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Phase field modelling of microstructure evolution and ripening driven grain growth during cooling slope processing of A356 Al alloy

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ABSTRACT

A phase field model is developed for simulation of microstructure evolution during semi solid slurry generation process of A356 aluminium alloy using a cooling slope. First, experiments are performed to evaluate the number of seeds required within the simulation domain to simulate near spherical microstructure formation, occurring during cooling slope processing of the melt. Subsequently, microstructure evolution is studied employing a phase field method. Simulations are performed to understand the effect of cooling rate and melt treatment in the form of grain refiner and modifier addition on the slurry microstructure. The results obtained from mesoscopic phase field simulations are grain size, grain density, degree of sphericity of the evolving primary Al phase and the amount of solid fraction present within the slurry at different time frames. The simulation is extended to predict the microstructure evolution during the post slurry generation isothermal holding stage, by feeding in the average particle size and the number of primary Al grains within the simulation domain, which are estimated from the simulated micrograph obtained at the end of slurry generation simulation. Results obtained from the simulation studies are validated against corresponding experimental observations. Insight into the cooling slope slurry generation technique is obtained from the numerical findings, which are found to be useful for process control during component development using a Rheo pressure die casting system.

1. Introduction

The phase field method enables simulation of microstructure evolution in alloys having complicated grain morphology without initial assumption of grain shapes. Phase field equations are coupled with the equations for heat and solute transport to avoid the necessity of prescribing boundary conditions at the solid/liquid interface. The technique also treats topology changes of two adjacent solid grains, present at close proximity, with relative ease. A brief review of the existing literature on phase field modelling of solidification problems is given in our earlier work [1]. The present study is focused on the application of phase field modelling technique to simulate microstructure evolution during semisolid processing of Al-7Si-0.3Mg (A356) alloy. Semi solid processing is widely accepted as an advanced manufacturing technology, showing promise to overcome some fundamental issues associated with the liquid state processing (conventional casting) of metals/alloys [2,3]. This process involves generation of non-dendritic slurry morphology for which several techniques have been invented, such as the electromagnetic stirring (EMS), stress-induced and melt-activation (SIMA), magneto hydrodynamic stirring (MHD), cooling slope, vibration, and gas bubbling. Of these methods, the cooling slope technique has emerged as the most popular and successful one, owing to its cost effective design and simplicity in industrial implementation. A brief review on the topic may be seen from our earlier work [4,5]. In this technique, superheated melt is poured on a metallic slope and an elliptical contact zone forms which promotes the necessary undercooling for solid (α-Al crystals) nucleation. Initial crystals form at the contact zone, get detached from the slope surface due to gravity force and melt flow inertia (crystal separation mechanism) and carried downstream with the melt front, towards the slope exit. The melt becomes semi solid slurry up to the slope exit and fills an isothermal holding bath. Coarsening mechanisms such as Ostwald ripening and coalescence plays their part to govern microstructure evolution process during isothermal holding stage. The microstructure evolution mechanisms prevailing during flow along the slope and isothermal holding stages are shown schematically in Fig. 1.

The present study is focussed on phase field simulation of microstructural evolution during cooling slope processing of A356 Al alloy, which is normally used for die casting of automotive

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Nomenclature

ϕ	phase-field parameter
η	interface thickness/grain boundary with
f^{IF}	interfacial part of the free energy
f^{CH}	chemical part of the free energy
σ	grain boundary energy/surface energy
$W_{\alpha\beta}$	double obstacle potential between two phase
μ_α	diffusion potential
$\vec{D}_\alpha$	multicomponent diffusion coefficient Matrix for phase α
μ	is the generalized chemical potential
M	is the mobility of the interface
$\vec{n}$	normal vector
K	local curvature of the interface
ΔG	thermodynamic driving force
$\vec{c}$	local (multicomponent) composition
M_α^{ch}	chemical motility of individual phases
υ^m	mean molar volume
T	is the matrix, comprises of the derivatives of diffusion potentials with respect to the composition of different phases

