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Forming of AlSi8Cu3Fe alloy in the semi-solid state

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ABSTRACT

AlSi8Cu3Fe alloy is a general purpose die casting alloy widely used to manufacture automotive parts. Forming of this alloy in the semi-solid state could largely eliminate problems inherent in die casting process and thus offers a number of advantages. Low superheat casting was employed in the present work to produce non-dendritic AlSi8Cu3Fe alloy feedstock. The ingots thus obtained were thixoformed in a laboratory press after they were held at 570 °C for 5 min, yielding a microstructure with predominantly α-Al globules and interglobular Si particles. The thixoformed parts attain hardness values as high as 125 HB after T6 heat treatment, implying a considerable age hardening potential. However, with a reheating temperature range of 568–572 °C, thixoforming of AlSi8Cu3Fe alloy components under industrial conditions may be challenging.

1. Introduction

The majority of aluminium castings intended for the automotive industry is produced by the highly efficient and low-cost high-pressure die casting (HPDC) process [1]. HPDC components, however, suffer from gas porosity which not only limits their use in safety-critical applications but also denies the opportunity for further hardening by heat treatment [2]. Thixoforming was recently considered to be a viable alternative in the production of automotive components, as it can help to largely overcome these adversities [3,4]. In thixoforming, the alloy is only partially liquid and the shrinkage is much less than that of a fully molten alloy [5]. In addition, the die filling process can be controlled to eliminate porosity, thanks to the high viscosity of semi-solid alloys. The key feature that permits the semi-solid shaping of alloys is a dendrite-free microstructure, with globular α-Al grains dispersed in a low melting point matrix phase [6–10], which may be handled like a solid, but flows readily when sheared. Since such material is readily obtained in casting alloys with relatively high volumes of Al–Si eutectic, commercial thixoforming practice largely relies on conventional casting alloys such as A356 and A357 [11,12]. Alloys nearer to the eutectic composition, on the other hand, are restricted in their applicability because of their narrow solidification range.

The present work was undertaken to explore thixoforming of a general die casting alloy, AlSi8Cu3Fe, nearer to the eutectic composition with a relatively higher Si content than the A356 and A357 alloys. AlSi8Cu3Fe alloy offers good fluidity, pressure tightness, resistance to hot cracking, good mechanical properties and is used to make various automotive parts such as air brake castings, gear cases and air-cooled cylinder heads. AlSi8Cu3Fe alloy melts with limited superheat were cast over a cooling plate and directly into a permanent mould in the present work to produce non-dendritic AlSi8Cu3Fe alloy feedstock which was then tested for its thixoforming potential.

2. Experimental procedures

The chemical composition of the AlSi8Cu3Fe alloy used in this study is given in Table 1. X-ray diffraction (XRD) was used for the identification of intermetallic phases and differential scanning calorimetry (DSC) was employed to determine its melting range. 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 both during melting and during solidification. The heat flow vs. temperature curve obtained in the former was used to calculate the change in solid fraction with temperature across the melting range. The DSC scan recorded in the course of solidification, on the other hand, was used to estimate the optimum pouring temperatures.

The AlSi8Cu3Fe alloy ingot was melted in an electric resistance furnace set at 700 °C and was treated with Al–10 wt.%Sr and Al–5 wt.%Ti–1 wt.%B master alloys for the modification of the eutectic phase and for grain refinement, respectively. The melt was then allowed to cool to the pouring temperature, selected so as to limit its superheat and was cast into a permanent mould with a diameter of 30 mm and a depth of 150 mm first over a cooling plate and then without it. The cooling plate was a 50 mm wide, 500 mm long U-shaped steel profile, inclined at 60° with respect to the horizontal plane and was additionally cooled by water circulation underneath. 35 mm long slugs, sectioned from the ingots thus produced were heated in a medium frequency induction coil (9.6 kHz, 50 kW) to the semi-solid temperature range. Temperature was monitored with a K-type thermocouple inserted in a 3 mm diameter hole drilled in the center of the slugs. Measures were taken to achieve rapid heating (>150 °C min^{-1}) to avoid undesirable grain growth. A set of slugs were isothermally held at semi-solid temperatures before they were quenched in water and analyzed

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Table 1
Chemical composition of the AlSi8Cu3Fe alloy used in the present work (wt.%)

Si	Fe	Cu	Mn	Mg	Ni	Zn	Sn	Al
8.25	0.92	3.31	0.15	0.19	0.05	0.96	0.02	Bal.

for their microstructures in order to determine the optimum reheating practice. The thixoforming operation was carried out with a laboratory press. A pneumatic cylinder was used to provide the forming load (5 $\mathrm{tonf_{max}}$). The maximum speed of the ram was 500 $\mathrm{mm\,s^{-1}}$ and the die was heated to 250 °C. The thermocouple was withdrawn from the slug just before forming into an arbitrary shape part with inner and outer diameters of 26 mm and 36 mm, respectively, and with an undercut solid section with a diameter of 26 mm.

The thixoformed samples were heat treated in an air furnace. The T5 heat treatment involved artificial ageing at 175 °C for 8 h while T6 heat treatment employed an additional solutionizing step at 500 °C for 1 h, followed by forced air cooling before artificial ageing. The thixoformed and heat treated samples were sectioned transversely and were prepared with standard metallographic practices. These samples 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 units with a load of 306.25 N and a 2.5 mm diameter indenter.

