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Effect of isothermal ageing on the semi-solid microstructure of rheoprocessed and partially remelted of A390 alloy with 10% Mg addition

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ABSTRACT

The semi-solid microstructure of commercial A390 (Al—17%Si—4.5%Cu—0.5%Mg) hypereutectic Al–Si alloy with an addition of 10% Mg was investigated for two different processing routes: 1) rheocasting after stirring with rotation speed of 260 rpm and 2) partial remelting after fast cooling in a steel mould. The results show that the morphology of α-Al grains becomes globular during isothermal holding time for both cases. However, at the same isothermal condition, the size of the α-Al phase particles for rheocast samples are larger and their morphology are more globular than for the samples examined after the partial remelting process. The microstuctural evolution, size and shape of the primary Mg_2Si as well as the silicon particles during isothermal ageing in the semi-solid region was also investigated for the two processing conditions.

1. Introduction

Semisolid metal (SSM) processing is an innovative technology for the treatment of alloys in the semi-solid state. This technique takes advantage of the rheological characteristics of suspensions of solid materials in liquids. A low apparent viscosity can be achieved due to the thixotropic behaviour of the metallic slurry when high shear stresses are applied, generally resulting in shear thinning [1,2]. It is observed that the dendritic morphology is transformed into a globular or non dendritic form and the solid phase particles are dispersed in a liquid matrix resulting in better castability due to the lower viscosity. In addition, the forming temperature and heat content as well as the shrinkage of semi-solid slurry are significantly reduced resulting in a "near net shaping" process [3]. Processing can be carried out by two methods: rheocasting and thixoforming [4]. In rheocasting, the molten liquid is mechanically or electromagnetically stirred while being cooled to produce non dendritic slurry for making a product. During thixoforming, reheated semi-solid ingots which exhibit desirable microstructure are shaped into parts by using a die cast machine. The ingots (feed stocks) must be prepared with an appropriate microstructure as a starting material for this process. Magnetohydrodynamic (MHD) stirring [5], cooling slope casting (CS) [6], strain induced melt activated (SIMA) [7] as well as recrystallisation and partial melting (RAP) [8] are other methods that can be used to produce a semi-solid slurry.

Hypereutectic Al–Si alloys such as A390 alloy (Al—17%Si—4.5%Cu—0.5%Mg) exhibit outstanding wear and corrosion resistance, high thermal conductivity, excellent castability, high strength, together with reduced density which are widely used in the automotive, aerospace, and military industries [9,10]. This is due to the presence of the hard primary silicon particles dispersed in the matrix. However, for conventional casting, the primary silicon appears in the form of coarse polygonal crystals which lead to poor properties of these alloys. On the other hand, hypereutectic Al–Si alloys with added Mg content can also be used to form in situ Mg_2Si/Al–Si metal matrix composite (MMCs) which have high potential as a wear resistant materials. In terms of properties and

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solidification behaviour, many similarities exist between Mg_2Si and Si [11] resulting in super light wear resistant materials due to their low density when compared with aluminium. The hard intermetallic particles of Mg_2Si in the composite alloy act in the same way as the hard primary silicon particles and make it ideal for high wear resistance applications. In this work the Mg content of A390 alloy was increased to 10 wt.% in order to generate both of two types of hard particles in the microstructure.

2. Experimental Procedure

The 10 wt.% Mg alloy was produced by adding AZ91 Mg-base commercial alloy into the molten A390 alloy at 750 °C (about 100 °C above the melting temperature). About 20% additional AZ91 wrapped in Al foil was added the molten A390 alloy to account for oxidation loss of Mg. The chemical compositions of the base alloy and the tested product are indicated in Table 1. Silicon and copper were also added to the melt in order to keep the chemical composition of these elements in the test alloy at the same level as in the A390 composition. The melt was degassed with argon and hand stirred 2 min before pouring in a steel mould with three 35 Ø×120 mm cylindrical cavities. These ingots were used as the starting material (feedstock) for the partial remelting experiments. Subsequently, 80 g of ingot was cut and placed into a 41 Ø×120 mm graphite crucible with wall thickness of 10 mm. Two k-type thermocouples were placed in the crucible wall near the surface of melt and near the bottom of crucible in order to measure the temperature during the process. The samples were then heated at a rate of 0.25 °C/s in a 3 zone electrical resistance furnace to the semisolid temperature of 560±1 °C where liquid, Mg_2Si and Si particles co-exist. In another test the sample was heated to 540±°C where Mg_2Si, Si and Al co-exist in the liquid phase. These temperatures were selected on the basis of previous experimental studies of the cooling curves and the solidification behaviour of the A390 alloy with added Mg content and DSC (Differential Scanning Calorimeter) measurements which were also evaluated using Factsage® software [12,13]. Samples were taken from the melt by using a small spatula and quenching in the water after isothermal holding times of 30, 60 and 180 min in the semi-solid region.

