a 2.5-mm diameter indenter.

3. Results and discussion

The as-received ingot exhibits microstructural features typical of dendritic solidification (Fig. 2). α-Al dendrites and the very fine interdendritic Al–Si eutectic are readily identified. The solidus and the liquidus temperatures of the parent alloy were estimated by

Table 1
Chemical composition of the A365 alloy used in the present work (wt.%)

Si	9.73
Fe	0.1113
Cu	0.0039
Mn	0.560
Mg	0.1689
Ti	0.0681
Sr	0.0167
Al	89.32

DSC to be 569 °C and 600 °C, respectively (Fig. 3). Pouring temperatures between 605 °C and 645 °C were thus employed in the casting experiments with and without a cooling plate in order to limit the superheat of the melt to the extent possible.

Ingots with predominantly non-dendritic features were obtained by pouring the molten alloy over the cooling plate between 620 °C and 630 °C. Fig. 4 shows the microstructure of an ingot cast over the cooling plate from a pouring temperature of 625 °C and with a cooling length of 400 mm. The change in the primary phase morphology upon CS casting is evident (Fig. 4a) while the Al–Si eutectic is slightly coarser possibly due to the conditions which prevail during solidification in the permanent mould (Fig. 4b). The α-Al dendrites in the as-received ingot are almost entirely replaced by α-Al globules and rosettes. Pouring temperatures lower than 620 °C present a risk of premature solidification of the flowing melt already on the cooling plate while ingots cast from above 630 °C increasingly resemble the as-received ingot.

With predominantly α-Al rosettes, the microstructures of the ingots cast directly into the permanent mould are not much different from those cast over the cooling plate, particularly at low pouring temperatures (Fig. 5). The pouring temperature appears to have an impact on the scale of the microstructure, lower temperatures promoting smaller α-Al rosettes, as expected (Fig. 5c). The lowest temperature from which the molten alloy could be cast into a full size ingot was 605 °C below which the fluidity of the melt has almost completely vanished. Even at this very low pouring temperature, the microstructure of the ingot obtained is relatively coarser than the microstructure of the ingot cast over the cooling plate from a higher pouring temperature of 625 °C. Furthermore, a comparison of the microstructural features in ingots cast from a pouring temperature of 625 °C with and without a cooling plate suggests that the degeneration of the dendritic structure is promoted by the CS-casting process. In view of the above, it is concluded that the CS-casting process produces superior non-dendritic feedstock of the present alloy and a relatively finer dispersion of α-Al globules and rosettes.

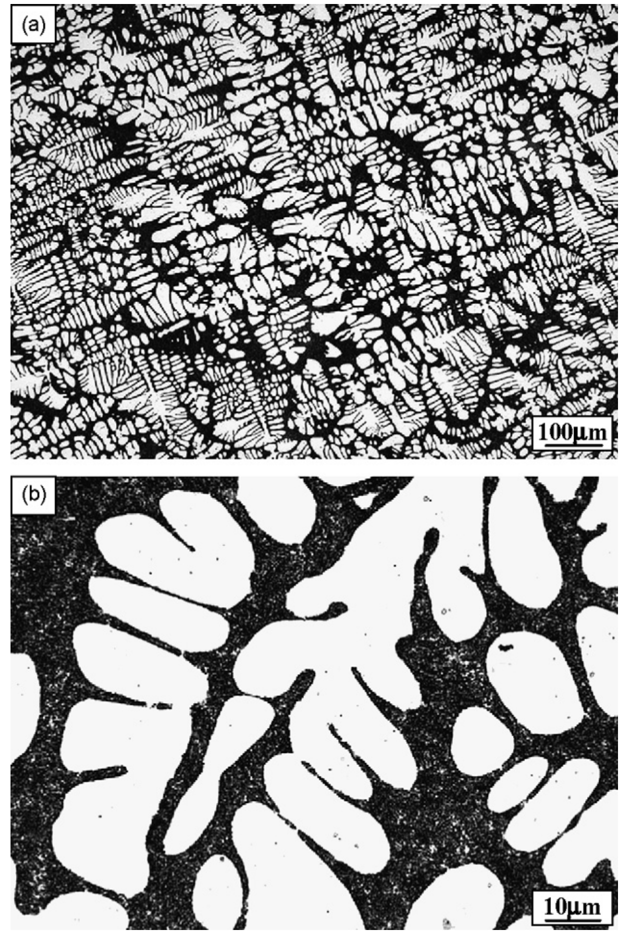

Fig. 2. Microstructure of the as-received A365 ingot.

The refinement and the change in the morphology of the primary phase in the CS-cast ingots may be accounted for the fractional solidification that occurs on the cooling plate [11]. This is encouraged further by the limited superheat of the melt. When the molten alloy flows over the cooling plate, the melt superheat is dissipated readily and the temperature quickly drops below the liquidus temperature. α-Al crystals thus nucleated are detached from the cooling plate, trapped in the flowing melt and are collected in the permanent mould at the bottom before they evolve into branched dendrites. This is probably why the dendritic features are more frequent in the case of the ingot

Fig. 1. Part produced from A365 alloy via thixoforming.

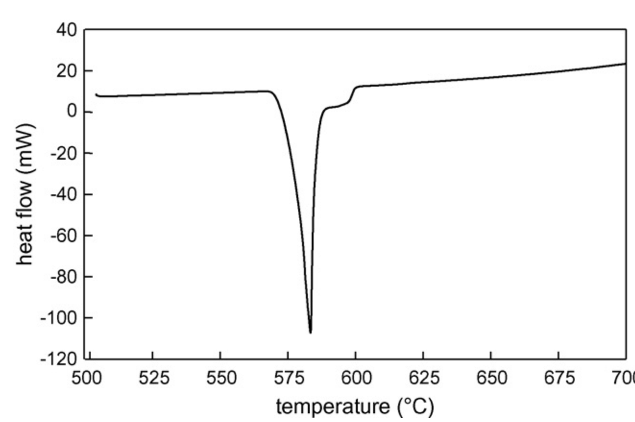

Fig. 3. DSC curve of the A365 alloy recorded during melting.