3. Results and discussion

The as-received ingot exhibits microstructural features typical of dendritic solidification with interdendritic eutectic silicon and occasional intermetallic particles in an aluminium solid solution matrix (Fig. 1). The latter were found by XRD and metallographic analysis to be β-Al_5FeSi and $CuAl_2$ particles (Fig. 2). The liquidus temperature is estimated from the DSC data to be 582 °C (Fig. 3). Pouring temperatures between 590 °C and 620 °C were thus employed in the casting experiments with and without a cooling plate in order to limit the melt superheat.

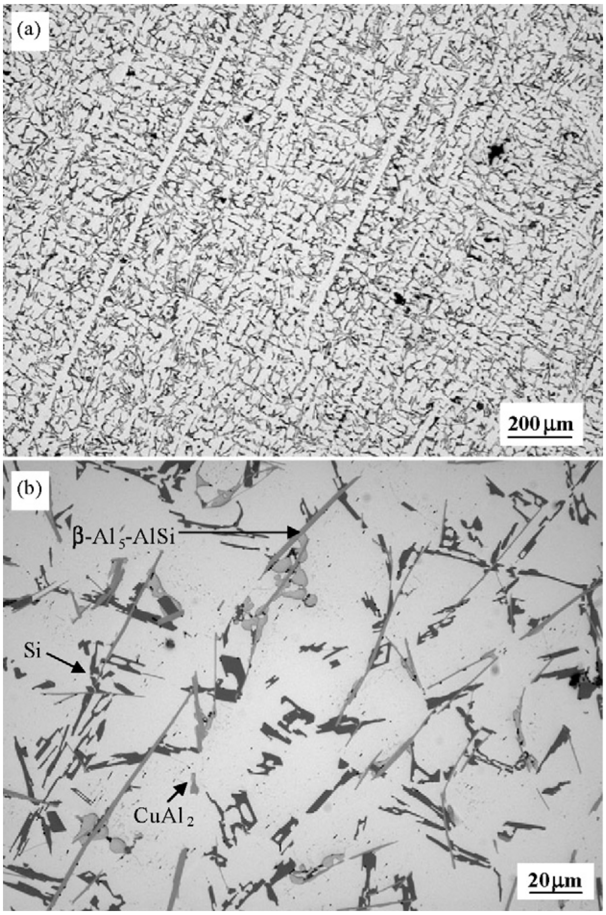

Fig. 1. Microstructure of the as received AlSi8Cu3Fe alloy ingot (a and b).

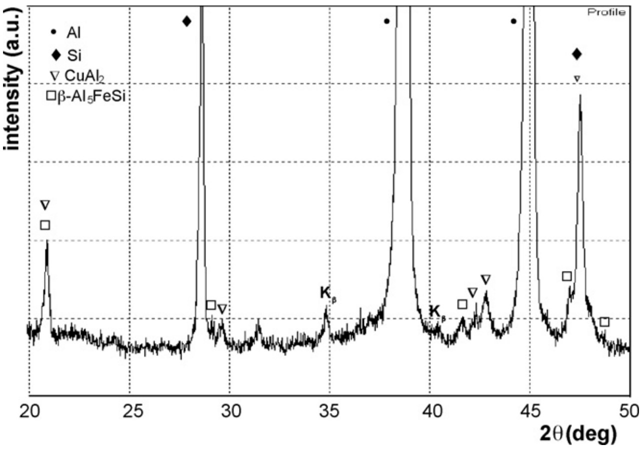

Fig. 2. XRD pattern of the as received AlSi8Cu3Fe alloy ingot.

Ingots with predominantly non-dendritic features are obtained by pouring the molten alloy over the cooling plate from temperatures between 610 °C and 620 °C. Fig. 4a shows the microstructure of an ingot cast in this fashion from a pouring temperature of 615 °C. The contact length of the molten alloy with the cooling plate was 300 mm. The change in the primary phase morphology is evident. The α-Al dendrites in the as-received ingot are almost entirely replaced by relatively smaller α-Al globules and rosettes. Fractional solidification that occurs on the cooling plate, encouraged further by the limited melt superheat, is responsible for the change in size and morphology of the primary phase [13]. The molten alloy loses its superheat while flowing over the cooling plate and its temperature drops quickly 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 before they evolve into ripened dendrites.

With predominantly α-Al rosettes, microstructure of ingots cast directly into the permanent mould is not much different (Fig. 4b). It apparently takes relatively lower pouring temperatures to achieve the same degree of structural refinement in this practice. Small α-Al globules in spite of higher pouring temperatures when casting over a cooling plate are accounted for by the additional cooling provided by the water cooled plate. Since they provide the desired microstructural features at even lower pouring temperatures, ingots cast directly into the mould were used for further studies in view of the apparent cost advantage of this very simple practice for the manufacture of non-dendritic feedstock.

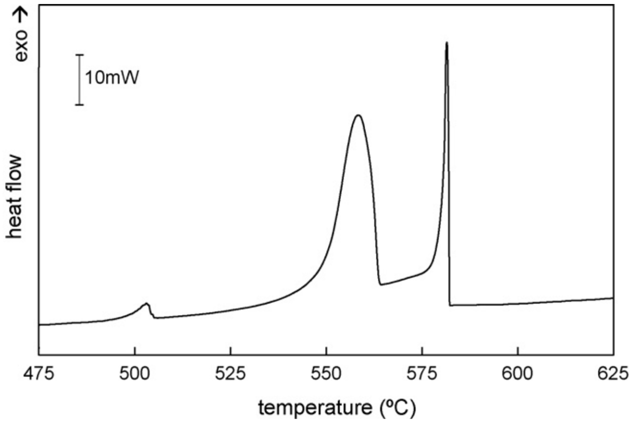

Fig. 3. DSC curve of the AlSi8Cu3Fe alloy recorded during solidification.