For the rheocast tests, the high Mg content alloy was continuously cooled from the liquid state at 750 °C and then held at the isothermal temperature of 540±1 °C. The semi-solid material is then stirred by immersing a spiral grooved cylindrical stirrer at this temperature for a period of 30, 60 and 120 min at 260 rpm representing a shear rate of 52 s^{-1}. At the end of each period, the samples were quickly removed and quenched in the water.

All samples were mounted, polished conventionally and etched by using 0.5% HF solution for microstructural analyses. The Clemex software was used to analyse the particle morphology and size observed in the microstructure. The shape factor is defined by the relation $F = \frac{4\pi A}{P^2}$ where A and P represent respectively the area and perimeter of the particles measured by the image analyser.

Table 1 – Chemical analysis of A390 base alloy, AZ91 Mg alloy and test ingot wt.%).

	Al	Si	Cu	Mg	Fe	Mn	P	Ti
A390	Bal.	16.7	4.58	0.58	0.32	0.02	0.0003	0.02
	Mg	Al	Mn	Zn	Si	Ni	Cu	Fe
AZ91	Bal.	9.30	0.12	0.62	0.02	0.0006	0.0007	0.0046
	Al	Si	Cu	Mg	Fe			
Test alloy	Bal.	16.83	4.12	9.73	0.28			

3. Results and Discussion

3.1. Microstructural Evolution During Partial Remelting

Fig. 1 shows the microstructure of 10% Mg alloy rapidly solidified from the liquid state by pouring into a steel mould. This was used as the starting material for partial remelting

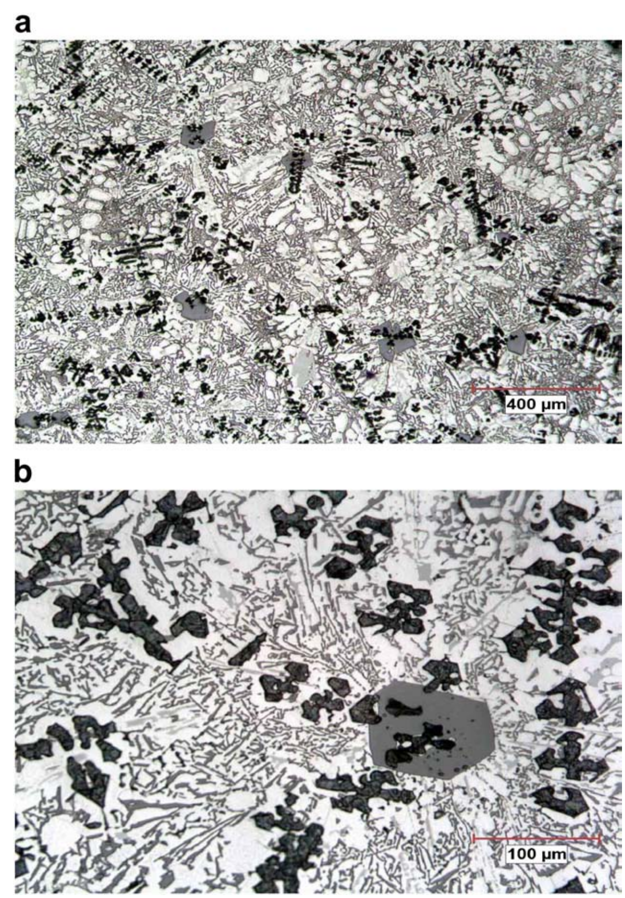

Fig. 1 – Microstructure of 10% Mg alloy rapidly solidified from liquid into a steel mould at: (a) 50× and (b) 200×. The microstructure contains the dendritic grains of α-Al (white), equiaxed dendrites of Mg_2Si (black), polygonal silicon (grey) and the eutectic in the matrix network.