Modeling the effect of SiC mass fraction on crystallization of magnesium metal matrix composite; AZ91/SiC

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ABSTRACT

The aim of this work was prepare micro-macro crystallization model of AZ91/SiC composite that depends on mass fraction of SiC particles. This model base on temperature and chemical elements concentration, it also takes into account primary α-Mg phase nucleation rate. The behavior of temperature and chemical composition field can be calculated using Fourier – Kirchhoff equation and modified second Fick's law. The nucleation rate for this alloy was calculated from log-normal Fras equation. Fitting parameters were found using experimental data.

Different composites castings with different mass fraction of SiC particles were performed. The grain density and undercooling in each case were measured. Obtained data was used as test values during statistical fitting of the unknown model adjustment parameters.

The simulation software on the base of prepared model was written. Experiment for the same composite as set as initial data of the simulation was performed. The simulation results were compared with an experimental data. Analysis shows good fitting of presented model with the real values

INTRODUCTION

Grain size is one of the most important parameter which determined mechanical properties. Knowing element properties the proper application regions for it can be chosen to achieve best mechanical properties and performance. Nowadays simulation software can be use to predict the element microstructure. Those programs base on micro-macro model of crystallization. The model consists of partial differential equations (PDEs) that described the nucleation rate, diffusion in the casting, casting cooling speed and every single grain growth rate. Often it is hard to find the theoretical value of the parameters that appear in those PDEs. It is possible to find them from experiment. The experimental data that after applying statistical methods let us find approximated values of the so-called "fitting parameters" in the mentioned models [1 - 4].

AZ91 alloy analyzed in this study is hypereutectic alloy. The magnesium primary α-Mg phase is dendritic. During crystallisation there appears eutectic reaction. In this study influence of eutectic is omitted because magnesium primary phase has most significant influence on mechanical properties of the casting.

EXPERIMENTAL PROCEDURE

Composite casting

The AZ91 alloy was selected as the matrix for the composites. The chemical composition is shown in Table 1. The reinforcement particles are silicon carbide with an average diameter of 45 μm. Composite specimen with 0, 1, 2, 3 and 4 wt.% of SiC particles were prepared using a liquid mixing and casting process.

Table 1. Chemical composition of AZ91 alloy

Chemical composition, wt. %								
Al	Zn	Mn	Fe	Si	Cu	Be	Ni	Mg
9,03	0,6	0,2	0,0026	0,0023	0,0016	0,0011	0,00062	Reszta

Processing of the magnesium composites consisted of mixing pre-heated SiC particles to 450 °C with liquid magnesium melt stirring and mould casting. About 1.4 kg of composite melts was prepared in an electric resistance furnace using a steel crucible under a SF_6/CO_2 gas atmosphere. The molten AZ91 alloy was held at 700 °C for 1 h. After putting SiC particles composite was stirred for 2 min, and then cast at 700 °C into mould to produce four plates of 100 x 100 x 10 (plate no 1), 15 (plate no 2), 20 (plate no 3) and 30 mm (plate no 4), Fig. 1. The mould was made with resin sand hardened with CO_2. An un-reinforced AZ91 alloy was also cast at the same temperature (700 °C).

Fig. 1. Photo of gating system with four plates (a) and synthetic resin sand hardened with CO_2 mould (b, c)

Thermal analysis

For the thermal analysis of AZ91 alloy and composite samples, cooling curves during solidification were obtained using a data acquisition system (Agilent) at a sampling rate of 5 data per second. A chromel-alumel (K-type) thermocouple positioned 50 mm from the bottom of the plate center, was used to monitoring temperature as the melt solidified.

Microstructural analysis and grain size determination

The as-cast plates were sectioned at a distance 3 mm from hot junction of a thermocouple and next polished and etched before microstructural analysis. In order to visualization of grain boundaries of magnesium primary phase, the metallographic specimens were etched for 80-95 s. The chemical composition of solution was: 50 ml Distilled Water, 150 ml Ethanol, 1 ml Acetic Acid [5-7].

The etched specimens were examined using a light optical microscope Carl Zeiss AXIO Imager.A1 with cross polarized light and λ filter. The grains density was counted on the surface of etched specimens using image analysis NIS-Elements 3.0 Software. The images on computer display reveal arms of different dendrite grains as areas with different colours, Fig. 2.