Superscripts

α	liquid phase
β	solid phase

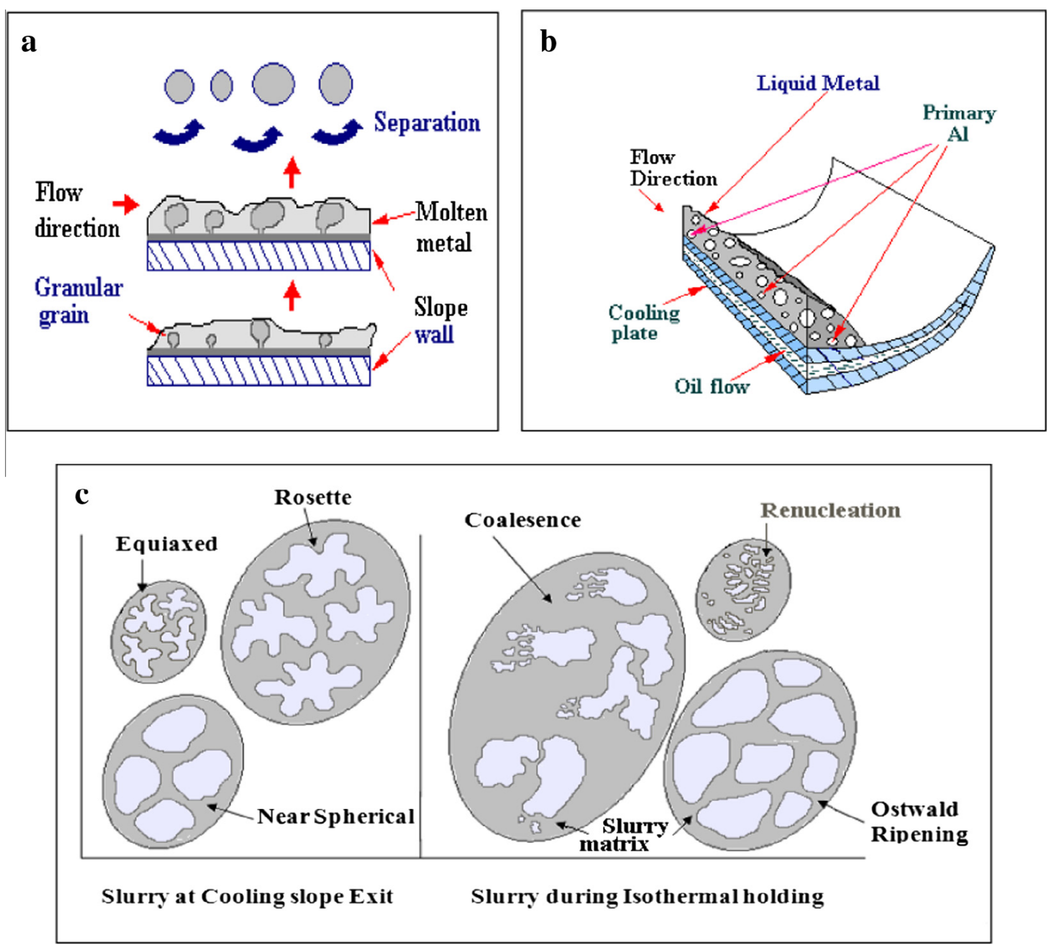

Fig. 1. (a) Crystal separation mechanism, (b) transport of detached crystals along with the incoming melt during cooling slope processing and (c) coarsening mechanism during isothermal holding stage.

components such as brake drum, brackets, manifolds, valve bodies, air cooled cylindrical heads and gear cases [6]. Presence of silicon in A356 alloy increases its fluidity and castability, while magnesium provides higher strength [7–9]. There is very little literature available on mesoscopic simulation of microstructure evolution during cooling slope rheoprocessing of Al alloys [1,13]. Also, the earlier work mostly deals with the effect of cooling rate on microstructure formation during melt flow along the slope. The uniqueness of the present model lies in its ability to predict the effect of melt treatment in the form of addition of grain refiner and modifier on the solid fraction evolution within the semi solid slurry during shear driven flow along the slope and during isothermal holding in a slurry holding bath. For the phase field simulation, commercially available solver MICRESS® [10–16] is used.