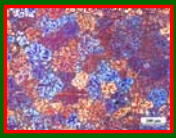

Fig. 2. Example of microstructure of AZ91/SiC composite for sample was cut from as-cast plate about thickness 10 mm with 2 wt.% of SiC

NUMERICAL MODEL

Numerical micro-macro model of AZ91/SiC composite solidification is base on differential equations heat and mass transport.

$$\frac{\partial T}{\partial \tau} = a\nabla^2 T + \frac{q_V}{c_V}$$

$$\frac{dC}{d\tau} = D_\alpha\left(\frac{\partial^2 C}{\partial r^2} + \frac{2}{r}\frac{\partial C}{\partial r}\right) + \frac{r}{R}\frac{\partial C}{\partial r}\frac{dR}{d\tau}$$

$$q_V = L\frac{\partial f_s}{\partial \tau}$$

$$\frac{dC}{d\tau} = D_L\left(\frac{\partial^2 C}{\partial r^2} + \frac{2}{r}\frac{\partial C}{\partial r}\right) + \frac{R_o - r}{R_o - R}\frac{\partial C}{\partial r}\frac{dR}{d\tau}$$

$$\frac{\partial f_s}{\partial \tau} = \sum_{i=1}^{n} 4\pi R_i^2 N_i \frac{\partial R_i}{\partial \tau}$$

$$\left(C_L - C_S\right)\frac{dR}{d\tau} = D_{Al}^{\alpha}\left.\frac{dC_\alpha}{dR}\right|_{R^-} - D_{Al}^{L}\left.\frac{dC_L}{dR}\right|_{R^+}$$

RESULTS

Grain density of magnesium primary phase

Fig. 3. The nucleation temperature dependence on mass fraction of SiC particles

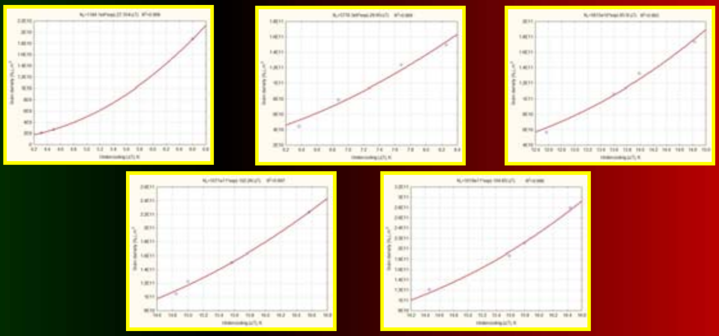

Fig. 4. The grain density dependence on undercooling for coposites the base on AZ91 alloy reinforced by: 0 wt.% SiC (a), 1 wt.% SiC (b), 2 wt.% SiC (c), 3 wt.% SiC (d) and 4 wt.% SiC (e)

$$N_V\left(\Delta T, mf_{SiC}\right) = 1.42\cdot 10^{13}\exp\left(61.9\cdot mf_{SiC} - \frac{36.25\cdot\exp\left(29.3\cdot mf_{SiC}\right)}{\Delta T}\right)$$

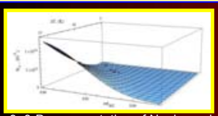

Fig. 9. 3-D representation of Nv dependence on alloy undercooling and mass fraction of SiC particles (dimensionless)

Numerical simulation

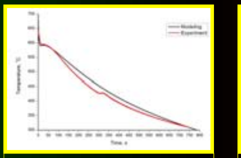

Fig. 10. Cooling curves obtain from simulation and experiment

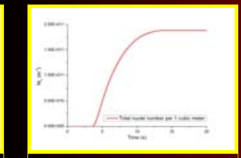

Fig. 11. Kinetic of primary phase nucleation

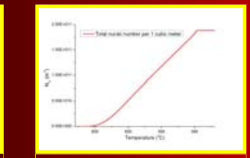

Fig. 12. Grain density versus actual alloy temperature

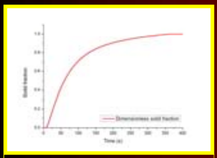

Fig. 13. Kinetic of primary phase solidification

CONCLUSIONS

The experimental data can be used to prepare micro-macro composite crystallization model. The model fits good with an experiment results. The differences are probably connected with the assumptions that were made during model preparation and with the fact, that simulation was performed just for one element of the composite.

Numerical simulation gives a lot of useful data that can give new view on the nucleation and solid fraction growth phenomenon. This knowledge can be later used to influence those processes.

The AZ91/SiC nucleation parameters as T_N and N_V can be described with mathematical formulas. Unknown adjustment parameters can be found using experimental data and statistical algorithms.

The mean volumetric grain density function shows grain density dependence on composite actual undercooling and mass fraction of SiC particles. This knowledge can be very useful for technologists during composite casting procedure preparation.

After setting the mass fraction of SiC particles and derivation the average volumetric grain density function gives information about nucleation rate. This is the key parameter for AZ91/SiC composite micro – macro model of crystallization.

ACKNOWLEDGEMENTS

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